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VEGETABLE PRODUCTION TRAINING MANUAL




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ASIAN VEGETABLE RESEARCH AND DEVELOPMENT CENTER
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Foreword

This Manual is intended to be a guide to the vegetable production training course for developing country specialists offered at the Asian Vegetable Research and Development Center. It is designed as well to be a resource book for extension subject matter specialists and vocational agriculture teachers.

The global demand for vegetables is expected to increase dramatically in the coming years. Two major trends will bring this about — rising per capita income and continuing population growth in the developing countries.

Vegetables supply vitamins, minerals, fibers, and supplementary amounts of protein and calories essential to the human diet. If the urban and rural poor in the developing countries were to have access to vegetables, there should be adequate and stable supplies to keep their prices affordable.

No less significant justification for trying to increase vegetable productivity in the developing countries, is their potential to generate high income for small producers and additional employment for landless workers and for those involved in food processing. As Swaminathan and Sinha have observed: People with purchasing power seldom go hungry.

We hope, therefore, that this Manual can contribute modestly to the goal of improving vegetable production in the tropics.

A good number of people representing several institutions were involved in the conceptualization, writing, review, editing, and production of this Manual. Their valuable contributions are hereby gratefully acknowledged.

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(Sgd.) EMIL Q. JAVIER
Director General

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CHAPTER 1

Introduction to Vegetables and Vegetable Production Systems

Vegetables are a complex group of a wide variety of different types of plants. Some species grow from year to year; others grow and die within one or two years. They have diverse forms of propagation: by seeds or vegetative parts. They may be herbaceous, viny, shrubby, or tree in growth habit.

They differ in growth requirements. Many vegetables can be grown under a wide range of conditions; while others have more exacting requirements for water, temperature, and light. Thus, in one place several species can be grown throughout the year, but there are others that can be grown only during certain times of the year. Irrigation is an absolute necessity for many species, but a few can be grown under rainfed conditions.

Vegetables can grow in the wild or have to be cultivated. Distribution of species that are used as vegetables may be worldwide or limited to specific areas of certain regions. They can be produced in fields of specialized production areas, outskirts of urban areas, villages, or in gardens around the home.

Different parts of a plant may be used as a vegetable, depending on localities and culture. In general, developing countries utilize more parts of a particular plant as a vegetable than developed countries. Most vegetables are high in water which makes them bulky and highly perishable, particularly the leafy ones.

Definition of Vegetables

Considering their diverse nature, it is very difficult to come up with a single, acceptable, all-encompassing definition of vegetables. Definitions of the word "vegetable" are generally based on their use. A ***vegetable*** could thus be defined as an edible, usually a succulent plant or a portion of it eaten with staples as main course or as supplementary food in cooked or raw form.

Since any definition of vegetable generally centers on its use, a plant may be a vegetable in one country but a fruit, a weed, an ornamental, or a medicinal plant in another country, depending on the crop. For example, tomato is a vegetable in Asia but a fruit in Europe. The garland chrysanthemum is a vegetable to some Asians, to others it is an ornamental. Although melons are generally used for dessert, they are considered as vegetables; since many members of the cucurbit family are vegetables.

In some cases, a plant could be a vegetable only at a certain growth stage. The bamboo is a crop used for its wood but bamboo shoot is a vegetable. Some of the legumes can be used at various stages of development: the sprouted seeds, the tender shoots, the immature tender pods, and the mature seeds. Some fruits, such as papaya and jackfruit, are used as vegetables in Southeast Asia when they are immature.

Role of Vegetables in Nutrition

Source of Nutrients

Vegetables as a group constitute an important component in a man's diet, especially in developing countries. However, per capita consumption of vegetables in developed countries tend to be higher than in developing countries, possibly because they have a better appreciation of the nutritive value of the crops. Vegetables are rich sources of essential minerals and vitamins. They generally produce more nutrients per unit land area than staples such as rice (Table 1.1).

Table 1.1. Amount of nutrients per hectare per crop.

Crop	Assumed Yield[a] (t/ha)	Protein[b] (kg/ha)	ß-carotene Equivalent[b] (g/ha)	Ascorbic Acid[b] (kg/ha)
Rice	5.6	414	-	-
Soybean	2.5	167	1.9	.28
Sweet potato	24.6	216	116.9	6.7
Potato	23.9	345	Tr	4.8
Mustard	39.7	707	537	20.6
Cauliflower	23.9	229	6.9	8.0
Onion	59.5	941	Tr	2.8
Garlic	9.5	565	0	0.6
Tomato	60.1	535	299	20.2

[a]Based on Table 1.9.
[b]Yield x % edible portion x % nutrient based on Table 1.3.

There is little chance for malnutrition to occur where enough vegetables are eaten. Malnutrition reduces the working capacity of farmers and their families. In severe cases, serious physical and mental retardation or even death may occur. As a result of reduced working capacity, incomes may decrease and poverty may increase. This relationship between productivity and nutrition is a cycle that continuously gets worse over time (Fig. 1.1).

The amount of nutrient intake for good nutrition has been established by the Food and Agricultural Organization and the World Health Organization (WHO). This recommended dietary allowance (RDA) is used as a guide to determine how much of a certain vegetable needs to be eaten for good nutrition (Table 1.2). Since vegetables contain a mixture of nutrients in different proportions, the nutrient composition of vegetables need to be known. The nutrient content of some vegetables is presented in Table 1.3.

Source of calories. Some vegetables can be good sources of calories. The root crops may be used as substitute for the staple grain crops, in which case, they become major sources of calories. The higher the water content of a vegetable, the lower is the calorie content. The roots, tubers, and seeds of plants have a higher starch and sugar content and less water than the other parts. Therefore, they provide more calories per unit weight.

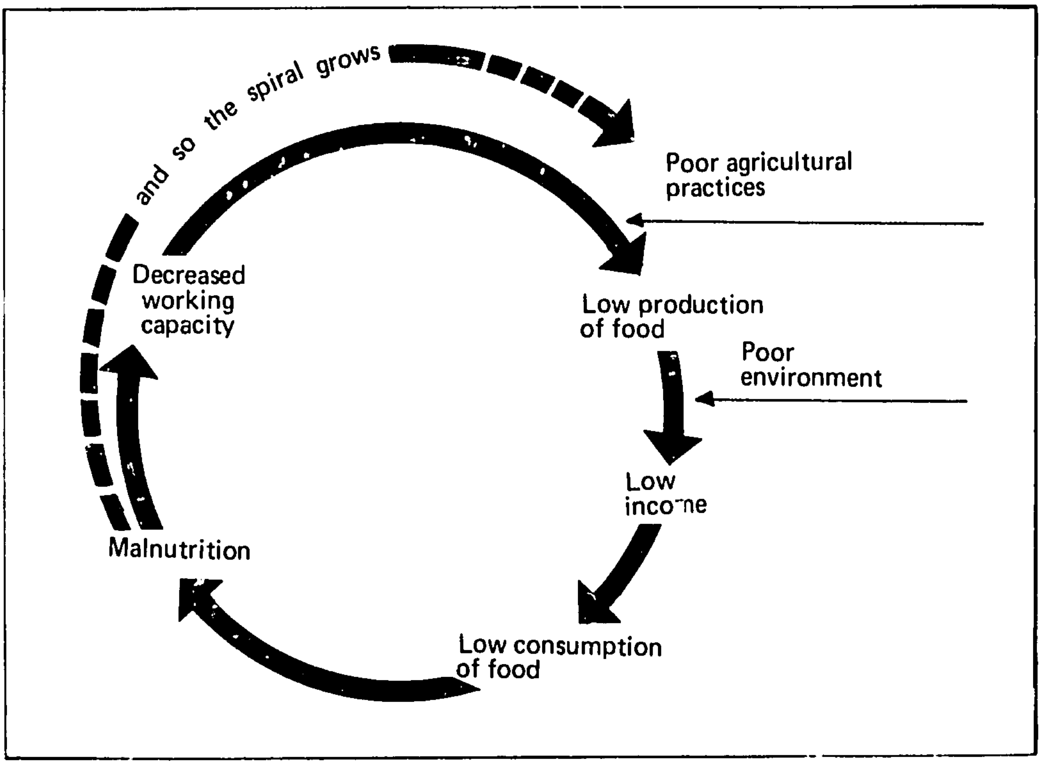

Fig. 1.1. The cycle of malnutrition, low productions, and low income.

Source of protein. Vegetables are generally poor sources of protein, except legumes which contain a high protein percentage. However, the protein in most vegetables are of poor quality. Two vegetables known to have good quality protein are soybean and potatoes. Legumes, known as "poor man's protein", make a good supplement to the starch-based diets common in rural areas of developing countries. Many of the legume seeds, also called beans, grain legumes, or pulses contain 20%-40% protein. In fact, in vegetarian diets or when meat and fish are expensive, vegetables become the main source of protein.

On a dry weight basis, many of the leafy vegetables contain as much protein as beans. However, the moisture content is 80%-90% in leaves as against 10% in beans. For example, swamp cabbage contains 1.4% protein on a fresh weight basis and 20% protein on a dry weight basis. When eaten regularly in adequate quantities, leafy vegetables can substantially contribute to protein nutrition. Their essential amino acids content are a boost to the family's nutrition (Fig. 1.2).

Source of minerals. Vegetables, along with fruits, constitute the most important source of minerals (Table 1.4). Of the minerals needed by the body, calcium and iron deserve the most attention. Calcium is necessary for the development and proper functioning of bones and teeth, while iron is needed to prevent anemia.

Source of vitamins. Vegetables are excellent sources of Vitamins A, C, and a group that includes Vitamins B_1, B_2, B_6, B_{12}, niacin, panthothenic acid, biotin, and folic

Table 1.2. Recommended intakes of nutrients (dietary allowance).

Age	Body Weight (kg)	Energy[a] (KCal)	Protein[a,b] (g)	Vitamin A[c,d] micrograms	Vitamin D[e,f] micrograms	Thiamine[c] milligrams	Riboflavin[c] milligrams	Niacin[c] milligrams	Folic Acid[e] micrograms	Vit. B_{12}[e] micrograms	Ascorbic Acid[e] milligrams	Calcium[g] (g)	Iron[e,h] milligrams
Children													
1	7.3	820	14	300	10.0	0.3	0.5	5.4	60	0.3	20	0.5-0.6	5-10
1-3	13.4	1360	16	250	10.0	0.5	0.8	9.0	100	0.9	20	0.4-0.5	5-10
4-6	20.2	1830	20	300	10.0	0.7	1.1	12.1	100	1.5	20	0.4-0.5	5-10
7-9	28.1	2190	25	400	2.5	0.9	1.3	14.5	100	1.5	20	0.4-0.5	5-10
Male adolescents													
10-12	36.9	2600	30	575	2.5	1.0	1.6	17.2	100	2.0	20	0.6-0.7	5-10
13-15	51.3	2900	37	725	2.5	1.2	1.7	19.1	200	2.0	20	0.6-0.7	5-10
16-19	62.9	3070	38	750	2.5	1.2	1.8	20.3	200	2.0	30	0.5-0.6	5-9
Female adolescents													
10-12	38.0	2350	20	575	2.5	0.9	1.4	15.5	100	2.0	20	0.6-0.7	5-10
13-15	49.9	2490	31	725	2.5	1.0	1.5	16.4	200	2.0	30	0.6-0.7	12-24
16-19	54.4	2310	30	750	2.5	0.9	1.4	15.2	200	2.0	30	0.5-0.6	14-25
Adult man (moderately active)	65.0	3000	37	750	2.5	1.2	1.8	19.8	200	2.0	30	0.4-0.5	5-9
Adult woman (moderately active)	55.0	2200	29	750	2.5	0.9	1.3	14.5	200	2.0	30	0.4-0.5	14-28
Pregnancy[i] (later half)		+350	38	750	10.0	+0.1	+0.2	+2.3	400	3.0	50	1.0-1.2	9
Lactation (first (6 months)[i]		+550	46	1200	10.0	+0.2	+0.4	+27	300	2.5	50	1.0-1.2	9

FAO/WHO 1972.

[a] Energy and Protein Requirements.

[b] As egg or milk protein.

[c] Requirements of Vitamin A, thiamine, riboflavin, and niacin; FAO/WHO 1965.

[d] As retinol.

[e] Requirements of ascorbid acid, Vitamin D, Vitamin B_{12}, folate, and iron, FAO/WHO 1970.

[f] As cholecalciferol.

[g] Calcium requirements; FAO/WHO 1961.

[h] On each line, the lower value applies when over 25% of the calories in the diet come from animal foods, and the higher value when animal foods represent less than 10% of calories.

[i] For women whose iron throughout life has been at the level recommended in this table, the daily intake of iron during pregnancy and lactation should be the same as that recommended for nonpregnant, nonlactating woman of childbearing age. For women whose iron status is not satisfactory at the beginning of pregnancy, the requirement is increased; and in extreme situation of women with no iron stores, the requirement cannot probably meet without supplementation.

Table 1.3. Nutrient content of some vegetables, 100 g edible portion (E.P.)[a]

Crop	Moisture (%)	Food Energy (Cal)	Protein (g)	Total Carbohydrate (g)	Ca (mg)	P (mg)	Fe (mg)	Na (mg)	K (mg)	ß-Carotene Equiv.[b]	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Ascorbic Acid[b] (mg)	Edible Portion (%)
Sweet potato (Yellow) (boiled)	68.1	126	1.0	29.4	66	58	0.8	5	393	540	0.09	0.04	0.6	31	88
Tomato (raw)	93.1	23	0.9	5.2	31	26	1.0	4	236	385	0.05	0.03	0.6	34	99
Garlic (raw)	66.5	116	7.0	24.6	28	121	1.2	10	302	0	0.23	0.08	0.4	7	85
Cabbage (raw)	92.8	23	1.4	4.8	74	28	0.8	11	212	20	0.04	0.07	0.3	42	81
Onion (raw)	87.0	48	1.7	10.5	40	51	0.6	11	102	Tr.	0.04	0.01	0.4	5	93
Eggplant (boiled)	93.6	21	1.0	4.9	30	28	0.5	4	223	80	0.07	0.04	0.5	Tr.	91
Ginger (raw)	88.8	42	1.1	8.5	32	30	3.0	6	264	0	0.04	0.04	0.6	4	74
Pechay (raw)	93.4	20	2.0	3.2	168	35	3.7	25	318	1450	0.05	0.11	0.9	54	84
Mungbean (boiled)	60.0	151	11.0	27.1	483	209	2.6	6	1141	80	0.14	0.06	0.6	2	100
White Potato (boiled)	83.8	61	1.7	13.7	34	44	0.8	4	449	Tr.	0.07	0.05	1.7	24	85
Gabi (boiled)	70.7	113	2.1	26.3	51	56	1.0	7	514	10	0.11	0.02	1.4	8	77
Radish (raw)	93.6	22	0.6	5.2	36	19	0.8	10	218	Tr.	0.06	0.03	0.4	27	70
Rice (boiled)	67.7	133	2.1	29.7	11	36	0.6	3	12	-	0.02	0.02	0.5	-	100
Soybean (boiled)	70.2	126	12.4	9.3	139	176	2.2	2	1329	140	0.25	0.14	1.2	21	54
Mustard (raw)	92.4	23	2.2	3.8	174	34	4.4	28	309	1670	0.05	0.10	0.5	64	81
Cauliflower (raw)	93.1	22	1.5	4.8	34	32	0.5	14	302	45	0.03	0.09	0.5	52	61

[a]Food and Nutrition Research Institute 1980, pp. 312; E.P. = edible portion.

[b]Tr. = trace.

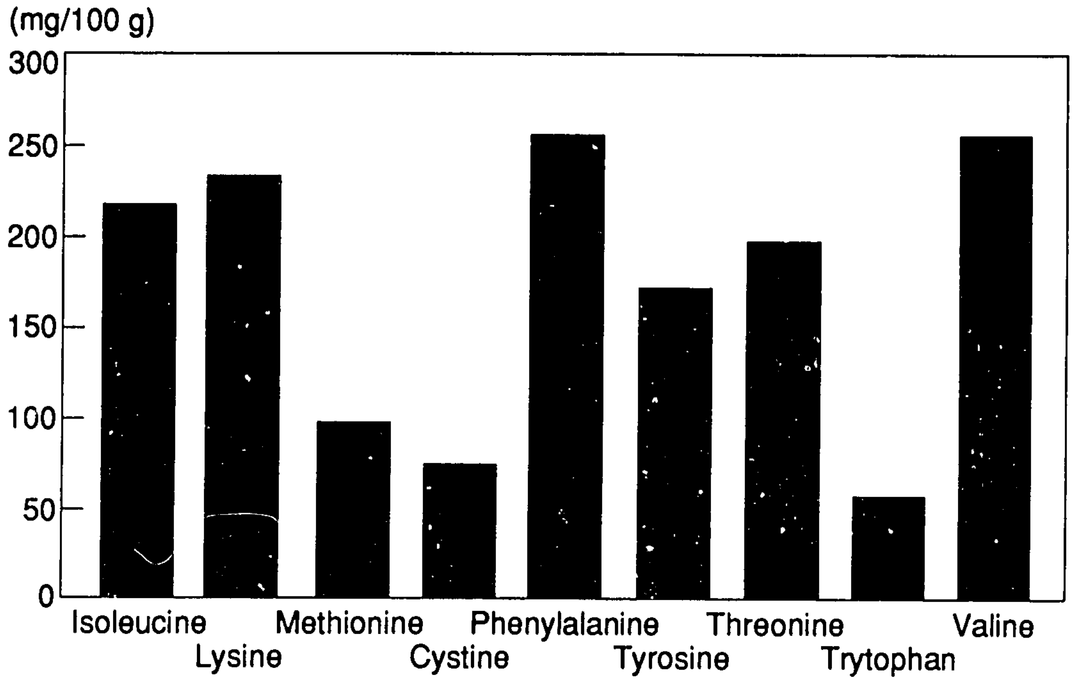

Fig. 1.2. Amino acid content of amaranth.

acid. B_1 is also known as thiamine, B_2 as riboflavin, B_6 as pyridoxine, B_{12} as cyanobalamin, and niacin as nicotinic acid.

Lack of Vitamin A causes poor growth and night blindness, or the inability of the eyes to adapt normally to dim light. As deficiency progresses, night blindness develops into Xeropthalmia, which is the deterioration of the eyesight. Eventually, complete blindness occurs.

The vitamin contents of vegetables vary greatly. Dark green and yellow vegetables are rich in provitamin A, with the young shoots containing more of this vitamin than the mature leaves. Provitamin A or carotene is converted to Vitamin A in the body.

Lack of Vitamin A is a common nutritional problem in many developing countries. If it accompanies protein and calorie malnutrition, the mortality may be as high as 80%; whereas in a group which is equally malnourished but not deficient in Vitamin A, it is only about 15%. Vegetables that are rich in vitamins are presented in Table 1.4.

Scurvy is a disease of the gums characterized by sponginess and bleeding caused by lack of Vitamin C. A single helping of vegetables, (91 g) daily, even if badly cooked, will usually provide at least 10 mg of ascorbic acid, an amount known to prevent scurvy. Green leafy vegetables are good sources of Vitamins C and B.

Aside from preventing scurvy, Vitamin C or ascorbic acid also has other functions in the body. It increases the resistance of the body to colds, coughs, and other respiratory diseases. It also improves the availability of iron. A six-fold increase in iron absorption has been observed with the addition of 70 mg ascorbic acid in a maize meal. The addition of 25 or 50 mg ascorbic acid to a simple Thai meal composed of rice, cooked vegetable, and a curry dish increased iron absorption by 50% and 90%, respectively. Foods rich in Vitamin C, such as green leafy vegetables, can therefore play an important supportive role in preventing iron deficiency.

Table 1.4. Vegetables rich in vitamins and minerals.

Vit. A	-	greater than 2,000 international units amaranth, Malabar spinach, kale, kangkong, leaf lettuce, and carrots
Vit. B	-	above .17 mg legumes, taro, and horseradish leaves
Vit. C	-	above 20 mg amaranth, Malabar squash, cabbage, kale, kangkong, and bitter gourd
Calcium (Ca)	-	above 20 mg amaranth, kangkong, head lettuce, leaf lettuce, kale, mustard, spinach, beans, onions, cabbage, turnip green, and soybean
Iron (Fe)	-	above 3 mg amaranth, kangkong, lettuce, spinach, and chillies
Phosphorus (P)	-	spinach, beans, lettuce, onions, tomatoes, cabbage, cauliflower, broccoli, and collard greens
Iodine (I)	-	onion, okra, asparagus

The B vitamins are necessary for the utilization of carbohydrates and protein and in the prevention of anemia. The legumes contain a reasonable amount of Vitamins B_1, B_2, and niacin.

Source of fiber. The contribution of vegetables as source of fiber is very important, especially in developed countries where a low fiber diet is consumed. Although edible fiber is not considered a nutrient and is not absorbed by the body, it is the component of vegetables that assist in moving food through the alimentary canal by aiding the muscular action of the intestines, thus preventing constipation. It also helps to satisfy the appetite.

The beneficial effect of fiber on blood cholesterol level and consequently high blood pressure and heart disease, in preventing gall stones and cancer of the colon has received increasing attention in recent years. Its large bulk and low energy value makes it also useful in preventing and treating obesity (fatness). Its role in the effective control of diabetes is also significant. Due to their fiber content vegetables have been dubbed as the health food.

Provides variety and appeal to diet. Due to the wide array from which to choose vegetables, they provide variety to the diet and make meals more appetizing. They give more flavor, better appearance, and zest to dishes which would otherwise look dreary or drab without them.

Availability of Nutrients

Anti-nutritional factors. Not all the nutrients found in a given vegetable are available. In vegetables high in oxalic acid or oxalates, such as taro, amaranth, beet greens, and spinach, calcium could be tied up by these components.

Some vegetables contain toxic cyanide-producing substances, the amount of which varies from one variety to another. When these substances break down, they yield hydrogen cyanide, also called prussic acid. It inhibits respiration at the cellular level causing difficulty in breathing. Bitterness is usually an indicator of the presence of such compounds. Bamboo shoots, for example, contain cyanide-producing substances;

hence, it is repeatedly boiled and the water thrown away, before it is cooked for food. The hyacinth or lablab bean and lima bean also contain these substances which are removed by soaking and boiling.

Legumes contain inhibitors of the essential amino acid trypsin. The presence of these inhibitors reduces the nutritional value of legumes. Compounds called condensed tannins can reduce protein digestibility in beans by 3%-5% and relative nutrient value by as much as 30%. Actually, this is not a problem since boiling increases protein digestibility and bean seeds are never eaten raw.

Cabbage and the other crucifers contain substances called goitrogens which make a person more susceptible to goiter by interfering with the production of the thyroid hormone. Goitrogens act like anti-thyroid drugs by blocking the absorption or utilization of iodine. However, these substances are destroyed by cooking the vegetables.

Solubility of vitamins. Vitamins of the B group and specially Vitamin C are soluble in water. About 35% of Vitamin C may be lost in water after boiling for ten minutes. Thus, cooking at a high temperature for a short period is recommended to retain Vitamin C. Uncooked tomatoes are more nutritious than cooked ones due to the solubility of Vitamin C. The B vitamins could be lost if the cooking water is thrown away.

On the other hand, Vitamins A, D, E, and K are lost if the vegetable is cooked in fat or oil. Only Vitamin A is a common nutritional problem since it is needed in greater amount than the others. Table 1.5 shows the stability of different vitamins upon exposure to different conditions.

Table 1.5. Stability of different vitamins upon exposure to different conditions.[a]

Vitamins	Air	Light	Heat
A	x	x	x
C	x	x	x
Biotin	/	/	x
B_{12}	x	x	/
D	x	x	x
Folic Acid	x	x	x
Imonitol	/	/	x
Niacin	/	/	/
B_6	/	x	x
B_{12}	/	x	x
B_1	x	/	x
E	x	x	x

[a]Symbols: x - not stable; / - stable

Economic Role of Vegetables

The economy of developing countries is usually agriculture-based. The majority of the rural populace depend on farming for livelihood; and a substantial number of farmers grow vegetables as a secondary, if not a primary crop. Vegetable production has the potential, therefore, of improving the lives of people.

Vegetable production is labor intensive (Table 1.6). Production of vegetables creates a number of job opportunities in the rural and suburban areas and in the complementary fields of business that arise, such as marketing, processing, and transportation. Vegetable growers tend to earn higher income than most other farmers because of the relatively higher yield and value of the crops. The comparison of cost of production and net income from vegetable and rice is shown in Table 1.7.

Table 1.6. Hours of labor required per hectare to produce tomatoes and rice in nine countries.

Country	Tomatoes[a]	Rice[b]
Colombia	4000	280
India	3384	632-736
Indonesia	3000-6000	1920
Japan	7040	371
Korea	2240-3200	1008-1112
Nigeria	3700-5700	1200-3600
Philippines	1384-2160	688-880
Taiwan	3874	321
Thailand	799-1844	648-936

[a]Gomez, A.A. et al. 1976. (except data from Taiwan).
[b]Rice data supplied by IRRI for India, Indonesia, Korea, Philippines, Taiwan, and Thailand.

Table 1.7. Comparison of production cost and net income from vegetable and rice in Taiwan.

Crop	Production Cost (US$/ha)	Yield (t/ha)	Net Income (US$/ha)
Rice	7,663	5.6	399
Soybean	1,579	2.5	649
Sweet potato	2,377	24.6	1,170
Potato	3,876	23.9	1,104
Mustard	2,426	39.7	1,016
Cauliflower	4,411	23.9	1,836
Onion	6,421	59.5	4,196
Garlic	6,834	9.5	5,677
Tomato	16,199	60.1	4,860

[a]Taiwan Department of Agriculture and Forestry, Dec. 1988.

Women in developing countries play a major role in vegetable production. They produce vegetables to meet their household's needs in addition to their primary responsibility to their family.

Data on the extent of vegetable production are only estimates and generally not very reliable because of the difficulty of accounting for all crops produced in small farms or home gardens. Moreover, plant species considered to be vegetables vary from place to place. Figures from the Food and Agriculture Organization (FAO) show the differences in the amounts of production, yield per hectare, and international trade of selected vegetables compared with other food crops (Table 1.8). Yields are higher in developed countries than in developing countries although total production in the former may be lesser.

Table 1.8. Production and trading of vegetables in relation to other food crops.

Crop	Area[a] (1,000 ha)	Yield[a] (mt/ha)	Production[a] (1,000 mt)	Import-1986[b] (1,000 mt)	Export-1986[b] (1,000 mt)
I. World					
Cereals, Total	702,083	2.48	1,742,985	19,828	20,287
Pulses, Total	68,536	.79	54,652	44,128	46,276
Chick peas	8,650	.67	5,803		
Dry beans	27,332	.56	15,533		
Dry broad beans	3,271	1.44	4,720		
Dry peas	9,854	1.57	15,505		
Groundnuts	19,535	1.16	22,752	9,083	9,258
Lentils	3,087	.81	2,508		
Soybeans	54,651	1.68	92,333	27,279	27,635
Roots and Tubers, Total	46,552	12.26	571,182		
Cassava	14,718	9.39	138,237		
Potatoes	18,135	14.87	269,702	54,073	55.404
Sweet potatoes	9,258	14.08	130,355		
Taro	1,000	5.48	5,486		
Yams	2,450	9.64	23,629		
Vegetables + melon, Total			426,187		
Artichokes	127	9.97	1,267		
Cabbages	1,663	22.63	37,640		
Carrots	590	21.47	12,670		
Cauliflowers	396	13.58	5,380		
Cucumbers	860	15.28	13,142		
Dry onions	1,789	14.19	25,387	19,125	19,513
Eggplants	430	13.12	5,644		
Garlic	456	6.22	2,839		
Green beans	448	6.52	2,924		
Green chillies and peppers	1,025	8.52	8,733	1,207	1,107
Green peas	755	5.90	4,455		
Pumpkins, squash, and gourds	544	11.66	6,346		
Tomatoes	2,669	23.97	63,988	22,747	21,630
II. China					
Cereals, Total	89,836	3.92	352,306	1,232	741
Pulses, Total	4,417	1.28	5,679	1,000	4,360
Chick peas	0		0		
Dry beans	1,417	1.14	1,629		
Dry broad beans	1,700	1.38	2,350		
Dry peas	1,300	1.30	1,700		
Groundnuts	3,316	1.76	5,855	0	2,624
Lentils	0		0		
Soybeans	8,111	1.34	10,918	2,032	1,370
Roots and Tubers, Total	9,253	15.66	144,926		
Cassava	237	14.49	3,435		
Potatoes	2,533	11.66	29,550	0	580

Table 1.8. Continued.

Crop	Area[a] (1,000 ha)	Yield[a] (mt/ha)	Production[a] (1,000 mt)	Import-1986[b] (1,000 mt)	Export-1986[b] (1,000 mt)
Sweet potatoes	6,371	17.36	110,660		
Taro	92	13.81	1,271		
Yams	0		0		
Vegetables + melon, Total			112,954		
Artichokes	0		0		
Cabbages	453	17.10	7,750		
Carrots	123	21.09	2,595		
Cauliflowers	79	13.29	1,050		
Cucumbers	241	15.84	3,818		
Dry onions	241	15.31	3,692	80	320
Eggplants	176	12.71	2,238		
Garlic	72	8.72	628		
Green beans	45	9.86	444		
Green chillies and peppers	165	12.13	2,002	0	312
Green peas	57	5.35	305		
Pumpkins, squash, and gourds	96	14.68	1,410		
Tomatoes	341	16.05	5,474	0	100
III. Southeast Asia					
Cereals, Total	47,163	2.61	123,548	672	96
Pulses, Total	2,211	.79	1,751	1,516	4,165
Chick peas	255	.94	240		
Dry beans	1,574	.78	1,239		
Dry broad beans	0		0		
Dry peas	30	.83	25		
Groundnuts	1,597	1.21	1,942	1,149	295
Lentils	3	.33	1		
Soybeans	1,702	1.11	1,890	664	27
Roots and Tubers, Total	4,661	10.71	49,943		
Cassava	3,605	11.90	42,914		
Potatoes	99	10.49	1,039	954	413
Sweet potatoes	855	6.45	5,521		
Taro	31	3.45	107		
Yams	6	4.16	25		
Vegetables + melon, Total			13,875		
Artichokes	0	0			
Cabbages	56	14.14	792		
Carrots	7	6.00	42		
Cauliflowers	5	9.40	47		
Cucumbers	50	6.00	300		
Dry onions	188	4.90	923	1,786	596
Eggplants	97	3.14	305		
Garlic	50	4.86	243		
Green beans	40	2.90	116		
Green chillies and peppers	146	2.42	354	400	214

Table 1.8. Continued.

Crop	Area[a] (1,000 ha)	Yield[a] (mt/ha)	Production[a] (1,000 mt)	Import-1986[b] (1,000 mt)	Export-1986[b] (1,000 mt)
Green peas	7	3.28	23		
Pumpkins, squash, and gourds	17	12.76	217		
Tomatoes	65	6.21	404	102	120
IV. South Asia					
Cereals, Total	128,042	1.75	224,792	409	170
Pulses, Total	24,435	.49	12,165	4,304	99
Chick peas	6,710	.60	4,037		
Dry beans	10,278	.35	3,644		
Dry broad beans	0		0		
Dry peas	609	.78	477		
Groundnuts	7,590	.97	7,403	7	224
Lentils	1,329	.60	804		
Soybeans	1,711	.79	1,358	0	0
Roots and Tubers, Total	1,751	14.05	24,604		
Cassava	316	17.82	5,633		
Potatoes	1,158	14.39	16,673	360	403
Sweet potatoes	240	8.76	2,104		
Taro	0		2		
Yams	0		0		
Vegetables + melon, Total			53,877		
Artichokes	0		2		
Cabbages	93	6.47	602		
Carrots	1	12.00	12		
Cauliflowers	100	7.43	743		
Cucumbers	6	5.83	35		
Dry onions	381	8.55	3,258	780	2,763
Eggplants	0		0		
Garlic	101	3.89	393		
Green beans	36	3.44	124		
Green chillies and peppers	95	1.96	187	81	156
Green peas	95	2.75	262		
Pumpkins, squash, and gourds	32	8.93	286		
Tomatoes	99	9.08	899	0	0
V. Near East					
Cereals, Total	45,185	1.67	75,632	2,974	43
Pulses, Total	3,308	1.16	3,854	2,904	5,557
Chick peas	888	1.05	941		
Dry beans	446	.98	440		
Dry broad beans	244	2.73	667		
Dry peas	83	.80	67		
Groundnuts	676	.90	649	62	135
Lentils	1,186	1.08	1,292		

Table 1.8. Continued.

Crop	Area[a] (1,000 ha)	Yield[a] (mt/ha)	Production[a] (1,000 mt)	Import-1986[b] (1,000 mt)	Export-1986[b] (1,000 mt)
Soybeans	176	2.32	410	296	0
Roots and Tubers, Total	601	17.05	10,251		
Cassava	30	2.16	65		
Potatoes	518	19.07	9,879	2,860	3,958
Sweet potatoes	7	10.42	73		
Taro	4	28.75	115		
Yams	43	2.79	120		
Vegetables + melon, Total			42,489		
Artichokes	4	18.00	72		
Cabbages	58	22.34	1,296		
Carrots	20	17.80	356		
Cauliflowers	15	21.60	324		
Cucumbers	134	14.67	1,967		
Dry onions	182	17.73	3,228	2,369	2,244
Eggplants	97	17.63	1,711		
Garlic	30	10.83	325		
Green beans	74	8.54	632		
Green chillies and peppers	82	13.76	1,129	7	2
Green peas	19	8.00	152		
Pumpkins, squash, and gourds	82	14.90	1,222		
Tomatoes	511	25.74	13,154	2,530	3,151
VI. Southern Africa					
Cereals, Total	9,355	1.18	11,060	144	53
Pulses, Total	1,549	.51	799	468	320
Chick peas	94	.46	44		
Dry beans	719	.56	407		
Dry broad beans	0		0		
Dry peas	77	.31	24		
Groundnuts	822	.61	506	26	232
Lentils	0		0		
Soybeans	76	1.63	124	0	0
Roots and Tubers, Total	2,273	5.31	12,090		
Cassava	1,934	5.59	10,812		
Potatoes	131	4.98	653	92	10
Sweet potatoes	204	2.92	597		
Taro	0		0		
Yams	2	5.00	10		
Vegetables + melon, Total			2,187		
Artichokes	0		0		
Cabbages	2	13.50	27		
Carrots	0		0		
Cauliflowers	0		0		
Cucumbers	0		0		

Table 1.8. Continued.

Crop	Area[a] (1,000 ha)	Yield[a] (mt/ha)	Production[a] (1,000 mt)	Import-1986[b] (1,000 mt)	Export-1986[b] (1,000 mt)
Dry onions	33	3.09	102	14	2
Eggplants	0		0		
Garlic	0		1		
Green beans	0		0		
Green chillies and peppers	0		0	0	0
Green peas	0		0		
Pumpkins, squash, and gourds	0		1		
Tomatoes	10	81.40	814	0	0
VII. Developing Africa					
Cereals, Total	58,777	1.07	63,053	1,611	81
Pulses, Total	10,905	.55	6,024	1,990	1,007
Chick peas	444	.61	275		
Dry beans	2,394	.65	1,557		
Dry broad beans	675	1.22		827	
Dry peas	455	.69	314		
Groundnuts	4,887	.78	3,820	330	615
Lentils	133	.81	109		
Soybeans	334	.72	243	17	0
Roots and Tubers, Total	13,652	6.94	94,783		
Cassava	8,063	7.06	56,955		
Potatoes	635	6.73	4,277	3,438	826
Sweet potatoes	1,164	4.99	5,819		
Taro	799	4.09	3,269		
Yams	2,275	9.82	22,350		
Vegetables + melon, Total				16,617	
Artichokes	16	6.00	96		
Cabbages	8	14.37	115		
Carrots	29	9.82	285		
Cauliflowers	1	13.00	13		
Cucumbers	1	18.00	18		
Dry onions	110	8.43	928	691	166
Eggplants	11	4.18	46		
Garlic	1	7.00	7		
Green beans	12	3.66	44		
Green chillies and peppers	139	7.92	1,101	35	25
Green peas	12	4.50	54		
Pumpkins, squash, and gourds	28	9.28	260		
Tomatoes	292	9.73	2,844	6	1,017
VIII. Latin America					
Cereals, Total	51,927	2.07	107,730	1,912	1,409

Table 1.8. Continued.

Crop	Area[a] (1,000 ha)	Yield[a] (mt/ha)	Production[a] (1,000 mt)	Import-1986[b] (1,000 mt)	Export-1986[b] (1,000 mt)
Pulses, Total	10,039	.56	5,660	5,234	3,508
Chick peas	184	.95	175		
Dry beans	9,175	.54	5,028		
Dry broad beans	272	.63	173		
Dry peas	149	.72	108		
Groundnuts	513	1.67	861	140	1,269
Lentils	90	.67	61		
Soybeans	16,289	1.85	30,209	1,481	4,494
Roots and Tubers, Total	4,150	10.96	45,491		
Cassava	2,452	11.84	29,044		
Potatoes	1,131	11.23	12,712	2,360	683
Sweet potatoes	321	7.13	2,289		
Taro	3	8.33	25		
Yams	99	7.38	731		
Vegetables + melon, Total			20,608	426,187	
Artichokes	6	15.83	95		
Cabbages	45	16.80	756		
Carrots	43	18.32	788		
Cauliflowers	6	11.66	70		
Cucumbers	31	12.74	395		
Dry onions	152	13.51	2,055	475	1,204
Eggplants	3	16.66	50		
Garlic	37	5.15	201		
Green beans	36	3.77	136		
Green chillies and peppers	102	8.35	852	8	93
Green peas	69	2.47	171		
Pumpkins, squash, and gourds	118	8.79	1,038		
Tomatoes	283	23.59	6,677	323	5,947

[a]FAO 1988. Production Yearbook, Vol. 42
[b]FAO 1986. Trade Yearbook, Vol. 40

Vegetables can be exported from areas where they can be grown easily and cheaply to countries where they are desired but cannot be grown in adequate amounts. As such, they can be a good source of foreign exchange (Table 1.7). An idea of places where vegetables can be grown at a lower cost is shown in Table 1.9. According to this table, Thailand has the lowest average farm price of tomato, compared with Taiwan and the Philippines. On the other hand, the Philippines has the highest farm price of garlic (US$ 3,062), which is approximately five times that of Taiwan and six times that of Thailand.

Vegetables are more efficient converters of farm resources than other crops in terms of yield per unit area per unit time since they grow very fast. A hectare of potato can yield from two to two-and-a-half times as many calories as a hectare of rice or wheat. Yield of yambean can be as high as 20-30 t/ha in five to six months. Yield of amaranth and kangkong can be as high as 10 t of edible leaves in 20-30 days.

Table 1.9. Farm prices of vegetables in Taiwan, Philippines, and Thailand (US$/mt).

1988	Taiwan[a]			Philippines[b]			Thailand[b]		
	Mean	Max (month)	Min (month)	Mean	Max (month)	Min (month)	Mean	Max (month)	Min (month)
Pulses, Total									
Groundnuts	1,061	1,144 (Jan)	1,025 (Dec)	416	498 (Nov)	342 (Mar)	297	358 (Apr)	247 (Jul)
Soybeans	700	700	700	263	408 (Dec)	174 (Nov)	364	424 (Jul)	333 (Mar)
Potatoes	694	694	694	306	538 (Dec)	247 (Mar)			
Sweet potatoes	361	396 (Dec)	330 (Jun)	100	120 (Dec)	90 (Jan)			
Vegetables + Melon, Total									
Cabbages	249	469 (Aug)	63 (Apr)	239	418 (Dec)	152 (May)	158	282 (Oct)	83 (Jan)
Carrots	277	361 (Nov)	217 (Apr)						
Cauliflowers	479	867 (Aug)	126 (Mar)						
Cucumbers	294	505 (Nov)	126 (Mar)				154	208 (Dec)	95 (Mar)
Dry onions	401	614 (Sep)	235 (Feb)	541	953 (Jun)	186 (Feb)	265	535 (Jan)	96 (Apr)
Eggplants	455	646 (Oct)	246 (Mar)						
Garlic	637	947 (Jun)	396 (Mar)	3,062	5,516 (Jul)	842 (Feb)	491	686 (Jan)	376 (Sep)
Green beans	608	846 (Oct)	354 (Mar)						
Green chillies & peppers	678	1,165 (Aug)	396 (Mar)						
Green peas	1,394	3,245 (Oct)	702 (Mar)						
Tomatoes	595	1,017 (Oct)	326 (Apr)	244	562 (Dec)	110 (Jan)	182	388 (Jul)	56 (Mar)
Watermelons				1,708	2,835 (May)	638 (Jan)			

[a]Department of Agriculture and Forestry. December 1988. Taiwan Agricultural Prices & Costs Monthly.

[b]FFTC. June 1989. Prices of Major Agricultural Products and Chemical Fertilizers in the Asian and Pacific Region. No. 21.

Utilization of Vegetables

Vegetables are utilized in different ways. Salads, as uncooked side dishes are called, are an integral part of the daily meal in some developed countries. However, in developing countries, eating raw vegetables is not as common. They are usually cooked and eaten as a side dish or mixed in a stew with meat, fish, other foods, or other vegetables in so many variations.

They are not only boiled but sauteed, curried, fried, broiled, or baked. They are cooked with water, oil, coconut milk, or sometimes wine. They are consumed with different seasonings or sauces. During festive occasions, some vegetables like parsley, green onions, tomatoes, and radish are used principally as garnish to decorate meat or fish dishes and may or may not be eaten.

Most vegetables are consumed unprocessed. Very few are canned or pickled. Dehydrated vegetables are usually used as ingredients in making canned or instant soups. Many vegetables can be frozen, but there is not as much demand for frozen vegetables on a commercial scale as for fresh vegetables in developing countries. Some of the beans can be processed into bean cakes (*tofu*) or fermented to *tempeh*. Processing extends the utility of beans and adds value to vegetables. Some of the vegetables that are processed are shown in Table 1.10.

The parts of the plants utilized as vegetables are tabulated in Table 1.11. A plant part may be commonly used as a vegetable but may be practically unknown to some other parts of the world. An example is cassava leaf, which is one of the most important vegetables in Africa. Elsewhere, cassava is known for its roots.

Table 1.10. Some vegetables that are processed.

Processing Type	Vegetable
Canned	Lima bean, okra, young cob corn, asparagus, tomato, navy bean, kangkong, sweet corn, potato, sweet potato, carrot, snap beans, and bamboo shoot
Pickled	cucumber, cauliflower, bitter gourd, sweet pepper, onion, turnip, radish, and ginger
Dehydrated	onion, carrot, garlic, leek, bell pepper, potato, sweet potato, garlic, mustard, petsai, and ginger
Fermented	cabbage, Chinese cabbage, radish, and mustard
Other products	potato (fries, crisps, flour), carrots, (jam, sweetmeat), mungbean and soybean (*tofu* and *tempeh*).

Table 1.11. Examples of plants parts utilized as vegetables.

Plant Part	Vegetable
Root	radish, carrot, sweet potato, and water chestnut
Bulb	onion, and garlic
Tuber	potato
Stem	bamboo shoot, asparagus, ginger, taro
Leaf	cabbage, lettuce, mustard, spinach, leek, parsley, and celery (petiole)
Fruit	cucumber, eggplant, tomato, pepper, beans, pea, watermelon, gourd, okra, sweet corn, and chayote
Flower	cauliflower and broccoli

Other Uses of Vegetables

Some vegetable crops are also valued for their medicinal uses, as handed down from generation to generation, especially in the rural areas of developing countries. Garlic cloves, for example, are used for curing high blood pressure and rheumatism. Some are known to have insecticidal properties, such as the hot pepper fruits. Still others are valued for cosmetic purposes. Slices of cucumber on the face cleanse and close pores to prevent dust from getting in.

Classification of Vegetables

It is estimated that there are at least 10,000 plant species used as vegetables worldwide, although only about less than 50 are of great commercial value. Therefore, to simplify discussion it is necessary to classify them into two groups: according to method of culture and according to botanical classification.

According to Method of Culture

Crops belonging to the same group have the same general culture and are subject to similar pests and diseases.

1. Leafy vegetables — crops used mainly for their leaves whether eaten raw or cooked, e.g., lettuce, mustard, amaranth, kangkong, and celery.
2. Cole crops, crucifers, or *Brassicas* — crops belonging to the cabbage family (Brassicaceae formerly Cruciferae) including Chinese cabbage, cauliflower, and broccoli (excluding radish).
3. Cucurbits — crops belonging to the Cucurbit family to which cucumber and the gourds belong.
4. Pulses or legumes — members of the Fabaceae formerly Leguminosae family like cowpea, vegetable soybean, yard-long bean, edible podded pea, and the other peas and beans.
5. Root, bulb, and tuber crops — onions, garlic, potato, sweet potato, radish, and carrot.
6. Solanaceous crops — tomato, eggplant, and pepper.

Botanical Classification

Botanical classification is based on the broad relationship of plants according to similarity or dissimilarity in flower structure as the main criteria of determining relationship. Plants can be classified starting from the broadest grouping into kingdom, division, subdivision, phylum, subphylum, class, subclass, order, family, genus, and species.

For practical purposes, a vegetable is classified starting from the family group. The combination of genus and species make up the scientific name of vegetables which is accepted worldwide. Sometimes synonyms are indicated. Plants recognized as a single vegetable, even if they have different scientific names, are said to be of one kind. The genus name is the same but the species may vary. The United States Department of Agriculture (USDA) classification (Terrell et al. 1986) has been followed in classifying plants by families, genus, and species basically following the International Rules on Nomenclature.

Amaranthaceae

Amaranthus viridis L. - slender amaranth, green amaranth
A. spinosus L. - spiny amaranth

Apiaceae

Apium graveolens L. var. *dulce* (Miller) Pers. - celery
Daucus carota subsp. *sativus* (Hoffm.) Arcang. - carrot
Petroselinum crispum (Miller) Nyman ex. A.W. Hill (*P. hortense* Hoffm.), (*P. sativum* Hoffm.), (*P. vulgare* Lagasca) - parsley

Araceae

Colocasia esculenta (L.) Schott - taro, eddo, dasheen, cocoyam

Asteraceae

Chrysanthemum coronarium L. var. *coronarium* - garland chrysanthemum, crown daisy
Cichorium endivia L. - endive, escarole
Tragopogon porrifolius L. - salsify, vegetable oyster
Lactuca sativa L. - garden lettuce, celtuce
Cynara scolymus L. - globe artichoke
Helianthus tuberosus L. - Jerusalem artichoke

Basellaceae

Basella alba L. - Malabar nightshade, Ceylon spinach (white)
Basella rubra L. - Malabar nightshade, Ceylon spinach (red)

Brassicaceae

Brassica napus L. var. *chinensis* L. - pak-choi or pet-sai
B. oleracea var. *acephala* DC. - kale or collard
B. oleracea L. var. *capitata* L. - cabbage
B. pekinensis (Lour.) Rupr. - Chinese cabbage
B. juncea L. Czernj. and *Cosson* var. *juncea* - Indian mustard
B. napus var. *napobrassica* (L.) Reichb. - rutahaga, swede
B. oleracea var. *gongylodes* L. (*Brassica oleracea* var. *cauloropa* DC.) - Kohlrabi
B. oleracea var. *gemmifera* DC - Brussel sprouts
B. rapa L. var. *rapa* - turnip
B. oleracea var. *botrytis* L. - cauliflower
B. oleracea var. *italica* Plenck - broccoli, sprouting broccoli
Nasturtium officinale R. Br. [(*Nasturtium aquaticum* L. Karsten)] - watercress
Raphanus sativus L. - radish

Chenopodiaceae

Spinacia oleracea L. - spinach
Beta vulgaris L. subsp. *vulgaris* - garden beet, sugar beet
Beta vulgaris subsp. *cicla* (L.) Koch - Swiss chard, Spinach beet

Convulvulaceae

Ipomoea aquatica Forsskal (*Ipomoea reptans* Poir.) - swamp morning-glory, water spinach, kangkong, water convolvulus, tropical spinach
I. batatas (L.) Lam - sweet potato, yam (in USA)

Cucurbitaceae

Benincasa hispida (Thunb.) Cogn - waxgourd, Chinese winter melon, Chinese fuzzy gourd
Cucurbita moschata (Duchesne) Duchesne ex. Poiret - pumpkin, squash (incl. butternut squash)
Cucurbita pepo L. - pumpkin, marrow, squash (incl. zucchini spaghetti squash)
Cucurbita maxima Duchesne var. *maxima* - pumpkin, squash, marrow (incl. turban squash and Hubbard squash)
Citrullus lanatus (Thunb.) Matsum. and Nakai var. *lanatus* - watermelon
Cucumis sativus L. - cucumber
Cucumis melo L. var. *reticulatus* Naud: Common muskmelon, netted melon and cantaloupe
Cucumis melo L. var. *inodorus* Naud - melon, muskmelon or winter melon or "Honeydew"
Lagenaria siceraria (Molina) Standley - (*Cucurbita siceraria* Molina) (*L. leucantha* (Duchesne) Rusby) (*L. vulgaris* Ser.) - white-flowered gourd, bottle gourd, calabash gourd, zucca melon, spaghetti squash
Luffa acutangula (L.) Roxb. - angled luffa, singkwa, towelgourd, Chinese okra, vegetable gourd
Luffa aegyptiaca Miller (syn.: *Luffa cylindrica* Roem) - luffa, loofah, smooth loofah, vegetable sponge
Momordica charantia L. - bitter gourd, balsam pear, balsam-apple
Sechium edule (Jacq.) Sw. - chayote, chocho, choko
Trichosanthes anguina L. - snake gourd

Fabaceae

Cajanus cajan (L.) Huth - pigeonpea
Canavalia ensiformis (L.) DC. and *C. gladiata* (Jacq.) DC.- sword bean, jackbean, horsebean
Cicer arietinum L. - chickpea, garbanzos, Bengal gram, yellow gram
Glycine max. (L.) Merr. (*Phaseolus max* L.) - vegetable soybean
Lablab purpureus (L.) Sweet (syn.: *Dolichos lablab* L.) sweet - bonavist bean, hyacinth bean, lablab bean
Pachyrrhizus erosus (L.) Urban - jicama, yambean
Phaseolus lunatus L. - lima bean, butter bean
Phaseolus vulgaris L. - garden bean, green bean, kidney bean, haricot bean, navy bean, snap bean
Pisum sativum L. subsp. *sativum* - garden pea, field pea, edible-podded pea, sugar pea
Tetragonolobus purpureus Moench (Syn.: *Psophocarpus tetragonolobus* (L.) DC. - winged bean, asparagus pea

Vigna unguiculata subsp. *sesquipedalis* (L.) Verdc. - yard-long bean, asparagus bean
Vigna unguiculata (L.) Walp. subsp. *unguiculata* - southern pea, cowpea, (including black - eyed pea, crowder pea)
Vigna radiata (L.) R. Wilczek var. *radiata*-mungbean, green gram

Liliaceae

Allium cepa L. var. *cepa* - onion, shallot, eschalot, potato onion, multiplier onion
A. odorum L. - Chinese chives
A. porrum L. - leek
A. sativum L. - garlic
A. schoenoprasum L. - chives
A. fistulosum L. - Japanese bunching onion, Green onion
A. cepa X *A. fistulosum* - Beltsville bunching onion
Asparagus officinalis L. - garden asparagus

Malvaceae

Abelmoschus esculentus (L.) Moench (*Hibiscus esculentus* L.) okra, gumbo
Hibiscus sabdariffa L.- roselle

Poaceae

Phyllostachys dulcis McClure - bamboo shoot
Zea mays L. subsp. *mays* - sweet corn

Solanaceae

Capsicum annuum L. var. *annuum* - bell pepper, green pepper, mango pepper, paprika pepper, chili pepper, pimiento pepper
C. frutescens L. - tabasco pepper, bird pepper, chili pepper, cayenne pepper
Lycopersicon lycopersicum (L.) Karsten - tomato
Solanum melongena L. - eggplant, aubergine, brinjal
S. tuberosum L. - potato, white potato, Irish potato

Tiliaceae

Corchorus olitorius L. - nalta jute, tussa jute, tossa jute, jews mallow, bush okra

Trapaceae

Trapa natans L. var. *natans* - waterchestnut

Zingiberaceae

Zingiber officinale Roscoe - ginger

The edible fungi or mushrooms are also considered vegetables, although their production method is quite different from other vegetables. Of commercial importance are French button mushroom (*Agaricus* spp.), oyster mushroom (*Pleurotus sajor-caju*), black ear mushroom (*Auricularia* spp.), and straw mushroom (*Volvariella* spp.).

Vegetable Production Systems

Vegetable production ventures can vary in farm size, amount of investment put in, methods employed, and economic role. Vegetable production systems are either market- or home-oriented.

Nutrition Gardens

The home-oriented types are also called nutrition gardens since nutrition is the prime consideration for production.

The ***home garden*** is the common type of nutrition garden. Its main purpose is to provide a supplementary source of essential nutrients for the family diet. Nutritional beneficiaries may include extended family members and even neighbors. For many people, raising vegetables in a home garden is a pleasant way of exercising and economizing on food cost.

In urban communities where home lots are small, home gardens are confined to the backyard, hence the term "backyard garden"; in rural communities where home lots are bigger, they may be located in any part of the home lot or even at a distance from the house. The size of the area occupied by vegetables may range from a few square meters to a hundred or more.

Vegetables may be grown in combination with fruit trees, ornamentals, and plantation crops in no definite arrangement. Vegetables that can tolerate some extent of shading can be grown under taller plants. Climbing plants can be trained on fences or roofs. Water-loving plants can be grown in drainage ditches. Plants may also be grown in pots or other types of containers. Vegetables grown in home gardens are those plants that the family want and can easily grow without too much care with practically no cash expense. Kitchen refuse and droppings of small livestock are utilized as fertilizer. The family members provide the needed labor.

School and community gardens are the two other types of nutrition gardens. School gardens are encouraged in the elementary grades and sometimes in secondary schools in areas where malnutrition is a problem. Sometimes a neighborhood may have a communal or community garden from which to get vegetables for their families. The techniques involved in nutrition gardens are similar.

Specialized Market-Oriented Vegetable Production

Home gardens were the earliest types of vegetable production enterprise. As communities and cities developed, there arose a need for specialization of work. Farmers produced vegetables for the community. Thus, market-oriented vegetable production started. Initially, the gardens were near population centers and these were called ***market gardens***. Production of vegetables is year-round. Many types of vegetables are grown at any one time. It is a highly intensive production enterprise. A new crop is planted immediately after harvest or sometimes before the standing crop is harvested. Most crops grown are fast growing. The aim is maximum profit.

The development of export markets and food-processing industries led to a greater demand for vegetables. The building of roads and the availability of efficient transport facilities have permitted the expansion of vegetable farms in areas that are far from centers of population. Hence, the term ***truck farms***. In the tropics, such farms grow vegetables year-round. The goal is high yield and inputs are correspondingly high. Suitability of climate and soils are important considerations.

Truck farms usually have one or more crops. It is not as intensively cultivated as the market gardens since a few weeks may be allowed in-between crops. The large enterprises may approximate the operations in developed countries in terms of mechanization and technology application.

As population continues to increase, the need for more vegetables also increases. Supply of fresh vegetables is inadequate when conditions are not favorable for vegetable production. Thus, control of the environment to produce more vegetables started to gain popularity.

The growing of vegetables in the open field, when environmental conditions do not generally permit, is a highly specialized type of vegetable production. It used to be called vegetable forcing. Now it is called ***controlled-environment agriculture***. In its simplest version, it is called protected cultivation. It requires the use of special structures to control environmental factors, thus providing an artificial climate. It is highly capital-intensive but highly productive, and the quality of its products is excellent.

The simplest type of controlled environment system involves only the control of water while in the most sophisticated systems, light, temperature, sometimes carbon dioxide, and nutrients are controlled in addition to water. In tropical countries, protection from rain is provided to grow crops during the rainy season. The structure may have glass or usually plastic film roofing. Usually the latter is used.

Plants grown in the greenhouse may be protected from insects by wire or plastic netting used as walls. Plastic tunnels are often used instead of the usual structure. These are long structures supported by bamboo or wire arches. High-value crops, such as tomato, cucumber, and lettuce are grown. For mushrooms, a stable uniform climate will allow production on a year-round basis.

Hydroponics, the technique of growing crops in nutrient solutions or with the use of an artificial medium, has greatly added to the efficiency of vegetable forcing. Traditionally, the shoots are the main concern of farmers. In hydroponics, the root system is the most important.

Plants in a greenhouse or plastic house may be grown in a solid medium to provide mechanical support, such as sand, gravel, vermiculite, or other medium. Those grown without solid support are grown with their roots in water in polyethylene trays. These are the liquid hydroponic systems. The nutrients are supplied in the water rather than in the soil.

Hydroponics makes possible high-density cropping, very efficient use of water and fertilizers and minimum use of land areas; but it requires a big investment a d a high degree of technical competence to be successful.

Unspecialized Market-Oriented Vegetable Farms

A lot of vegetables are grown as secondary crops after or with rice or corn and in plantations as cash crops. This scheme gives the farmers more flexibility to respond to market opportunities and even reduce production risks.

Vegetable Production Systems According to Purpose

Vegetable production enterprises can also be classified according to purpose or the type of outlet; i.e., fresh market, seed processing plant, and food processing plant.

Commercial seed production is a highly specialized business usually limited to areas that are relatively dry for sufficient periods of time to grow a crop (See Chapter 5).

Production of crops for processing is also a highly specialized business, since processing plants have certain requirements which are met only by certain varieties having the desired qualities. Yields must be high, but cost of production must be low. If the processing variety is also acceptable for the fresh market, it must be the variety preferred by the customers in the fresh form. Farms producing for processing must be near the processing plant, or transportation facilities must be available and adequate.

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CHAPTER 2

Growth and Development of Vegetable Crops

Vegetables are the result of seed germination, the growth of seedlings, and their eventual development into mature plants. As the plant increases in size and bulk, it also becomes more complex. Some of the undeveloped buds develop into flowers and the flowers develop into fruits. The irreversible changes in size and weight are referred to as ***growth*** and the change into specialized parts is termed ***development***. The latter involves cellular, structural, and organizational changes, as well as changes in processes that occur within the plant. An understanding of these processes of change will enable a grower to provide the appropriate conditions for promoting growth and development.

The plant can be divided into two parts: the shoot and the root. The ***shoot*** is the part of the plant we see above ground. The ***stems***, ***leaves***, ***flowers***, and ***fruits*** make up the ***shoot***. Stems are usually jointed, each joint forming a node; and the part between two nodes is the internode. The stem is usually solid and thicker at the nodes. The different parts of the plants are shown in Fig. 2.1. The ***buds*** are the closely packed undeveloped leaves. They usually grow from the intersection of the leaf and stem called ***axils***. These are called ***axillary buds***. The tips of the stems or roots are called ***apices*** (from the singular apex). The buds from the shoot apices are called ***apical*** or ***terminal buds***. Although the root system is largely unseen, it plays an important role in the growth and development of a plant. It absorbs the necessary water and mineral nutrients, aside from anchoring the plant to the soil. Roots also produce growth substances that are used for the normal functioning of the plant. In the leguminous crops, roots produce nodules that harbor nitrogen-fixing bacteria. In many crops, roots associate with fungal or other soil organisms, resulting in a complex but generally beneficial relationship. Roots also serve as storage of food materials as in the case of root crops, such as sweet potato and carrot.

The root and shoot system tend to balance each other There are as many roots as are necessary to absorb water and nutrients needed by the shoots. As the shoot grows larger, it needs more water and nutrients; and the roots usually grow in proportion to such a need.

Photosynthesis and Respiration

The yield of vegetables ultimately depends on the size and efficiency of their photosynthetic system. Crop management practices to increase yields are based on this assumption. Since photosynthesis is the basis of vegetable production, it is important to know its associated physiological processes and how the plant parts act together to capture and store energy from the sun.

The solar energy that a plant stores in carbohydrates during photosynthesis is used to run and maintain processes in the plants, such as absorption of water and nutrients, transporting them to leaves, and converting other products of photosynthesis to cell walls and other cellular parts; so that the plant can grow and develop. For the carbohydrates to be utilized, their energy must be released in the process of respiration.

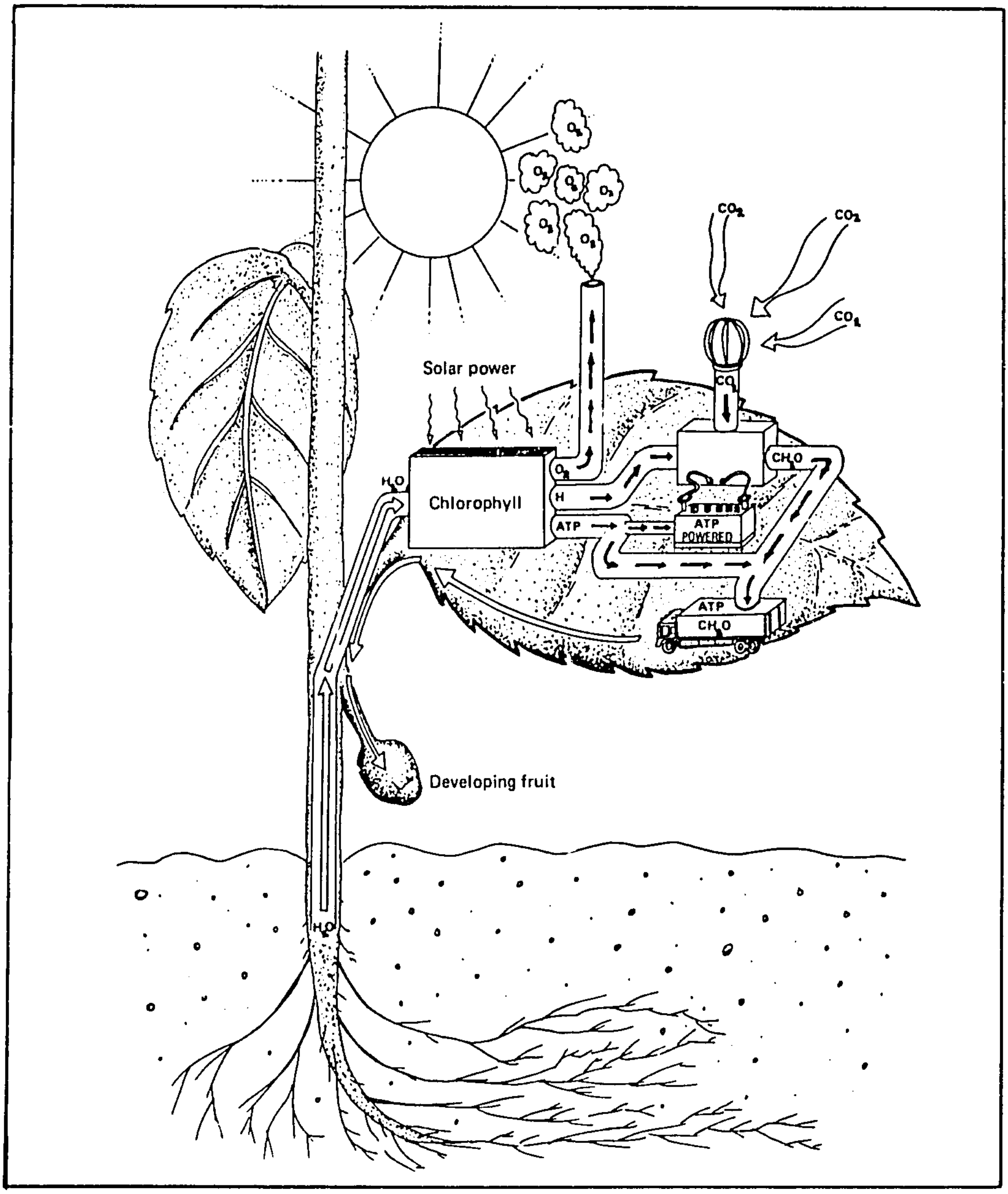

Fig. 2.1. Parts of a plant.

The products of photosynthesis are the raw materials for respiration and the fuels for work in the plant are the products of respiration. Since the general overall reaction of respiration is the breakdown of carbohydrates into CO_2 and water, it would seem that it is photosynthesis in reverse, which is not actually so.

Some aspects of photosynthesis occur only on a sunny day, some in light and dark but the process starts when there is light. Respiration does not require light for it to occur but it can occur in light. While photosynthesis is a building up reaction, respiration is a breaking down reaction. Hence, the ultimate growth of the plant in terms of dry weight

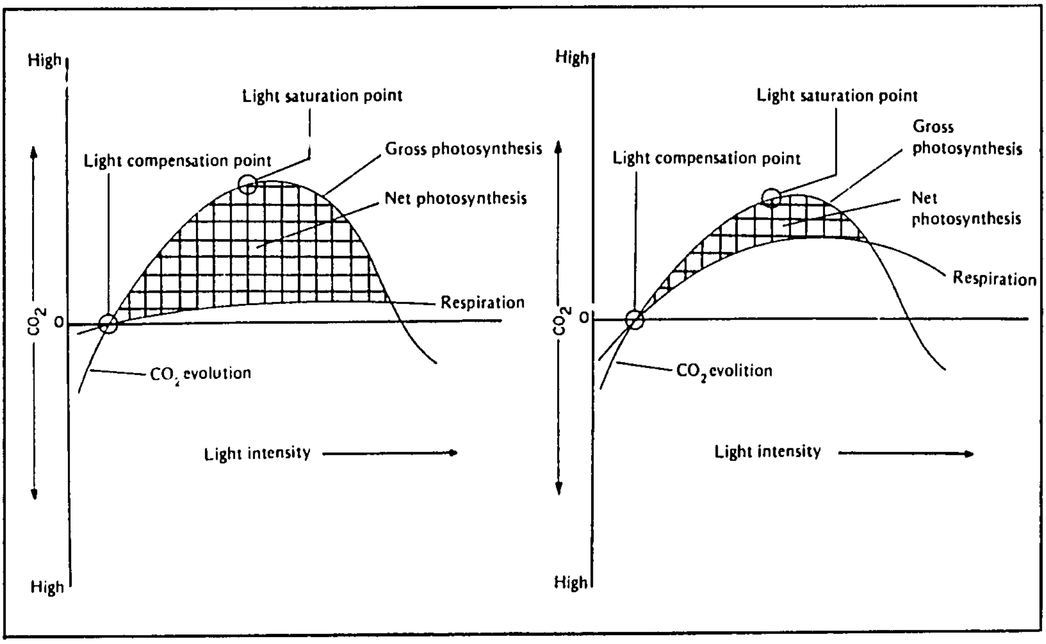

Fig. 2.2. Relative amount of net photosynthesis as determined by photosynthesis and respiration.

often termed as net photosynthesis is the difference between total or gross photosynthesis and respiration (Fig. 2.2).

$$NP = TP - R$$

Where: TP = total photosynthesis
R = respiration and
NP = net photosynthesis

Given high total photosynthesis, the greater the difference between total photosynthesis and respiration, the faster the growth of the plant. Sometimes the difference is zero which means that there is no growth since the amount produced in photosynthesis is all broken down during respiration. The level of light at which net photosynthesis is zero is called ***light compensation point***.

By no means are photosynthesis and respiration the only processes going on in the plant. The products of photosynthesis may be used immediately or stored as starch. They may also be converted into more complex compounds, such as cellulose, proteins, fats, pigments, flavor components and many other kinds of compounds. This is accomplished by joining several units of glucose, converting them into other sugars, then joining the converted sugars or adding other nutrient elements to the above substances to form new compounds. These compounds are termed assimilates or photosynthates.

Before these complex compounds can be utilized in respiration, they are broken down into simpler substances. For example sucrose, which is a sugar composed of the simpler sugars (glucose and fructose), is broken down first into the two simple sugars. Eventually, the energy will come from the breakdown of the simple substances into carbon dioxide, water and heat. Collectively, all these transformations are called ***metabolism***. Photosynthesis and respiration are the processes on which all the other metabolic processes directly or indirectly depend, hence are the most important.

Photosynthesis

Definition. Photosynthesis is the process by which carbohydrates and energy-rich chemicals are formed from carbon dioxide and water, using light energy with the release of oxygen. In simple form, the process could be represented as:

$$CO_2 + H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} CH_2O + O_2$$

Where: CO_2 = carbon dioxide
H_2O = water
CH_2O = carbohydrates

Site of photosynthesis. Photosynthesis occurs in the chloroplasts of the cells where the pigment chlorophyll and sometimes other pigments like carotenoids are found (Fig. 2.3a). Chlorophyll gives leaves their green color. Carotenoids are orange or yellow pigments. Photosynthesis thus occurs in green parts of the plant: leaves, and to some extent, in stems and green fruits.

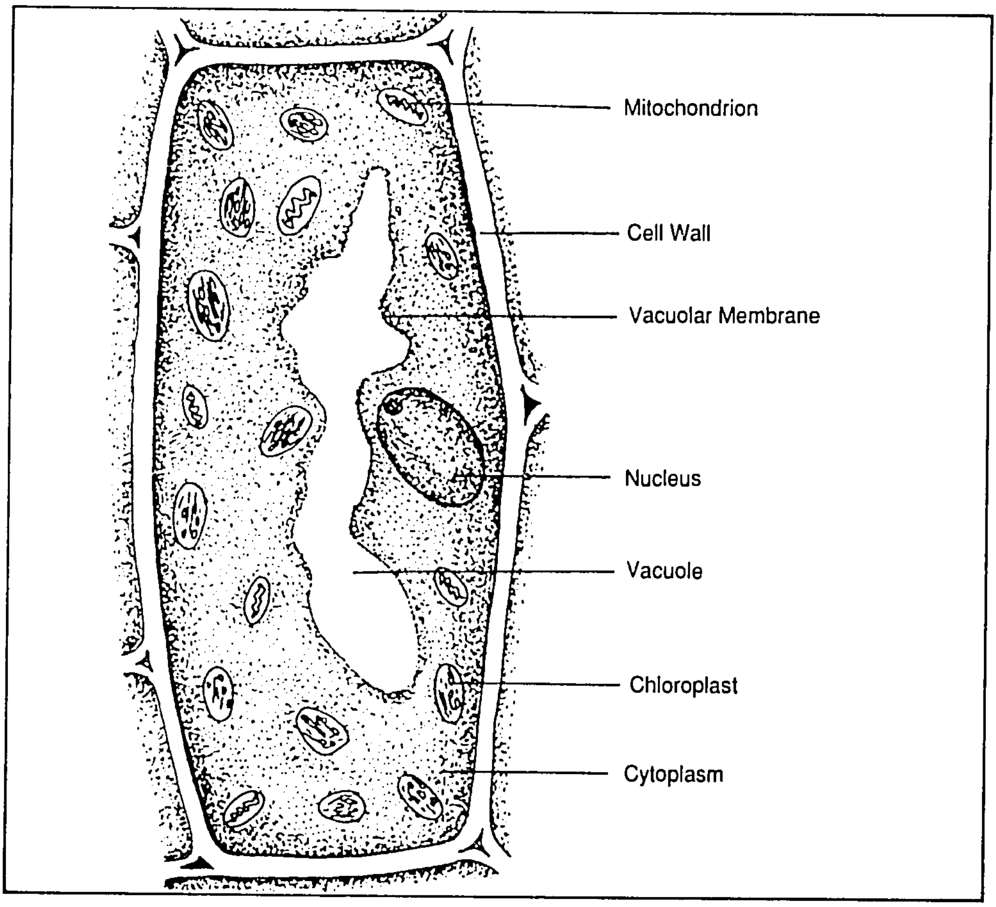

Fig. 2.3a. Parts of a typical photosynthesizing cell showing chloroplasts which contain the green pigment chlorophyll.

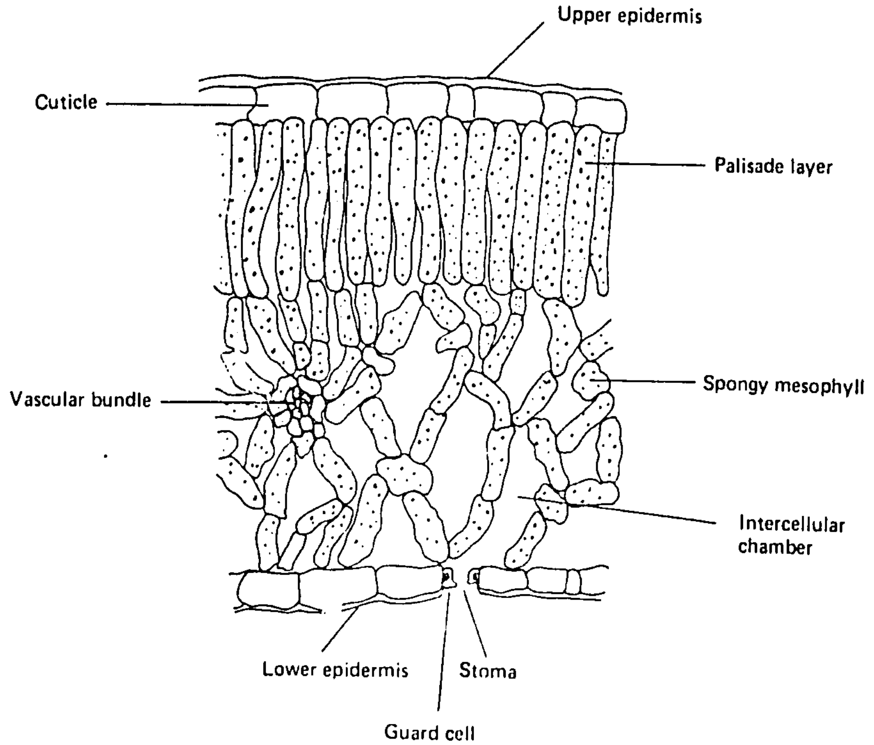

Fig. 2.3b. Cross section of a leaf showing a stoma (plural = stomata), a vascular bundle, and air spaces.

A very important feature of leaves as a photosynthesizing organ is the presence on their surfaces of a large number of tiny openings called ***stomata*** (Fig. 2.3b). In a cabbage leaf, for example, there are 14,100 stomates per square cm of the upper surface and 22,600 on the lower surface. Carbon dioxide (CO_2) used in photosynthesis enters and O_2, a by-product of photosynthesis, exits through the stomata.

The cells that conduct water from the roots, the ***xylem vessels***, continue up to the leaves and the ***phloem vessels*** which distribute food materials from the leaves. The xylem and phloem vessels, together called ***vascular bundles***, make up the network of veins in the leaves. The leaves have the greatest surface area among plant organs. The leaves also have plenty of interconnected air spaces through which carbon dioxide and water can pass to go from cell to cell.

Steps in photosynthesis. Photosynthesis is composed of many reactions, which are all triggered and speeded up by protein bodies called enzymes. It occurs in two phases (Fig. 2.4). The first phase is the ***light reaction***. Light transmitted to earth called solar radiation or radiant energy, is absorbed by the chlorophyll. The energy from the sun increases the energy level of the chlorophyll. As sufficient light strikes a sufficient number of chlorophyll, the energy is transferred to water, causing it to split into its hydrogen and oxygen components. Before oxygen is given off, it participates in a series of reactions and in the process, a high-energy chemical called adenosine triphosphate (ATP) is formed. In effect, captured energy from the sun is changed into chemical energy.

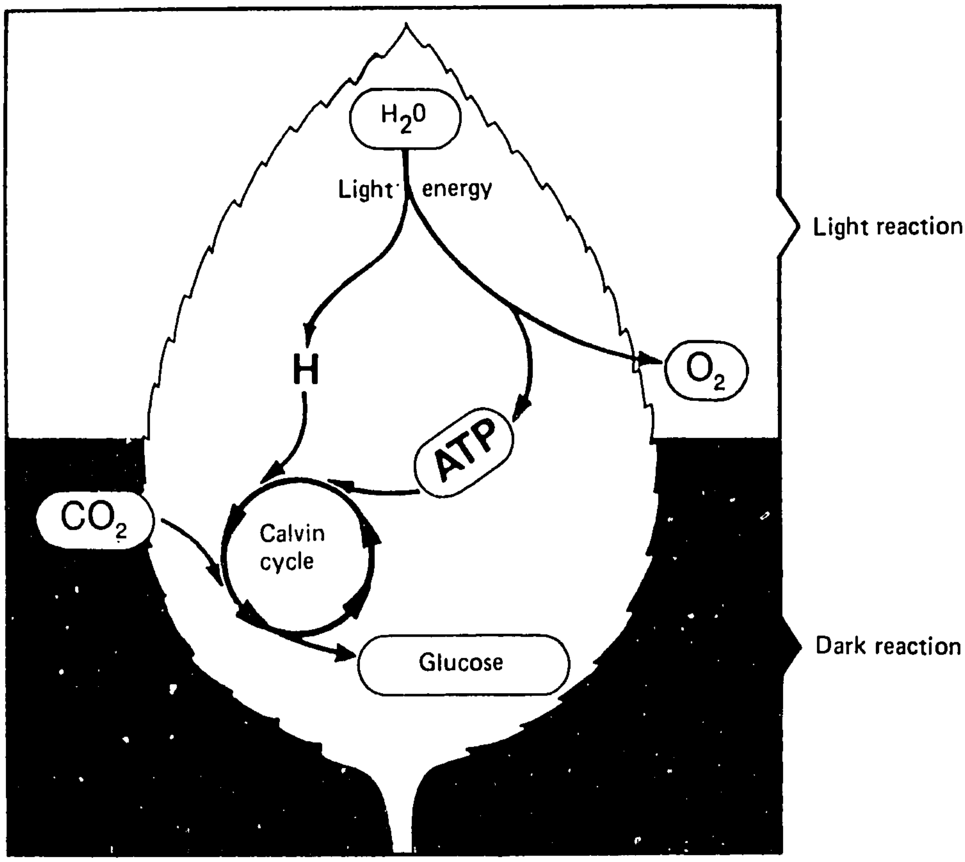

Fig. 2.4. Schematic representation of photosynthesis.

The second phase is the ***dark reaction.*** The chemical energy from ATP thus formed is used to convert the hydrogen from water and carbon dioxide into glucose in a series of reactions that occur in a cycle called Calvin cycle. For every glucose produced, 677.2 kg calories have been taken from the sun and stored in glucose. This part of photosynthesis does not have to occur in light, hence the name "dark" reaction.

Photosynthesis can be pictured as the process by which the plant produces its own food in the leaves which serve as the factory (Fig. 2.5). The enzymes are the workers of the factory and chlorophyll is the machinery. The factory has two sections. In the first section, water is the raw material. Instead of electricity providing the energy to run the first section of the factory, the sun provides the energy. Water is fed into the factory from the roots. It is chopped up into its smaller pieces (hydrogen and oxygen) and in the process also form 'batteries' (ATP) to provide the power to run the second section of the factory.

The carbon dioxide is fed into the second section of the factory from the air then combines with the hydrogen earlier removed from water. The combination forms the carbohydrate glucose with some of the 'batteries' built into it. The glucose units produced, with their 'batteries', are either joined together or changed to other substances that may be needed by the plant.

Types of photosynthetic patterns. The first stable compound formed before glucose is finally formed is a three-carbon acid, phosphoglyceric acid, hence plants

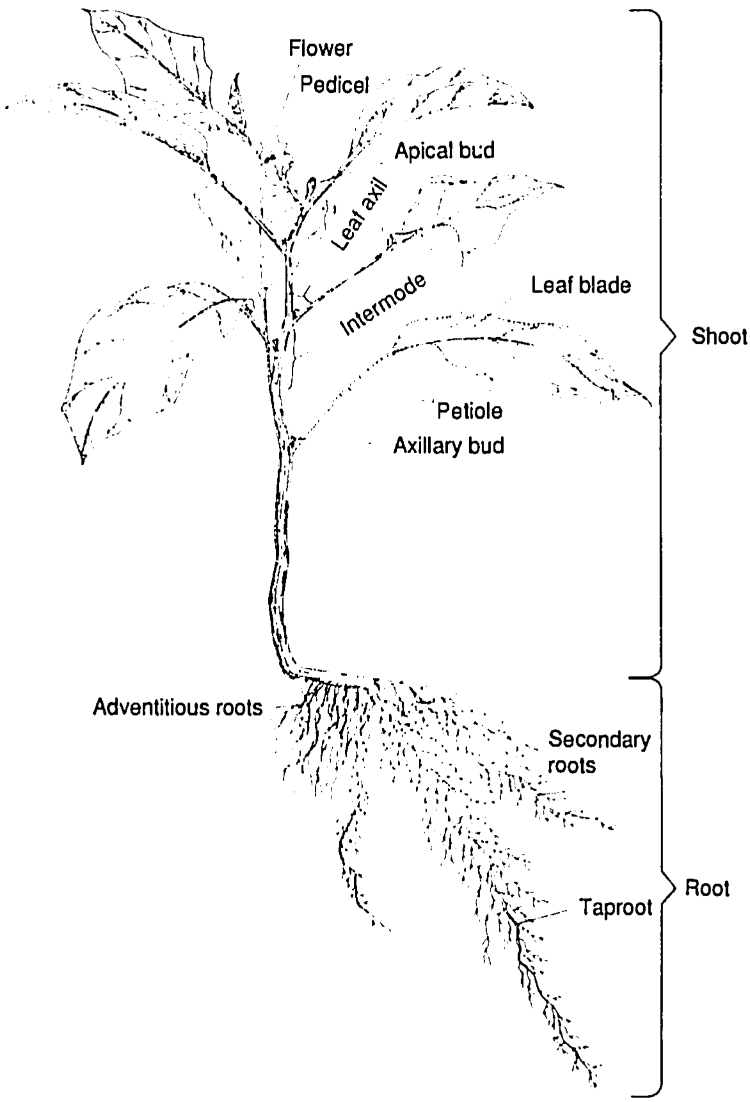

Fig. 2.5. Diagramatic representation of photosynthesis.

exhibiting this pattern of photosynthesis are called C_3 plants. Most vegetables are C_3 plants.

Some vegetab'e crops have a four-carbon acid as the first stable product of photosynthesis. Such plants are called C_4 plants. In general, C_4 plants are those that originated from hot or dry areas, sandy or salty soils, conditions usually unfavorable for the normal growth of plants. Examples of C_4 vegetable plants are amaranth, sweet corn, and Malabar spinach. These C_4 plants have a distinct form and structure. The xylem and phloem vessels are so arranged that they can rapidly supply the cells that are actively involved in photosynthesis with the needed water and nutrients.

C_4 plants also have more phloem vessels than C_3 plants. Thus, C_4 plants are more efficient than C_3 plants. They photosynthesize much faster than C_3 plants. They also do not respire in light unlike C_3 plants, thus their net photosynthesis is higher (Fig. 2. 6). Under natural conditions (21% O_2 and 0.03% CO_2 in the air, strong sunlight, temperature from 20°-30°C) the C_3 plants lose about 20% or, in extreme cases, 50% of carbon fixed by photosynthesis. As a result, net photosynthetic production is two times higher in C_4 than in C_3 plants.

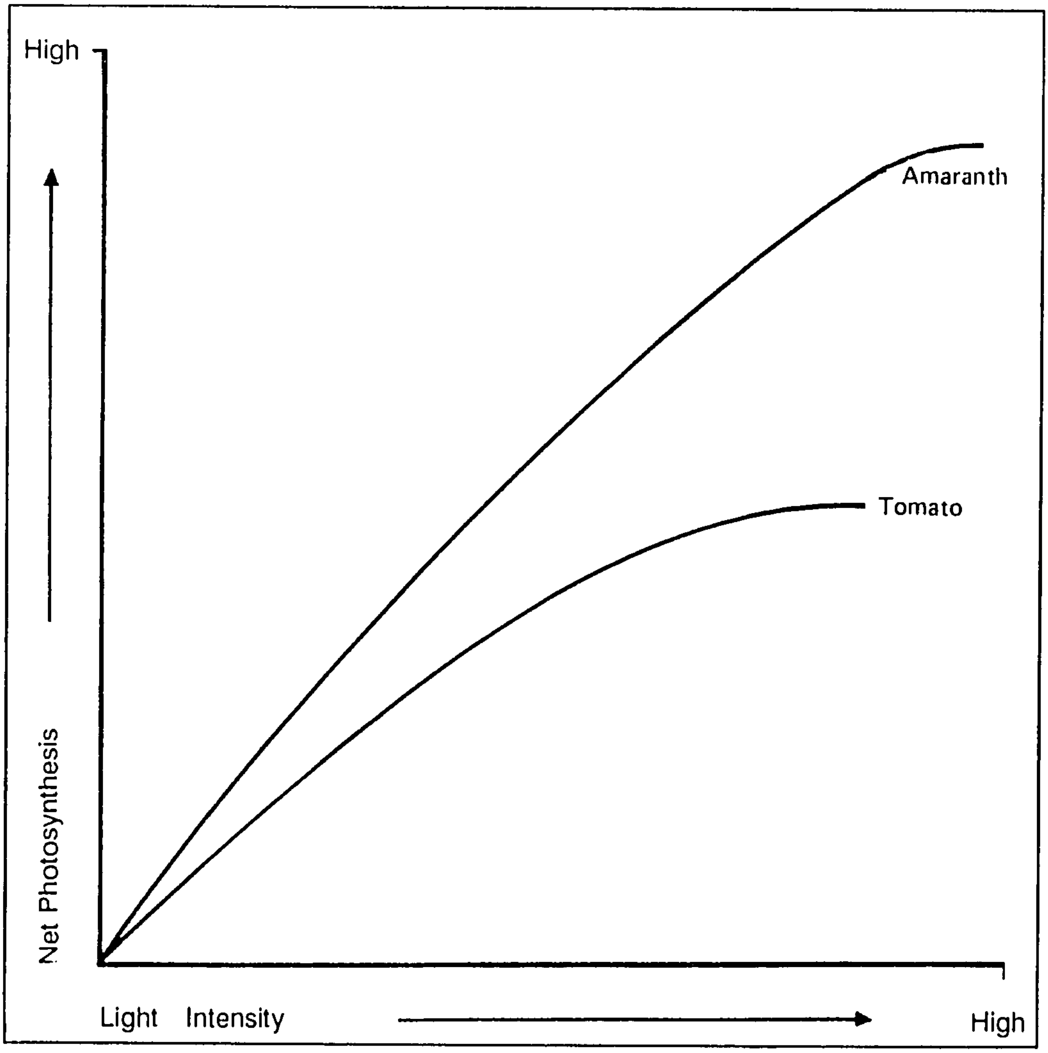

Fig. 2.6. **Relative net photosynthesis rate of a C_3 plant (tomato) and a C_4 plant (amaranth) with increasing light intensity.**

Requirements of photosynthesis. Photosynthesis requires light, leaves, carbon dioxide, water, and enzymes.

- **Light.** In general, the greater the intensity and duration of sunlight, the more chance there is for the leaves to capture sufficient amount of light energy. There is a point, however, when the amount of light (light intensity) is too high that the

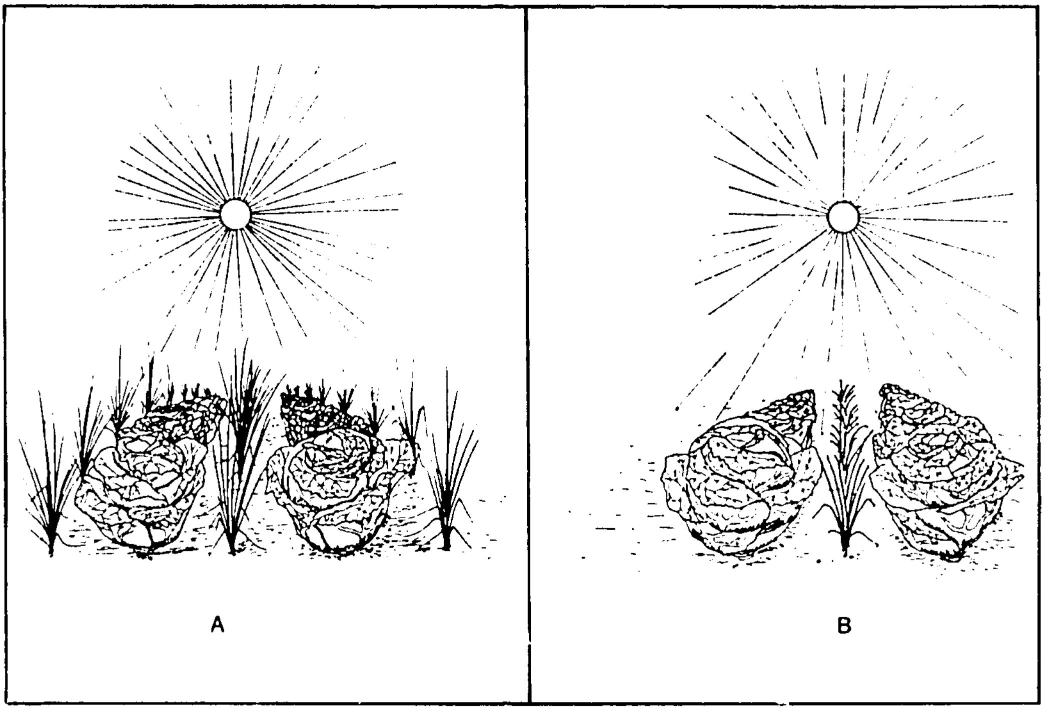

Fig. 2.7. Effects of intercropping on light interception.

leaf can no longer use all the energy from sunlight. On the other hand, during cloudy days, very little light is available for photosynthesis.

Intercropping or relay – cropping increases the efficiency of using light energy per unit of ground area (Fig. 2.7). In plants that are properly spaced, light is being used by the leaves instead of being wasted on bare soil (Fig. 2.8).

- **Leaves.** While sunlight is available, the plants must have leaves to capture the sun's energy or it will be lost. Light energy falling on the soil does not contribute to the growth of the crop. The greater the leaf area, the better the photosynthetic rate. Theoretically, the larger the leaves and the greater the number, the bigger the leaf area. However, the arrangement of the leaves also has much to do with photosynthetic rate.If the leaves are so arranged that sunlight will fall on them, photosynthesis will be greater than in plants where less leaf area is exposed to light. Light can better penetrate the canopy of plants with small erect leaves than those with big but horizontal leaves. The arrangement and potential size of leaves are determined by the species and variety. The size and number of stomates and their time of opening and closing also affect the entry of carbon dioxide into the plant.

  If the plants are so planted that the leaves of one overlap those of another, the lower leaves of both plants cannot capture sufficient sunlight. Eventually, such leaves will not be able to manufacture enough carbohydrates for their own use and will eventually fall off. The closer the plants are to each other, the more they shade each other. Since there is lesser effective leaf area that can catch sunlight then yields are reduced correspondingly.

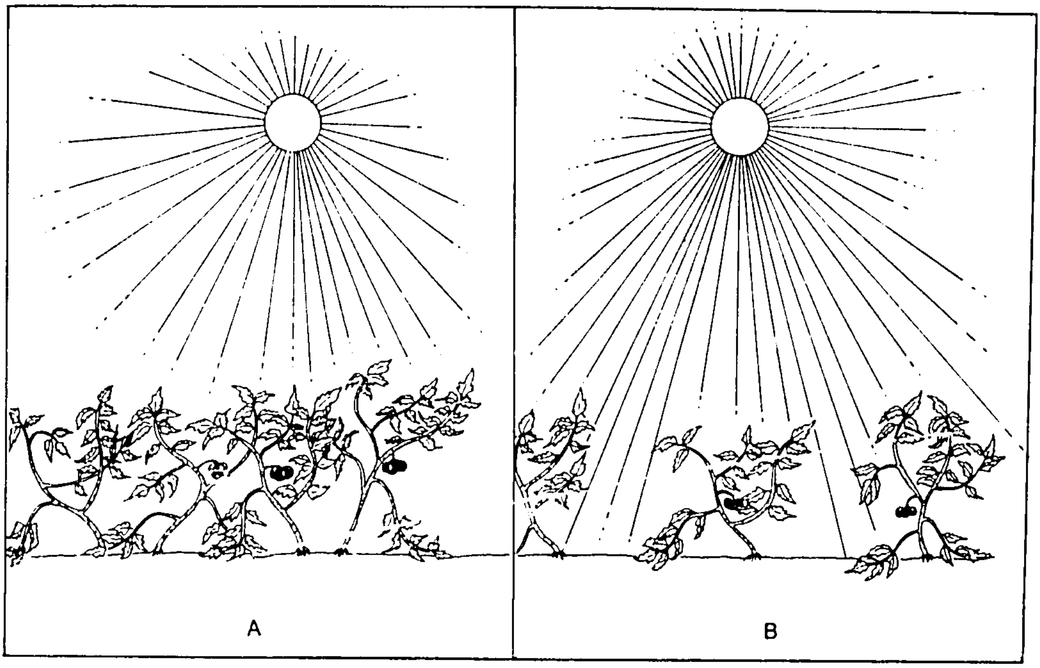

Fig. 2.8. **Effect of proper spacing and light interception. Light is better used in A than in B.**

Anything that will reduce the effective leaf area will also reduce photosynthesis. Insect-damaged leaves have reduced leaf area, while shaded leaves have lesser effective leaf area. Shading could be brought about by too close spacing, taller weeds, or vines growing on the plant.

The chlorophyll in the leaves must also be present in sufficient quantity in order to trap optimum amount of light. Carbon, hydrogen, oxygen, nitrogen, magnesium and iron are needed for the synthesis of chlorophyll. The first five nutrients are part of the chlorophyll molecule. Iron is necessary for the manufacture of chlorophyll. Deficiency of these nutrients therefore results in very low amounts of chlorophyll, a condition called chlorosis. Chlorotic leaves are pale yellow. Chlorosis could also be caused by disease or water deficiency.

- **Carbon dioxide.** The atmosphere contains 0.03% of CO_2. The amount can be increased to enhance photosynthesis, provided other conditions are optimum; but this is possible only inside a greenhouse or polyethylene film chamber and for specialty crops. Increasing CO_2 to 0.1% can double the photosynthetic rate of some vegetables. This is the basis for the CO_2 - enrichment practice. When the leaves are coated with dust or molds and when the stomates are closed, CO_2 cannot get into the cells.

- **Water.** Since water is a major raw material for photosynthesis, the process will slow down if the amount available for photosynthesis is less than optimum. In addition, lack of water will cause the closing of the stomates, thus CO_2 cannot get into the leaf and oxygen cannot go out consequently slowing down photosynthesis. Hence, irrigation, mulching, and other practices to prevent loss of the water added are necessary during dry months of the year.

The effect of waterlogging, or too much water in the soil, on photosynthesis is indirect. It exerts its effect on photosynthesis through its effect on root respiration and water uptake.

- **Enzymes.** Although photosynthesis appears to be a simple reaction, it is actually composed of many chemical reactions, each being triggered and speeded up by an enzyme. For enzymes to be manufactured and to function, some nutrients have to be present in adequate amounts: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, iron, magnesium, chlorine, molybdenum, boron, sulfur, copper, zinc, and manganese.

  An enzyme does not require all these nutrients but each enzyme has its own requirements. If there is too much of one element, the availability of another element may be affected.

  The reactions of photosynthesis depend on temperature because the enzymes can function well only at certain temperature ranges. The efficiency of photosynthesis increases as temperature is increased to a certain point. Most tropical vegetables photosynthesize best at higher temperatures than temperate vegetables.

Respiration

The release of energy from carbohydrates can be shown as:

$$CH_2O + O_2 \longrightarrow CO_2 + H_20 + \text{energy}$$

Respiration takes place in the mitochondria of cells. It is composed of many reactions which are all activated by enzymes. These reactions can be grouped into two parts: glycolysis and Kreb's or tricarbolyxic acid cycle (Fig. 2.9). In glycolysis a 6-carbon sugar, which is usually glucose, is broken down into a 3-carbon acid called ***pyruvic acid*** or ***pyruvate***. In the Kreb's cycle, the pyruvic acid is changed from one organic acid to another. In the process plenty of ATP is released as a source of energy, CO_2 is given off, and the hydrogen removed from the acids combines with oxygen to form water. As pyruvate gets converted in the cycle, compounds formed may separate from the cycle to serve as building blocks for other plant constituents.

The ATP produced is used to drive processes within the cell that are necessary for the growth and development of the plant. Following the earlier comparison of photosynthesis to a factory, when the plant needs to do work like build cells, produce flowers, etc. All it needs to do is to break down the glucose, so the 'batteries' (ATP) will be released to provide energy for the soil processes.

The rate of respiration varies in the different parts of the plant. It is high in growing or immature organs and low in seeds and in specialized storage organs. However, in certain fruits the respiration rises as ripening starts.

Aside from carbohydrates, oxygen and enzymes are the other two requirements for respiration. Oxygen is hardly a problem for respiration in the leaves; but it is a problem in the roots when the plant is grown in waterlogged soils.

The many enzymes involved in respiration perform the same general functions as in photosynthesis - to trigger and speed up reactions. They also need nutrient elements for their manufacture and action activities.

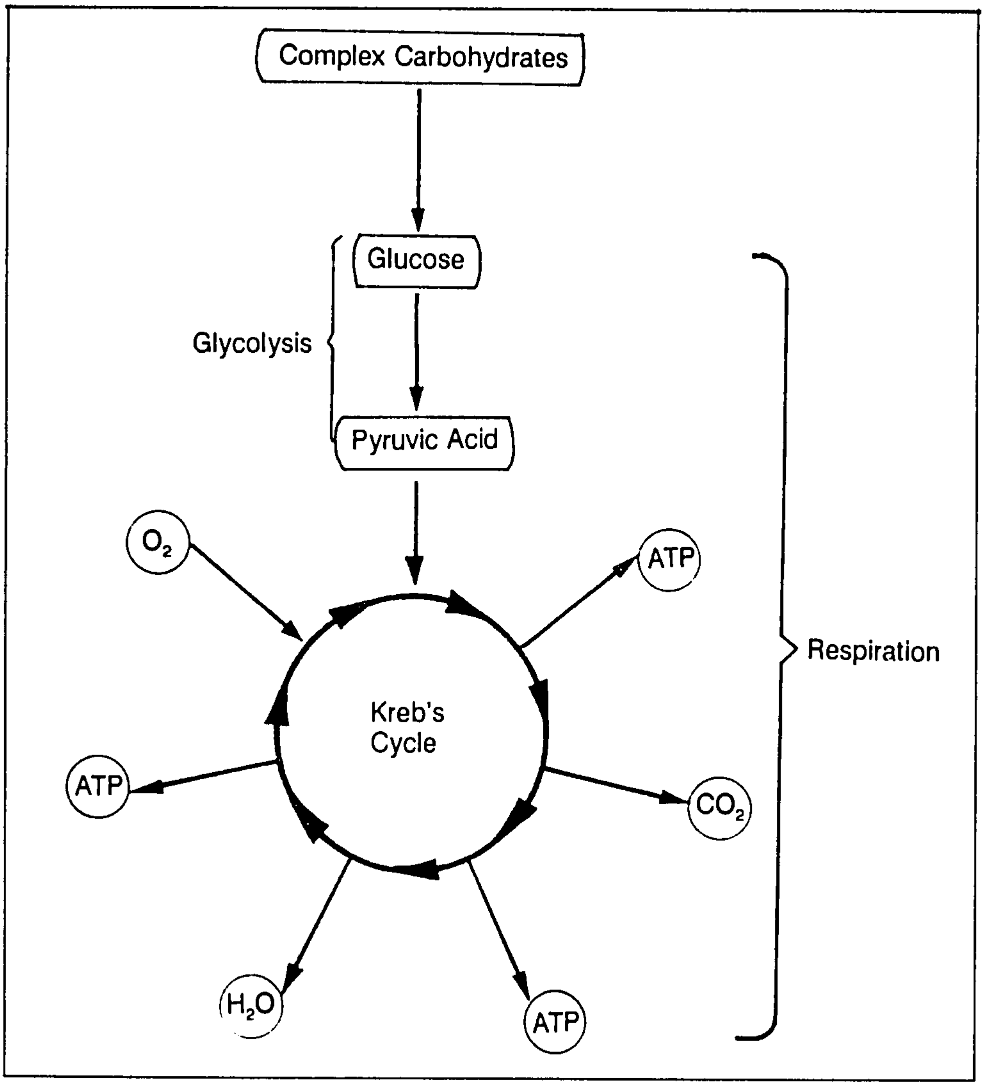

Fig. 2.9. Schematic diagram of respiration.

The rate of respiration increases rapidly with the increase in temperature. It doubles approximately with every 10°C increase up to a certain point when it destroys the enzymes (Fig. 2.10). Hence, during warm days and warm nights, respiration is generally wasteful and may decrease net photosynthesis appreciably and result in low yield.

Shade-loving plants, like ginger, have lesser palisade layers than sun-loving plants, therefore they have lower levels of chlorophyll. Their spongy mesophyll layers have larger intercellular spaces, hence they have lower rates of photosynthesis. However, their rate of respiration is lower than that of sun plants, so that net photosynthesis is high. This adaptation permits them to survive under low light intensities or under shade, where sun-loving plants cannot survive.

Respiration has to be reduced when storing seeds or vegetables for long periods of time. Reducing temperature and excluding oxygen will slow down respiration. For seeds, reducing the moisture content will also slow down enzyme activity, since moisture is necessary for enzyme activity.

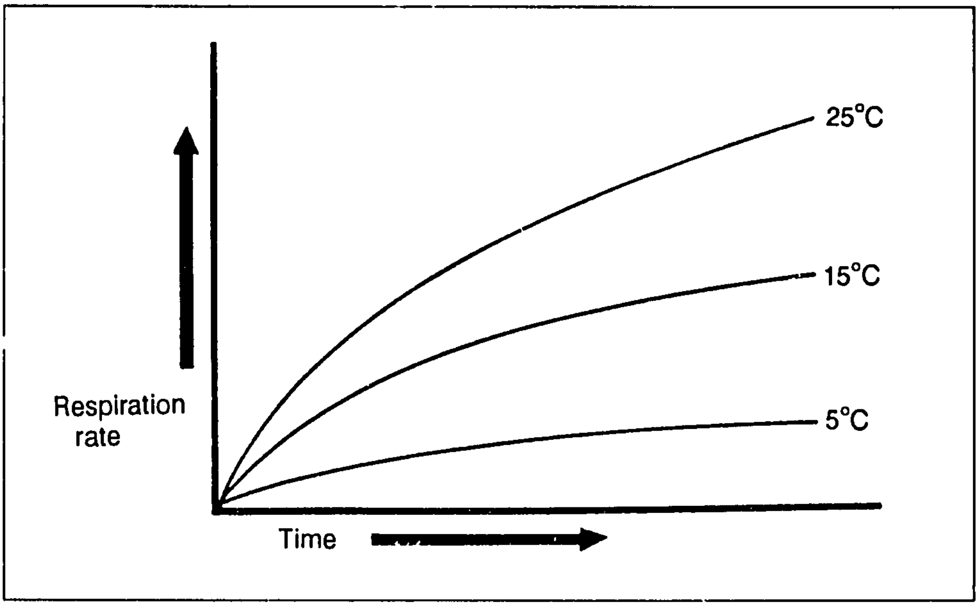

Fig. 2.10. Relative rates of respiration at different temperatures.

Translocation

Water and nutrients absorbed by the roots must be brought to the leaves and other parts of the plant for photosynthesis to occur. Likewise, food from the leaves must be distributed throughout the plant. The movement of these dissolved substances is called ***translocation***. Water with its dissolved nutrients moves through the xylem vessels (Fig. 2.11). The carbohydrates produced during photosynthesis move primarily in the phloem tissues to parts where they are needed. Much of the food reserves translocated within plants is sucrose.

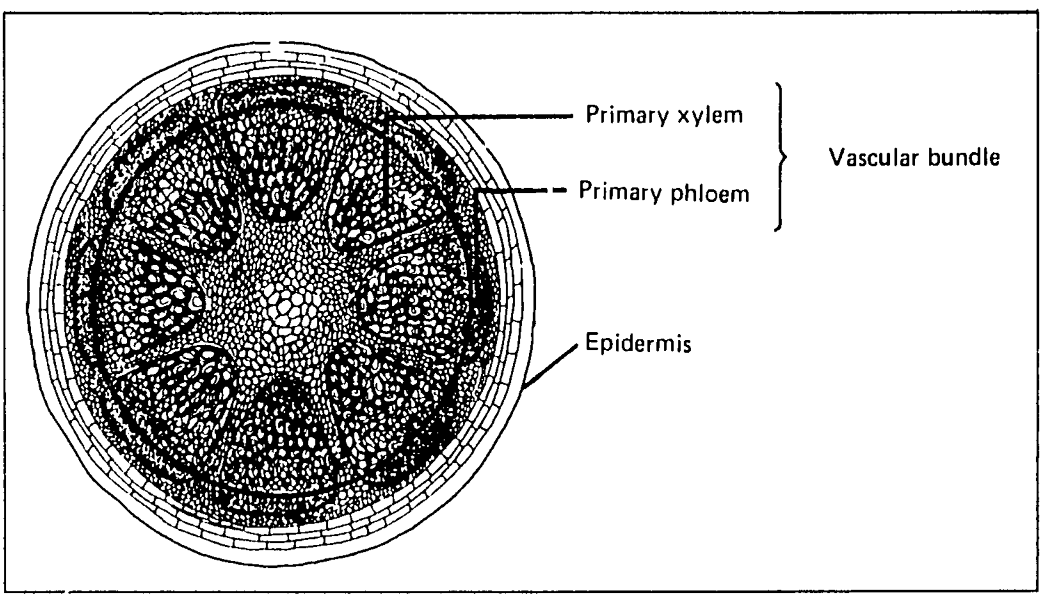

Fig. 2.11. Cross section of a stem of a dicot plant showing the vascular bundles.

Plants showing a C_4 photosynthesis, transfer more carbohydrates from the leaves to the sites where they are needed within a given time than C_3 plants. This greater efficiency in translocation enables them to adapt easily to unfavorable conditions and have higher yield.

Plant parts that require more food are the growing tips, buds, the young flowers, and the developing fruits or storage roots. Developing leaves also need carbohydrates since they produce less than what they need. These parts need great energy for such activities as cell division and enlargement, which are responsible for rapid growth. They get as much food as they need at the expense of the other plant parts and are termed as ***sink tissues***. The fully developed leaves which produce and thereby supply the carbohydrates are referred to as the sources. The carbohydrates from a source go to the nearest sink (Fig. 2.12). Thus, the more leaves there are above a developing fruit, the bigger the fruit will develop. The products of the lowest leaves are translocated to the root system and those in the upper part of the plant, to the shoots; or if there are flowers, more are translocated to the flowers.

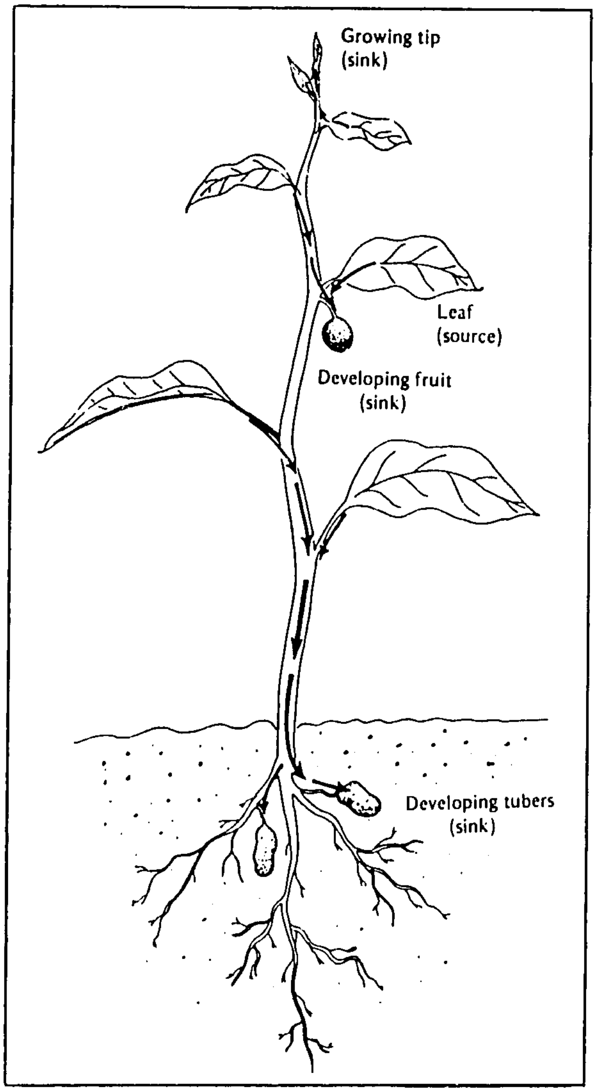

Fig. 2.12. Source and sink tissues.

The ability of a plant part to compete is called ***sink strength***. It depends on the interplay of metabolic activity and on the size of the sink. The plant part which usually grows at a faster rate has higher metabolic activity. For example, young fruits have higher metabolic activity than old fruits. Sink size refers to the weight or volume of a part or group of parts which greatly needs the products of photosynthesis. A cluster of flowers needs more photosynthetic products than a single flower. The latter is a smaller sink. The plant part with greater metabolic activity and larger size will have greater competing power for the assimilates. In herbaceous crops, the assimilates coming from a single leaf are distributed among several parts which need them; and conversely, each plant part needing food draws from several sources.

During the vegetative stage, the buds are very powerful sinks. Their removal results in a redirection of the assimilates to the remaining sinks resulting in their rapid growth. In okra, yield is drastically reduced if the old fruits are allowed to mature and remain on the plant.

Regulation of Growth

Growth occurs in a very organized manner. The basic unit of plants are cells. Cells with similar structures and functions become tissues; and the various tissues are united in an organized pattern to form organs such as roots, stems, leaves, flowers, fruits, and seeds.

Growth is controlled and coordinated mainly by a group of substances called ***plant growth regulators***. Knowledge of the nature and influence of plant growth regulators can guide a grower to manipulate growth and development. It has also led man to manufacture them and use them commercially to influence plant growth and development (See Chapter 7).

Naturally produced plant growth regulators are referred to as hormones. There are five naturally occurring ones: auxins, gibberellins, ethylene, cytokinins, and abscissic acid (Fig. 2.13). Of the five, only the first three are of commercial importance. Growth regulators promote or inhibit a process or act by permitting another growth regulator to dominate a process. A summary of their effects are shown in Table 2.1.

Auxins

Auxins influence many aspects of plant growth: dropping of plant parts, flower initiation and development, root initiation, fruit set and growth, tuber and bulb formation, and seed germination. At the cellular level, they influence cell enlargement.

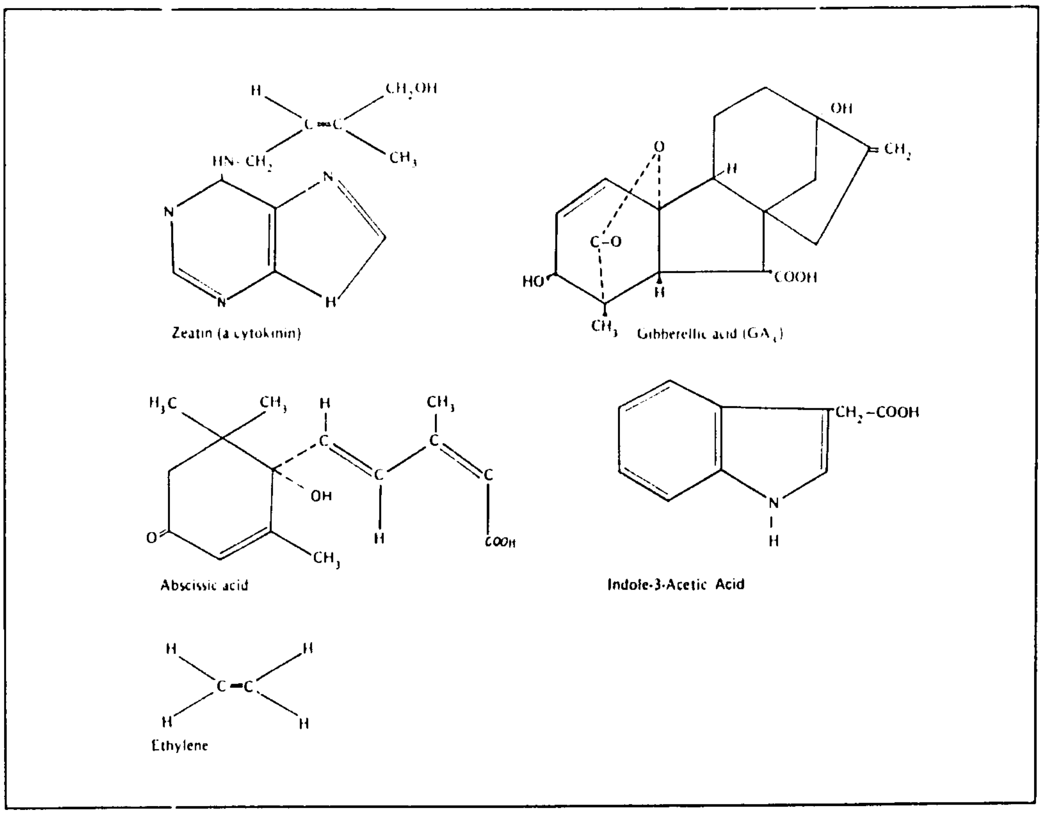

Fig. 2.13. Chemical structure of the hormones.

Table 2.1. Comparative effects of the different phytohormones on different plant processes of vegetables.[a]

Process	Auxin	GA	Cytokinin	ABA	Ethylene
Seed germination	-	+	-	-	+
Apical dominance	-+	-	-	?	-s
Yellowing	-s	-s	-s	+	+s
Respiration	+ if plenty	-	-	-	+
Flowering	?	-	-	+-	?
Sex expression					
Femaleness	+	-	+-	+	+
Maleness	-	+	+	-	-
Abscission	+s	-	-s	+s	+
Fruit growth	+	+	+s	-	-
Root growth	-	+s	-s	-s	+-
Shoot growth	-	-	?	-	-
Parthenocarpy	+s	+s	+s	-	-

[a]
\+ accelerates, releases, promotes, simulates, or causes.
\+ - maintains or no effect.
s some cases.
\- inhibits, suppresses, affects negatively.
? not known, not sure.

Auxins are produced in growing tissues, such as buds, lengthening nodes, and developing seeds. They are then transported to parts where they are needed. The growing tips produce plenty of auxins. Their presence in large amounts prevents the growth of buds below them, a phenomenon known as ***apical dominance.*** If the tip is cut or destroyed, the supply of auxins is cut off and the growth of the lower buds proceeds, resulting in the growth of many new shoots below the cut portion. This is the basis for pruning.

Auxins are known to have something to do with fruit setting; hence, in practice growers can use commercially available auxins to replace the stimulus of pollination and/or fertilization in order to produce seedless fruits. The center of such fruits is usually hollow. Auxins at higher concentrations can kill plants; hence they are used as weed killers. An example is 2, 4-dichlorophenoxyacetic acid (2, 4-D).

Gibberellins or gibberellic acid (GA)

More than 70 different kinds of gibberellins have been discovered in plants. They are designated by number, such as GA_1, GA_2, etc. Gibberellins are produced in large amounts in roots, and lesser amount in shoot tips, growing fruits, and seeds. These regulate stem growth, and dormancy of tubers. In some plants, they also regulate flower initiation and the sex expression of the flower, fruit growth and development.

GA_3 has been produced for commercial use. So far, its greatest use in vegetable production is in altering the sex of cucumber flowers for use in hybrid seed production. Application of GA_3 to cucumber leaves stimulates the production of more males.

It has also been used to overcome dormancy in potatoes to enable the farmer to plant soon after harvest. It is also used in seed production to induce flowering of radish and the crucifers. In both cases, it replaces the cold requirement necessary to break dormancy and to stimulate flowering.

Ethylene

Ethylene has also many beneficial effects: root initiation, flower initiation, fruit growth stimulation, promotion of sprouting (breaking dormancy), change in the sex of the cucumber and gourd flowers, acceleration of ripening, and uniformity in ripening. The application of gibberellins results in more males; whereas the application of ethylene results in more females. The use of ethylene to induce more flowers to be female, is especially useful in hybrid seed production. Its importance and use after harvest is discussed in Chapter 12.

Cytokinins

Cytokinins promote cell division, but they also participate in many aspects of plant growth and development, such as cell enlargement, change into specialized parts, dormancy, flowering, fruiting, and leaf aging. They usually interact with other hormones to exert their effect. Although, they are strongly involved in plant growth regulation, there are no important agricultural uses developed for them.

Abscissic Acid

This growth regulator inhibits rather than promotes growth. It influences growth by its joint action with other growth regulators. Abscissic acid is involved in dormancy and in the dropping of leaves and fruits.

Seed Germination

Most vegetables are started from seed. The seed contains the sleeping plant called the ***embryo*** and its food reserves, the ***endosperm***. These are protected by a seed coat or testa (Fig. 2.14). The part of the embryo that points upward becomes the initial shoot or ***plumule*** and the part that points downward becomes the initial root or ***radicle***. The part between the two becomes the initial stem called ***hypocotyl***.

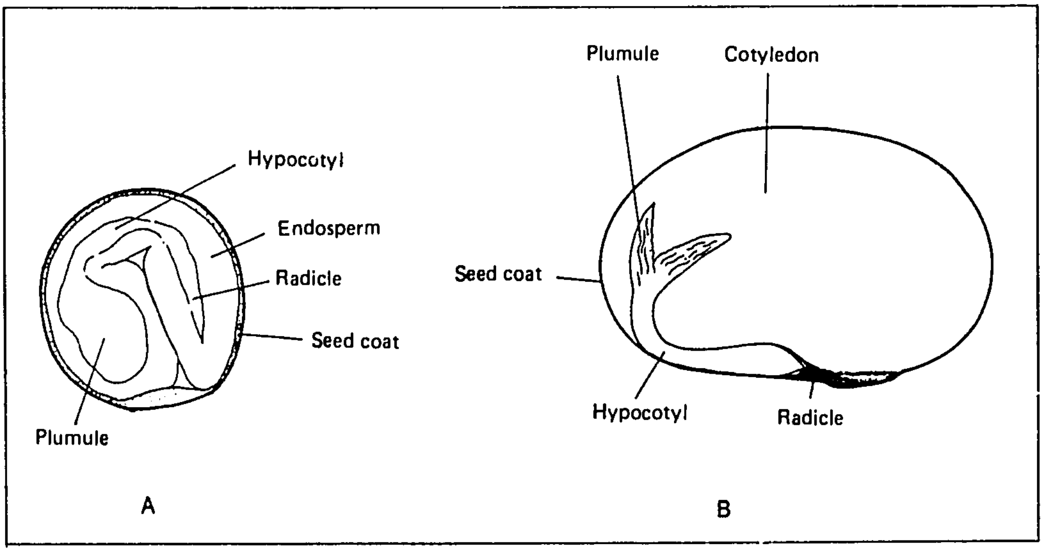

Fig. 2.14. Parts of a seed: (a) okra, (b) lima bean.

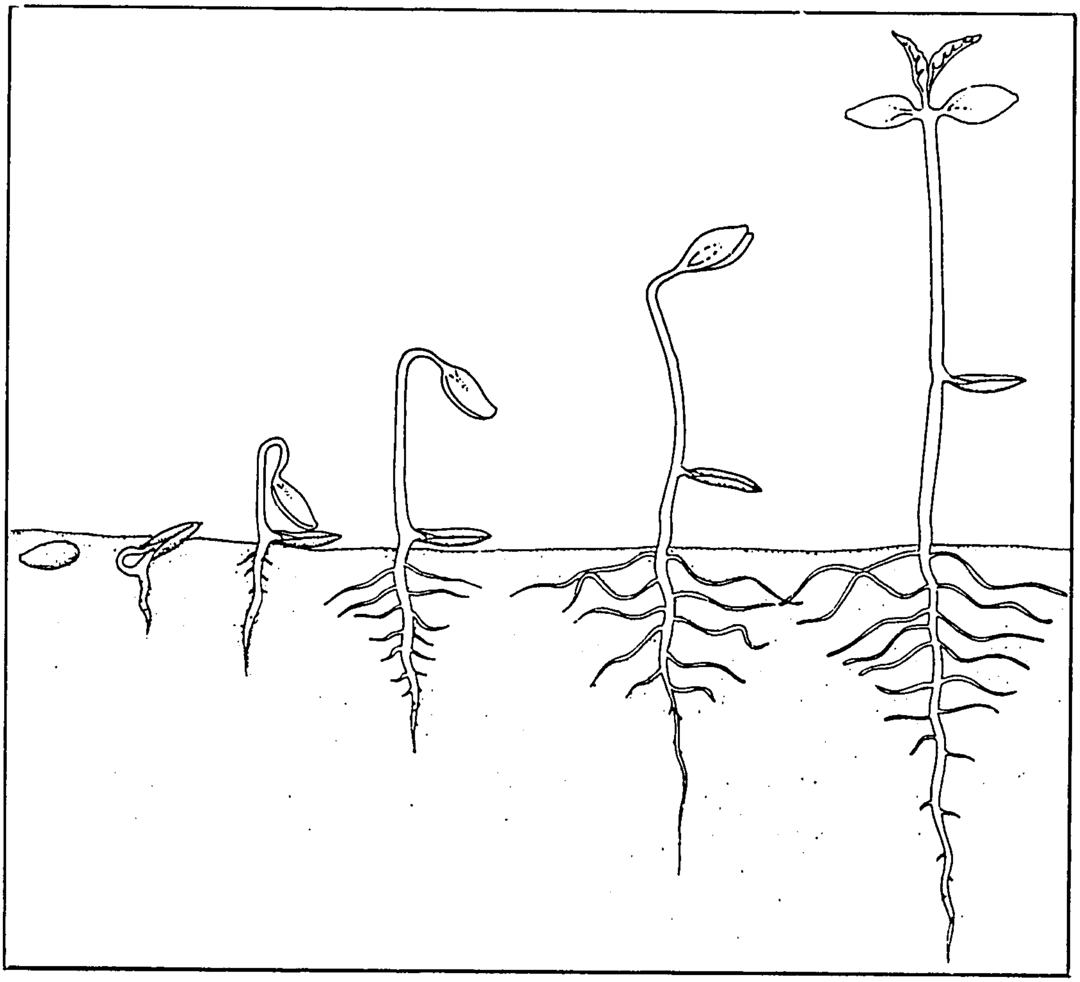

Fig. 2.15. Steps in the germination of muskmelon.

Germination usually starts as soon as the seed is sown in moist soil. The seed absorbs water which softens the seed coat and activates the enzymes of respiration (Fig. 2.15). The stored food of the seed is broken down into energy, carbon dioxide, and water. Using the released energy from respiration, the cells divide and enlarge. The seed coat then bursts and the radicle pushes downwards to become the root. The young root can now absorb water and nutrients from the soil. Then the plumule forces its way upward to become the shoot.

As the embryo grows, the food reserves are continually used up until the shoot comes out. Then the seedling is ready for photosynthesis. The seed has been transformed into a seedling. If small seeds like carrots are planted deep in the soil, the seedling will run out of food reserves before it comes out of the soil. Hence, it is important to plant seeds at a proper depth.

For a seed to germinate immediately and vigorously, the embryo must be viable, the endosperm or cotyledon must be intact, water and oxygen must be available immediately(Fig. 2.16). The embryo is viable if the seed comes from a mature fruit that is newly harvested or has been stored properly. An immature fruit may yield an undeveloped embryo which may not survive.

A seed from a newly harvested, mature fruit is viable. However, it eventually loses its viability in storage, especially if the conditions favor continued and rapid metabolic activity of the seed that will deplete it of its food reserves. The seed also loses its viability when attacked by insects and/or diseases. This is the basis for proper storage and seed treatment.

Water may be available to the seed; but if the seed coat is thick or hard, it will take a long time for the seed to germinate. Most vegetable crops, however, easily allow water to penetrate the testa. Some exceptions are okra and some legumes. Means to facilitate entry of water into the seed is discussed in Chapter 7.

Optimum temperature is necessary for respiration to generate the necessary energy for germination. Too high a temperature, such as that during heat treatment of seeds, will hasten the respiration process; and deplete the food reserves before the seed is planted or before it can germinate. Too low a temperature during germination will result in very slow respiration; so energy released may be too little for the seed to be able to germinate.

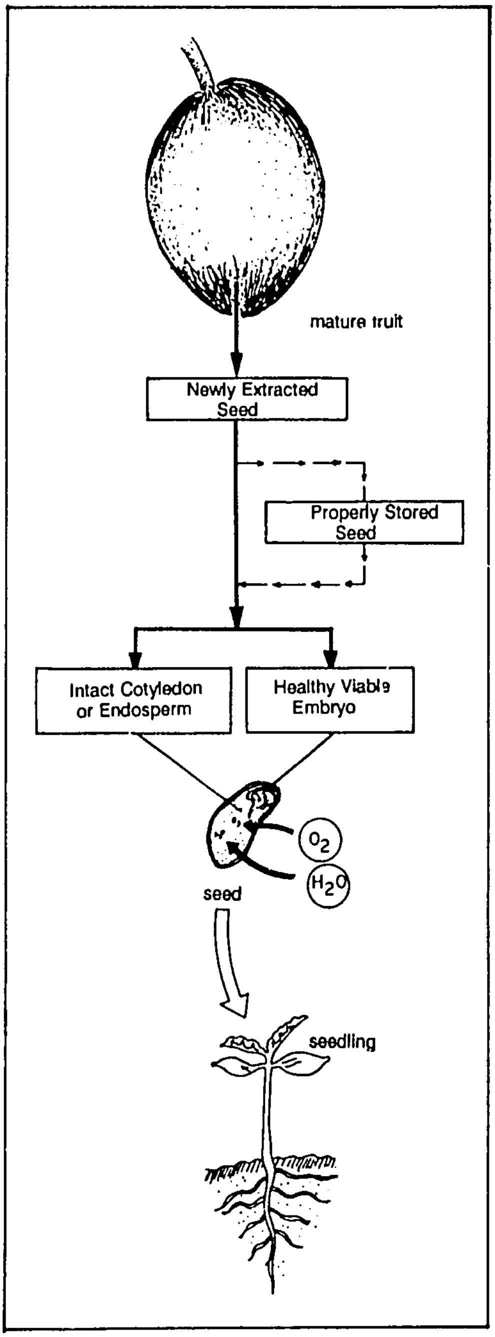

Fig. 2.16. Requirements for germination.

Growth Patterns

Most vegetable crops die after bearing seeds. These are the ***annual crops***. They complete their life cycle (seed to seed) in one growing season. A few require two growing seasons to complete their life cycle (***biennials***): cabbage, Chinese cabbage, parsley, carrot, onion, beet root, turnip, cauliflower, lettuce, some varieties of spinach, and celery. They grow vegetatively and accumulate food reserves in storage organs for one season; then flower and fruit the next season. For the biennial vegetables with no storage organs, other parts of the plant serve to store food. When flowering of onion is desired, the bulbs are produced first; then, when the bulbs from the previous season's crop are planted, they flower.

The ***perennials*** continue to grow from year to year. These are usually woody plants. Examples of perennial vegetables are asparagus and bamboo shoot.

Phases of Growth

Growth and development occur in two phases: vegetative and reproductive. The period of growth that occurs as soon as the seed germinates up to the stage when the plant is ready to flower is the vegetative stage. The ***vegetative stage*** is the juvenile phase when the plant is too young to produce flowers and fruits. Thus, the plant cannot be readily made to flower. The period from flowering to fruit harvest is the ***reproductive stage***. It is the maturation period or the adult phase when the plant is capable of reproducing itself.

The final stage of the life of a plant is called ***senescence***, although it also refers to the terminal stage of leaves, seeds, flowers, or fruits. Senescence is the process of aging when the changes are irreversible and lead to death of the plant or plant part. Senescence is of great interest when fruits are harvested, since ripening is considered to be part of the senescence process. In root, bulb, and tuber crops the reproductive phase is replaced by the development phase of the storage organ.

We are interested only in the vegetative growth of leafy vegetables, unless they are grown for seeds. In legumes, cucurbits, and solanaceous crops, we are interested in the reproductive stage, but the vegetative stage is equally important because the leaves produce the carbohydrates and other compounds that support the growth of the flowers, fruits, and seeds. In fact, for such crops, the vegetative stage is important only as a photosynthetic factory which produces food in order to accumulate the maximum amount while it is actively operating. The food will be used when very little or no food is produced. Once flowering in many vegetable crops begins, vegetative growth usually stops.

Vegetative Growth

Shoot Growth and Development

There are variations in growth of the shoots. The shoot ends of most vegetable crops turn into flowers; so these shoots have a bushy appearance. These are called ***determinate*** plants (Fig. 2.17). However, the viny vegetables, like the cucurbits bear flower clusters along the axils of the leaves; so the shoots continue to grow until the plant senesces. They have an ***indeterminate*** shoot growth habit. In other words, vegetative and reproductive growth proceed together in indeterminate plants.

Tomatoes and some of the legumes have determinate and indeterminate varieties. The determinate varieties are suited for mechanical harvesting, while the indeterminate varieties are suited for hand picking.

Removal of all the flowers in determinate plants, which include most vegetables, will result in a continuation of vegetative growth and the production of new flowers and fruits. In the case of sweet corn, however, harvesting of the ear will not result in the production of more ears.

A crop that grows fast vegetatively can compete well with weeds by growing taller than the weeds in a relatively short time. As a result, the crop will be able to receive more sunlight than the weeds. For plants that grow vegetatively at a slow rate, like celery, weed control is difficult.

In cabbage, the first few leaves grow naturally; then they start to overlap over the shortened stem (Fig. 2.18). The succeeding leaves, therefore, grow inside the initial

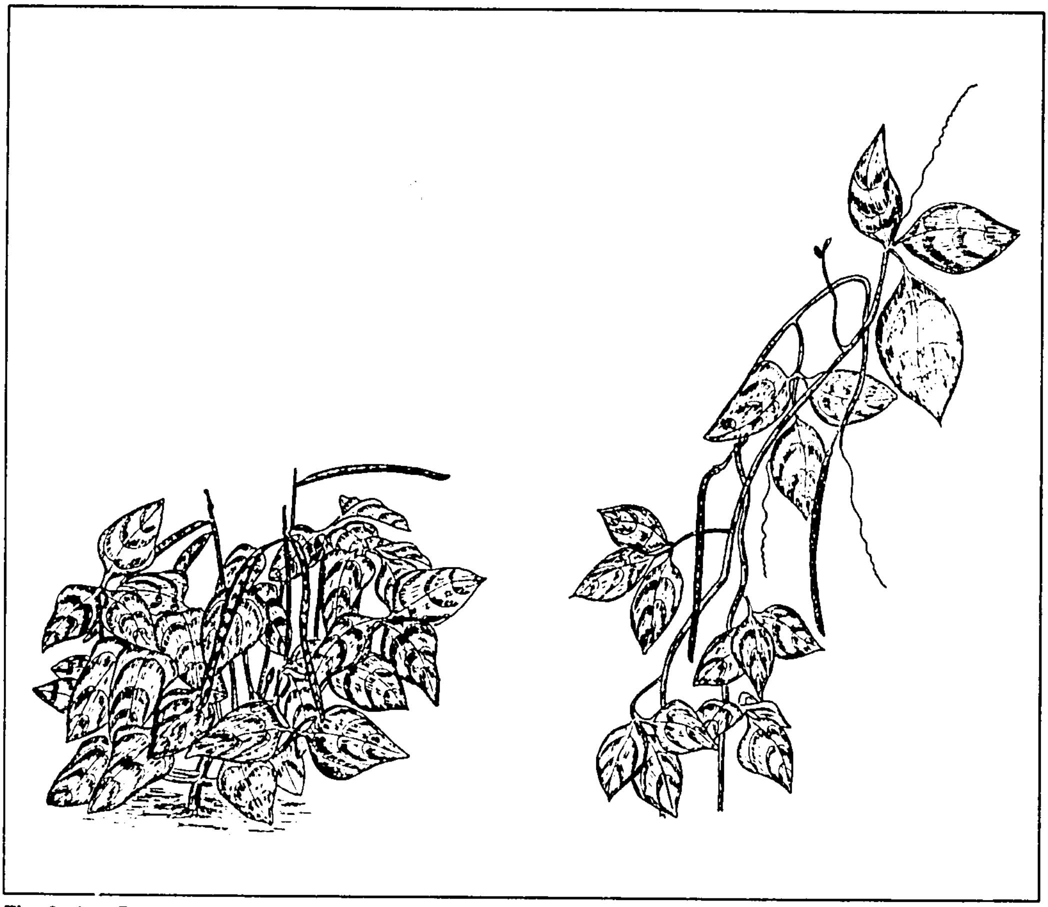

Fig. 2.17. Determinate (bush bean) and indeterminate plants (yard-long bean).

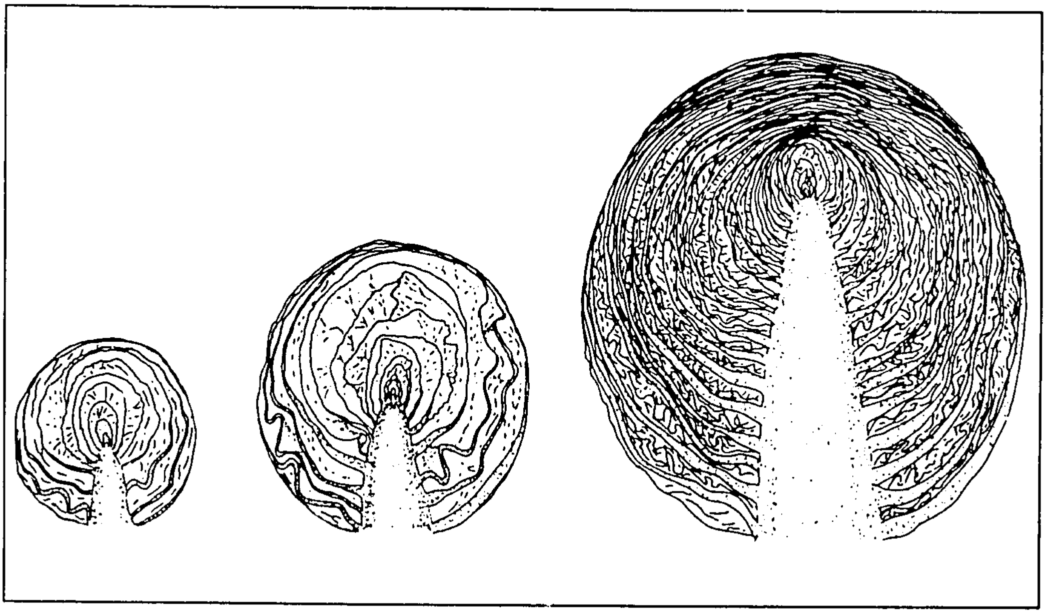

Fig. 2.18. Growth of cabbage.

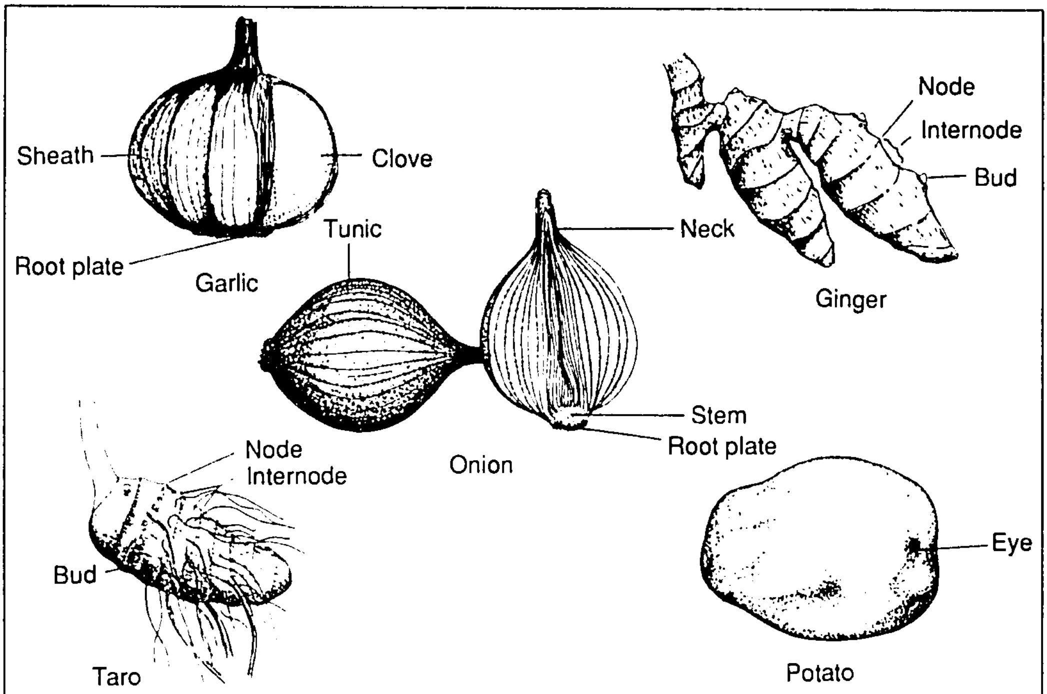

Fig. 2.19. Storage organs.

overlapped leaves forming a head. As growth proceeds, the heads become more and more compact; so that at maturity, there is no space inside the head. A mature cabbage is therefore more resistant to pressure after harvest than an immature one which has empty spaces in the head (puffy).

The bulb and tuber crops utilize the lowest part of the stem or leaves to store food reserves and modify it into a storage organ (Fig. 2.19). Some of the modified organs have relatively tough coverings that cannot be penetrated by water but could be used for vegetative propagation. Onion and shallot bulbs are thickened basal leaves enclosing a short plate-like stem. The leaves near the center are wholly used as the storage portions, while the leaves away from the center have only their bases thickened. The outer leaf bases are thin, fibrous and dry; they serve to protect the inner fleshy ones.

Garlic is a compound bulb consisting of segments called ***cloves***. The cloves are formed in the axils of the inner leaves of the bulbs. The outer leaves form the sheath. The potato ***tuber*** is the enlarged terminal portion of the underground stem. The taro ***corm*** is an upright, thickened, solid stem structure with nodes, and internodes, and a few rudimentary leaves. Ginger is a cylindrical ***rhizome***, which is a horizontal underground stem with nodes and internodes.

In asparagus and bamboo, it is the newly emerged shoots that are used as vegetables. Bamboo shoots arise from rhizomes; while asparagus ***spears***, as the emerging shoots are called, are usually derived from fleshy underground rhizomes called ***crown***.

Root Growth and Development

Plants may either have ***fibrous*** or ***tap*** root system (Fig. 2.20). Fibrous roots are fiber-like and are similar to each other. Corn and *Allium* species have fibrous roots. For

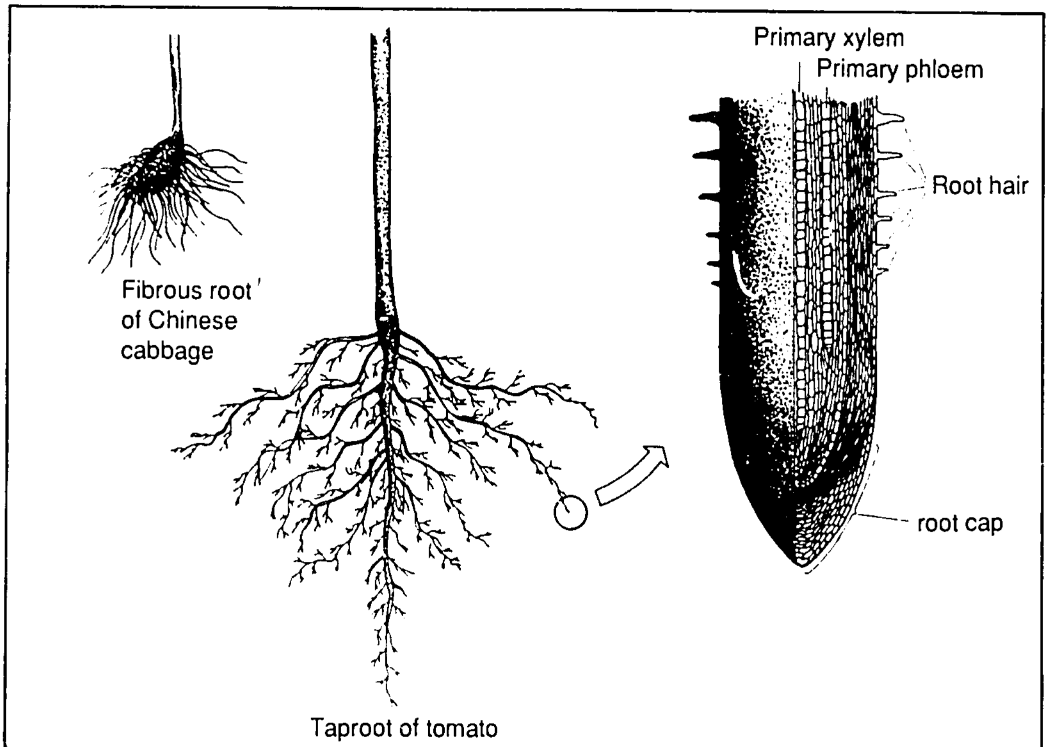

Fig. 2.20. Types of roots.

plants with a tap root, there is a prominent main root and other roots arising from it. Plants with a tap root can generally reach deeper layers better than fibrous-rooted plants. The tap root of carrot, radish, beet, turnip, and sweet potato enlarges into a storage root and the lower half of the radish (the top half is the hypocotyl). So, if the tap root is damaged, then the yield decreases, both in quality and weight. Corn and *Allium* species have roots arising from the nodes closest to the ground. Such roots are called ***adventitious roots***.

The early period in the growth of the seedling is largely devoted to the development of a deep root system. Plants with tap roots, such as tomato, develop very deep root systems if there are no barriers to penetration (compact layer for example) and if the soil is well drained up to the lower depths. A plant that is only 30 cm tall may develop roots of more than 1 m long. It may comprise one-third to one-fourth of the plant's dry weight. If the tap root encounters a barrier or if oxygen becomes too limiting, the plant develops many smaller fibrous roots above the problem layer. If that layer is near the surface, the root system becomes shallow, making the plant very susceptible to drought stress. Irrigation is difficult, too, since the plant can make use only of the water near the surface.

Water and nutrients are absorbed through the root hairs, which are hair-like extensions of the root cells. As the plant grows, the root hairs in the older parts die; others develop on the younger parts of the root. Thus, the part of the root most active in the absorption of water and nutrients is the root tip; and the root has to grow continually to provide the necessary water and nutrients to the plant.

Frequent irrigation with small amounts of water encourages rooting at the upper levels of the soil; hence; close and deep cultivation of the plants becomes dangerous as the roots might possibly be damaged.

In legumes, roots develop nodules which are swellings that contain bacteria which fix free nitrogen from the air into complex nitrogenous compounds utilized in part by the plant. These nodules allow legumes to grow and yield well in soils where, normally, a plant cannot survive because of nitrogen deficiency.

Reproductive Growth

Reproductive growth is more complicated than vegetative growth. It involves several phases: (1) flower formation, (2) flower development, (3) pollination and fertilization, (4) fruit set and seed formation, (5) growth and maturation of fruit and seed, and (6) fruit senescence.

Flowering

The flower is the reproductive organ of the plant. A group of flowers with a common stem is called ***inflorescence***. The parts of a perfect flower are shown in Fig. 2.21.

The enlarged tip of the stem that bears the flower is called the ***receptacle***. From it arises the different parts of a flower. The individual petals, collectively called ***corolla***, are the colorful expanded parts of the flower which serve to attract pollinators. The sepals, collectively called ***calyx***, are the leaf-like scales around the base of the petals which

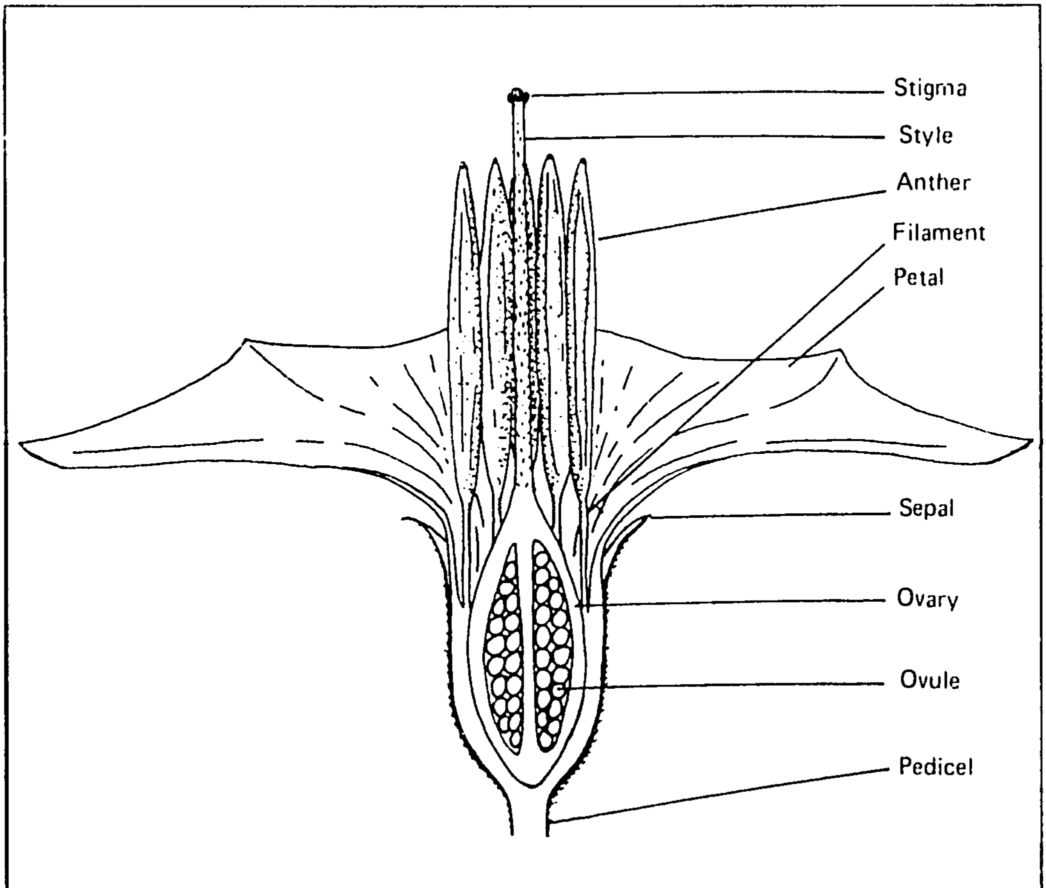

Fig. 2.21. Parts of a perfect flower.

serve to protect the ovary. The female reproductive organ is the ***carpel***, and several may unite to form the pistil. If a flower has only one carpel, the carpel is also called ***pistil***. It is composed of the ***stigma***, the part on which the pollen lands and is received; the ***ovary*** which contains the ovules that develop into seeds, and the ***style*** which is the tube connecting the stigma and the ovary. The sac that encloses the ovule is the ***embryo sac***.

The male part, called the ***stamen***, may be in the same flower (perfect flower as in tomato), in a different flower from the same plant (monoecious as in watermelon) or in a different plant (dioecious as in asparagus). It consists of an ***anther***, the part which produces the pollen, and the ***filament*** which bears the anther. The filament may be very short or nonexistent. The pollen contains the sperm cell.

A plant will flower to produce seeds that will reproduce the plant. It will normally flower if it has produced a minimum amount of vegetative growth. In other words, it has passed through a juvenile stage and has reached a certain stage of development when it is ready to flower, provided the conditions are right. This stage is called the ripeness to flower stage. However, other management practices can affect flower initiation. For example, a large amount of nitrogen fertilizer can delay flowering in tomato but hasten it in sweet corn.

Some vegetable crops are very sensitive to the periods of light and dark. They flower when exposed to specific periods of light and dark. This phenomenon is known as ***photoperiodism***. Examples of photoperiodic vegetables are winged bean and soybean. Further discussion of this phenomenon is in Chapter 3.

Flowering starts when the vegetative growing point deep inside a bud is transformed into small flower parts. This is called ***flower initiation*** or differentiation. Then the individual floral parts form and develop and finally the flower opens. Flower opening is called ***anthesis***. By the time the flower opens, the pollens and ovules are developed, if the male and female organs occur in the same flower.

Some vegetables need to be exposed to low temperature for certain periods of time in order to flower early and produce plenty of seeds. The phenomenon is called ***vernalization*** (See Chapter 3).

A plant may flower prematurely, a phenomenon called ***bolting***. When this happens, the leaves cannot produce sufficient food to support plenty of flowers. Removal of the first flowers will allow the leaves to produce more food for the succeeding flowers to develop and set into fruit. When only a limited number of flowers are allowed to grow and develop into fruits, larger fruits will be obtained. Male flowers of cucurbits are weak competitors and their removal by physical means or chemical sprays, if not needed as a source of pollen, will increase fruit yield since the assimilates that they use can be better utilized by the developing fruit.

Pollination

A flower is pollinated when the pollen is transferred from the anther to the stigma. Inadequate pollination results in misshapen fruits (as in the gourds), missing kernels (as in sweet corn), or low fruit set. For well-shaped fruits, the female flowers of cucurbits have to be visited by bees at least 12 times.

The transfer of pollen could be from the anther to the stigma of the same flower, as the pollen is shed when the anther bursts or as the flower is gently shaken by wind. In this case, the flower is ***self-pollinated***. The transfer of pollen from one flower to the stigma of another flower of the same plant is also self-pollination. Legumes are self-pollinated and are already pollinated when the flowers open. Tomatoes and lettuce are also self-pollinated.

When the transfer of pollen is from one plant to another, the plant is ***cross-pollinated.*** Cross-pollination occurs for several reasons. It occurs in plants in which the pollen is shed either before (***protandrous*** plants) or after (***protogynous*** plants) the pistils are ready to receive the pollen. Receptivity of the stigma is indicated usually by its stickiness.

Cross-pollination also occurs when the pollen fails to germinate on the stigma of a flower of the same variety, or the pollen tube stops growing before it could reach the ovule, or it grows very slow, so that the ovule dies before the pollen tube could reach it. Such plants are called ***self-incompatible*** plants. Examples of cross-pollinated crops that have self-incompatibility mechanism are the *Brassicas*.

A lot of vegetable crops are pollinated by pollen from other flowers either by wind or insects. Plants that have separate male and female flowers need insects or wind to transfer the pollen. Those with flowers that are attractive to insects are ***insect-pollinated***; those that are not, are ***wind-pollinated.***

Sweet corn and spinach are pollinated by airborne pollen from other plants of the same kind. Examples of those pollinated by insects are asparagus, broccoli, cabbage, carrot, cauliflower, celery, Chinese cabbage, cucumber, eggplant, gourd, kale, muskmelon, mustard, onion, parsley, pepper, pumpkin, squash, radish, turnip, and watermelon.

If there are few insects in the production site to pollinate insect-pollinated flowers, a lot of the flowers will not develop into fruits. Raising bees in the farm increase the number of fruits formed.

Cross pollination occurs readily among varieties within a species. The taste, color, and shape of the fruit that is formed are not affected. However, if the seed from these fruits are saved and planted the next season, the fruits produced will have different colors, shapes, sizes, textures, or tastes depending on how different the parents are (See Chapter 4).

Fertilization

After the pollen lands on a receptive stigma, the pollen grain germinates to produce a pollen tube which elongates through the style, enters the ovary, and penetrates the embryo sac of the ovule. The pollen tube has two sperm nuclei. There are two polar nuclei plus the egg cell in the embryo sac. One of the nuclei of the pollen tube unites with the egg in the ovule to form the ***zygote***, which is the fertilized egg that will give rise to the embryo. The second nucleus unites with the two polar nuclei in the embryo sac, giving rise to the ***endosperm***, which is the source of nutrients for the growing embryo. The process is called ***double fertilization*** or simply fertilization (Fig. 2.22).

The seed starts to form once fertilization has taken place. The endosperm develops before the embryo. As the embryo begins to grow, the food reserves in the endosperm is also used up. The endosperm may be completely absorbed as the seed matures, in which case stored food may be in a part of the embryo itself called the ***cotyledon*** or seed leaves as in bean seeds. The seed coat is the last part to be formed.

Some vegetables produce fruits without seeds. This phenomenon is called ***parthenocarpy***. This may happen even without pollination. In some cases, pollination occurs but no embryo is formed, which means there is no fertilization. In other cases, fertiliza-

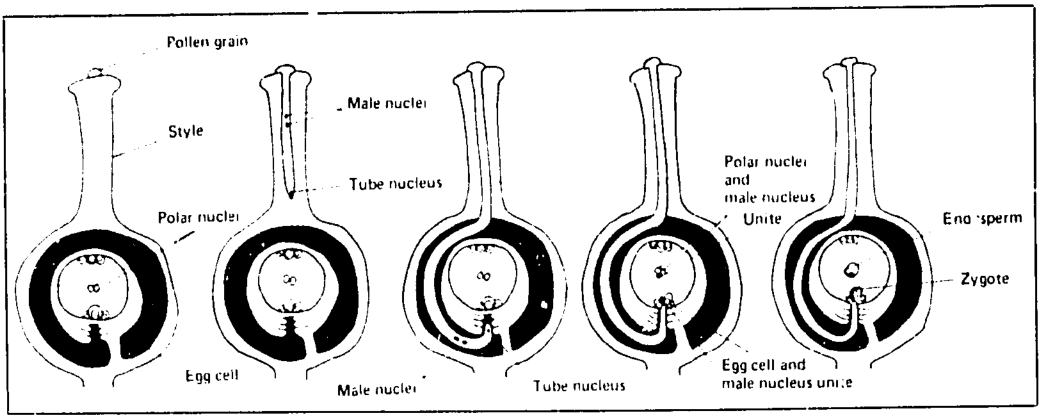

Fig. 2.22. **Steps in double fertilization.**

tion may occur but the embryo dies, as in watermelon. The fruit may have what appears as small seeds but are actually just seed coats of undeveloped seeds.

Seedless fruits occasionally occur naturally in cucumber, pepper, pumpkin, tomato, and eggplant. In tomato, for example, pollination can occur below 14°C and above 32°C but the pollen tube does not grow, so there is no fertilization. However, fruit development can still occur. Parthenocarpic tomatoes are frequently hollow inside. Fruit development without pollination is often noted by growers who spray auxin-like growth regulators.

Fruit Set

After fertilization many important changes occur in the ovary and tissues surrounding it leading to the formation of the fruit. Hormones produced in the developing seed stimulate the tissues surrounding the seed to become a fruit. The change of the ovary of a flower into a young fruit is called ***fruit set***. One of the main problems in producing fruit vegetables, which normally have plenty of fruits per plant, like the solanaceous crops, is obtaining an optimal percentage of fruit set.

If fertilization does not occur or the zygote fails to develop, the flower or immature fruit usually drops, so there is low fruit set. Low fruit set results in low yield. A too high fruit set may result in small and poor quality fruits. Hence, removal of some fruits (thinning) is practical.

Fruit Growth and Development

Initially, there is an increase in the number of cells followed by their enlargement. Fruit vegetables initially grow slowly for a brief period, then grow rapidly; the growth rate decreases toward fruit maturity. This is called the ***sigmoid pattern of growth*** (Fig. 2.23).

The control of fruit development is very complex. There are many plant hormones involved and there is considerable competition among them.

As soon as the fruit has almost attained its fullest size, it accumulates components that will lead to the desired end-product (the ripe fruit); after which, it is then said to be physiologically mature. However, many of the fruit vegetables such as cucumber, gourd, eggplant, and okra are harvested before they reach physiological maturity. Legume pods are harvested at mature or immature stages. Tomato, sweet pepper, and melon are allowed to ripen.

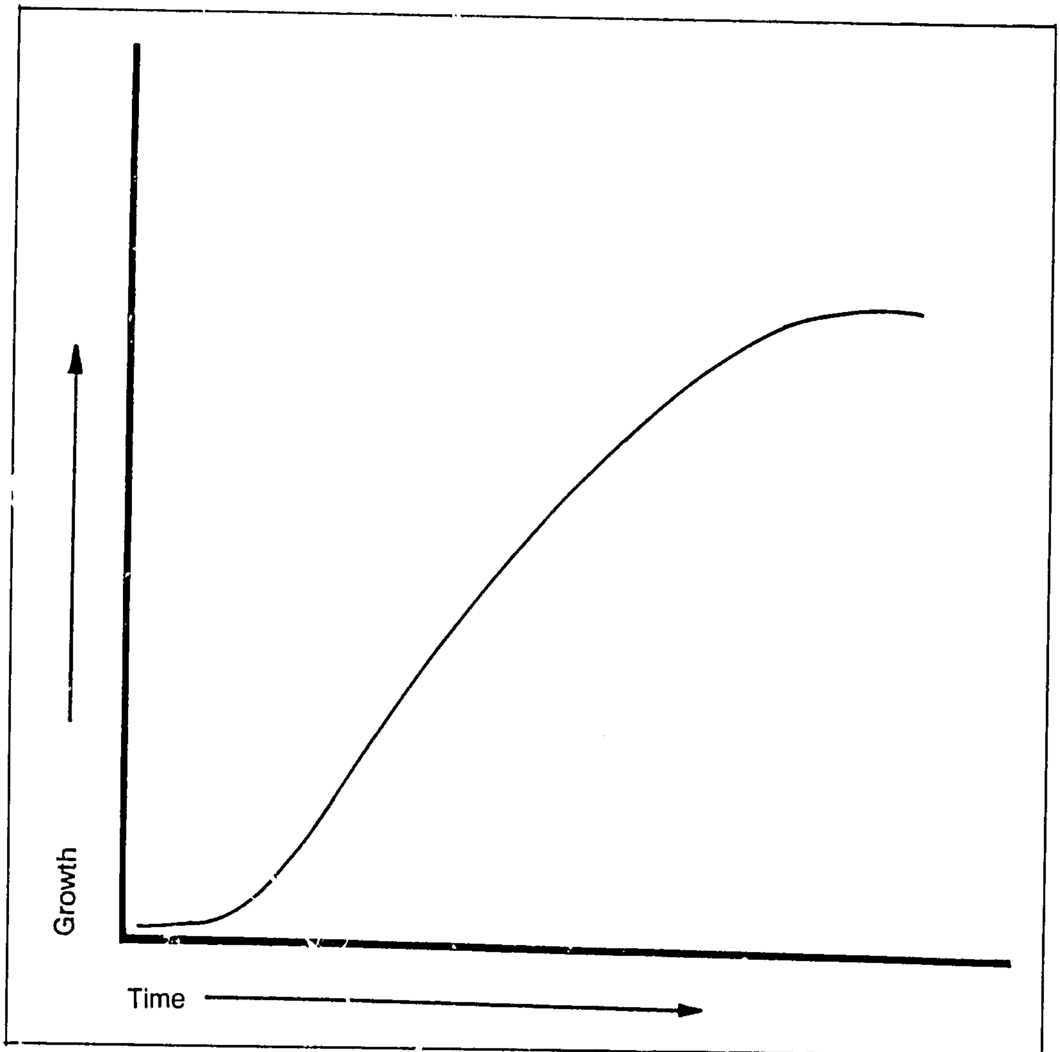

Fig. 2.23. Sigmoid pattern of fruit growth.

The developing fruit should be supplied with a certain amount of food and water; otherwise, some of the fruits will fall off. A fruit may stop growing without falling off the plant. Removing some of the fruits (thinning) will allow the development of the remaining fruits into bigger ones. All the manufactured food will go into developing these few fruits. Among the fruits in a plant, those that were formed earlier are more effective sinks.

In watermelon, for example, the first and sometimes the second fruit on the main stem will have the greatest ability to draw the assimilates and will, therefore, suppress the development of the rest of the fruits. Although any of the fruits may be removed from other plants, in watermelon only the first and sometimes the second fruit are allowed to develop.

In cucurbits, each lateral branch can support a fruit, or a few fruits; hence, destruction of the growing tip will result in development of many lateral shoots and consequently result in more fruit yield. However, total weight of the fruits produced by the plant remains the same. This concept is especially useful when small fruits sell for a much higher price than large ones.

In plants where vegetative and reproductive growths occur simultaneously, there may be competition between these two components and may reduce the yield of fruits. If high yield is desired, more of the products of photosynthesis have to go to the desired part by removing all competing sinks.

In sweet corn and vegetable soybean, the young seeds are watery and high in sugar content. As they continue to develop, they make starch, protein, or fat. The fruits then lose their sweet taste and form woody-like material in the seed coat making the seeds tough. In vegetable soybean, the pod develops and enlarges first, then the embryo, followed by the seed. Thus, edible, immature vegetable soybean seeds can be harvested when pod enlargement and seed development are complete and seed maturation begins.

Ripening and Senescence

A fruit ripens when it becomes soft; loses its green color and changes into red or yellow as the case may be; becomes sweet, juicy, delicious; and smells good. These changes take place after maturation either off or on the plant. Harvesting and ripening will be considered in greater detail in Chapter 12.

In annuals, the food reserves is transferred continually to the fruits as they form and develop at the expense of the shoot and roots. With time, photosynthesis starts to decline too. As a result, the plant senesces and dies.

Dormancy in Seeds and Storage Organs

When a part of a plant grows very little or does not grow at all at some stages of its life cycle, that part is said to be dormant. Its development is arrested because of structural or chemical properties that prevent germination or sprouting when environmental conditions are favorable. Seeds, buds, and storage organs usually exhibit this phenomenon.

In the tropics, the problem is dormancy of seeds and storage organs and not of the buds. Actually, dormancy ensures the survival of the plant by allowing germination over a wide range of time. Dormancy in seeds may be caused by the difficulty of the seed coat to be penetrated by water and gases or by the presence of growth inhibitors that cause nongermination. For more detailed discussion, see Chapter 5.

Dormancy is a probler ·e bulbs, tubers, corms, and storage roots when these are used as planting materials immediately after harvesting. Dormant organs cannot germinate unless the dormancy has been broken naturally or by the use of chemicals. If a long storage period is desired, varieties with a long dormancy period should be selected; or shoot growth may be delayed by growth inhibitors applied before or after harvest. The use of plant growth regulators for breaking dormancy is discussed in Chapters 6 and 7.

Vegetative-Reproductive Balance

The vegetative and reproductive phases of plant development may be likened to a balance (Fig. 2.24). On one side is the vegetative phase, and on the other is the reproductive phase. This concept presents three possibilities:

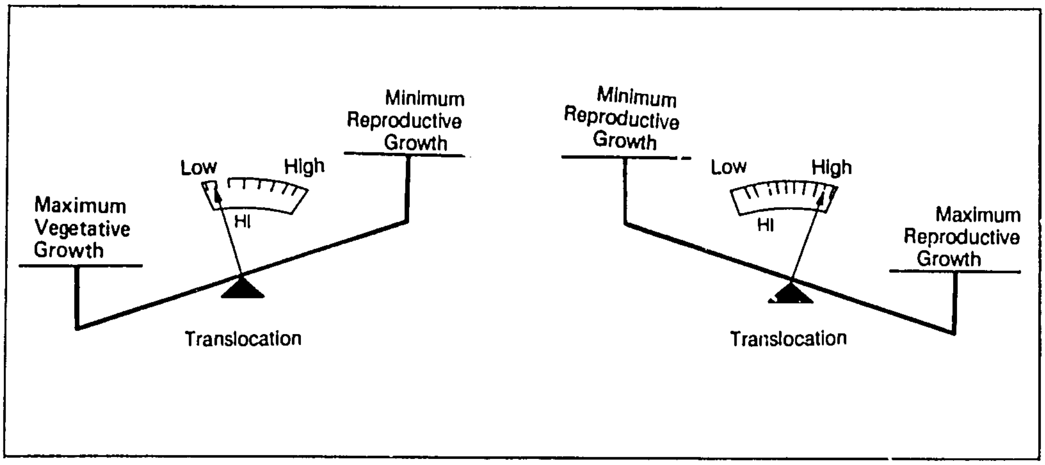

Fig. 2.24. Vegetative and reproductive balance.

- The vegetative phase may be dominant over the reproductive phase; in which case,the plant continues to produce more shoots than flowers and fruits, so the balance is tipped on the vegetative phase.
- The reproductive phase may be dominant over the vegetative; in which case, the plant produces more flowers and fruits than leaves, so the balance is tipped on the reproductive side.
- Neither the vegetative nor the reproductive phase may be dominant, with the plant producing as much shoots as flowers, so both sides of the balance are practically equal.

When the vegetative phase of plant development is dominant over the reproductive, more assimilates are used than stored. When the reproductive phase is dominant over the vegetative, more assimilates are stored than used. When the vegetative and reproductive phases are balanced, practically equal amounts of assimilates are used and stored.

In vegetable crops grown for their vegetative storage organs such as tubers, bulbs, or fleshy roots, the reproductive phase becomes important only in breeding and seed production. Since these storage organs are the places where assimilates accumulate, their yield is determined by assimilates accumulated. Before storage organ formation can take place, the stem, leaf, and absorbing root systems must not only be formed but already functioning vigorously. This means that the utilization of assimilates is dominant over accumulation. However, when the plants are still developing their storage organs, the accumulation of stored food is dominant over utilization for growth and development of shoots and absorbing roots.

With the indeterminate varieties, two distinct phases of growth and development can be recognized: prefruiting (vegetative) and fruiting (reproductive). During the prefruiting stage the plants develop their stems, leaves, and absorbing roots; consequently, utilization of assimilates is dominant. However, because vegetative growth very often continues after fruiting has began, these two phases overlap for some time. A balance between utilization of food for shoot and root growth and accumulation in the fruits is necessary during the fruiting stage.

Expressions and Components of Yield

Expression of Yield

Yield can be expressed in several ways. Biological yield is the total weight of all the plant parts, regardless of edibility; hence, it is not of interest to a farmer. He is more interested in economic yield, which is the weight of that particular part of the plant for which the plant is being grown and utilized.

Yield, whether biological or economic, could be expressed as fresh weight, dry weight, or digestible dry organic matter. The farmer is interested only in fresh weight, but the processor producing dehydrated onions would be interested in the dry weight. Digestible dry organic matter, on the other hand, is of interest to researchers. In some cases, the yield of other components of a plant, such as the oil yield of soybean, becomes of particular interest. If the harvest is to be sold in fresh form, quality becomes an important consideration; and only those meeting the quality requirements of the consumer is included in the economic yield.

To determine what proportion of the entire plant (biological yield) that is useful (economic yield), the harvest index, is computed. It can be expressed as follows:

$$HI = \frac{[EY]}{[BY]} \times 100$$

Where: HI = harvest index (%)
EY = economic yield (kg)
BY = biological yield (kg)

In leafy vegetables, a large proportion of the plant is considered economic yield. When that same crop is grown for seed, the yield is a very small fraction of the biological yield. Ideally, a desirable crop is one in which the economic yield is a large fraction of the biological yield. A crop with an economic yield that is merely a small fraction of the biological yield will be worth growing only if the product can sell for a very high price.

The HI is, therefore, a measure of how the net photosynthesis has been utilized in producing the desired plant. Its value can vary from as little as 20% to as much as 70%. Since a high HI is preferable, it is one of the objectives of crop improvement.

The HI of different crops vary greatly. In vegetable soybean, it ranges from 29-40% while in dry bean, from 53-67%.

Yield Components

Yield, whether it be a root or leafy head, shoot, flower, fruit, or seed is expressed on a unit area basis (per hectare) rather than on a plant basis. It is a product of factors that contribute to the yield and it varies for different types of vegetables.

Seed yield or weight per unit of land area reflects the interplay of the number of plants per unit area, the number of pods per plant, the number of seeds per pod, and the weight per seed. The seed yield is expressed as:

$$Ys = P \times F \times S \times Ws$$

Where:
- Ys = is the seed yield in grams per hectare
- P = number of plants per hectare
- F = number of pods or fruits per plant
- S = number of seeds per pod
- Ws = mean seed weight (g)

The yield of fruit vegetables is computed similarly, except that number of seeds per pod is omitted and weight per fruit is included.

$$Yf = P \times F \times Wf$$

Where:
- Yf = fruit yield
- P = number of plants per hectare
- F = number of fruits per plant
- Wf = mean weight per fruit

The number of pods or fruits per plant can be estimated from the number of flowers per plant if the percentage of fruit setting is known.

$$F = \frac{1 \times \%A}{100}$$

Where:
- I = number of flowers
- A = pod setting

The components of yield affect each other. In general, the number of flowers or fruits per plant decreases as the number of plants per unit area (planting density) increases within certain limits. In like manner, the more fruits there are per plant, the smaller the fruit side is.

In general, yield per unit area increases with population until a certain point beyond which, further population increase causes yield reduction or shows very little decrease in yield.

As plant population increases, per unit area, a point is reached at which each plant begins to compete for certain essential growth factors: nutrients, sunlight, and water. The effect of increasing competition is similar to decreasing the availability of a growth factor. The optimum population, therefore, is the one which produces the greatest net return, to the grower. In this case, yield must be interpreted in both quantitative and qualitative terms. The value of the total yield should be based not only on quantity, but also on quality (size, color, appearance, etc.) in relation to the desires of the consumer.

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CHAPTER 3

Environmental Factors Affecting Vegetable Production

Since the yield potential of vegetables revolves around photosynthesis and respiration, directly or indirectly, all the environmental factors that affect the efficiency of these processes must be at optimum level. The factors can be grouped into two: abiotic and biotic, referring to nonliving and living components of the environment, respectively. The abiotic factors include the climate and the soil. The biotic factors include beneficial and harmful insects and microorganisms and higher plants and animals. A knowledge of the environmental factors affecting vegetable production will make it easier for the grower to modify the environment or adjust his practices to attain the same result.

Weather and Climate

In a given location, the daily condition of the environment can be described in terms of temperature, rainfall, light intensity and duration, wind direction and velocity, and relative humidity. Collectively, they comprise the ***weather.*** The weather changes each day and assumes a certain pattern which repeats itself year after year. The pattern is the ***climate*** of that particular location.

The climate differs in the extent of changes with distance from the ground surface into the atmosphere and the changes that occur there as time passes. For example, temperature changes greatly in the first few centimeters from the surface into the air. Humidity, which has reference to the moisture in the air, is highest near the surface of the soil under the plant canopy. Wind speed increases as it gets higher from the ground surface it travels.

Each crop has certain climatic requirements. To attain the highest potential yield per unit of land, a crop must be grown in an environment which meets these requirements. A crop that is well matched to a particular climate can be grown with minimal adjustments. However, the high demand of some crops has led to their cultivation in areas that are less than ideal. Unfavorable climatic conditions produce a stress or strain on the metabolic processes of the plant resulting in lower yields. In such a case, the environment can be artificially modified to meet the crop requirements. However, modifying the environment artificially can be very expensive; so it is done only when it is highly profitable or for experimental purposes.

There are other ways of modifying the effects of environmental factors. For example, temperature can be reduced at low elevation when the air is dry by using sprinkler irrigation for crops like potatoes. The evaporation of water will lower the temperature sufficiently in the vicinity of the crop so that it can perform well.

In the temperate zone where the temperature changes constantly, temperature is the determining factor in crop production. In the tropics, rainfall is the key element of climate since temperature is more or less constant. Climatic zones in the tropics are usually based on the seasonal distribution of rainfall. However, topography, altitude (elevation), nearness to the sea or other bodies of water, and direction of prevailing winds have modifying effects on the climate.

Topography refers to the levelness or roughness of the earth's surface, the degree of slope on hillsides, and the general form of the earth's surface. An example of the modifying effect of topography on climate is the greater amount of sunlight received by a slope facing the sun compared to that facing away from it. A large body of water near a farm reduces fluctuations in temperature.

While climate determines what crop can grow best in a particular location, the rate of growth and development depends largely on the weather. Cloudiness, amount and duration of rain periods during a day, and wind movement influence the basic plant physiological processes. The weather also determines when to undertake farm operations, such as land preparation, weed control, fertilization, harvesting, and irrigation.

Varieties can be bred to grow well in regions where ordinarily, the species is not adapted. Thus, there are now varieties of vegetables that are heat-, drought-, salt-, or shade-tolerant.

Temperature

In the tropics, low temperatures are obtained in the mountain areas or highlands. In general, there is a 0.6°C decrease in temperature for every 91.5 m rise in elevation above sea level. In the low-elevation areas, it is cooler during certain parts of the year. Cool-season vegetables could be grown successfully, therefore, in the highlands or during cool months of the year at sea level.

Temperature is usually the most important factor to consider in deciding what crops to grow in a place. It influences all physiological activities by controlling the rate of chemical reactions. It affects flowering and pollen viability, fruit set, hormonal balance, rate of maturation and senescence, quality, yield, and shelf life of the edible product.

Temperature also affects the harvest time of vegetables. Sweet corn and vegetable soybean, for instance, are harvested before dawn, as a rising temperature enhances respiration, and the fruits become less sweet. Leafy vegetables are picked during the day when they have lost some of their water through transpiration, so that they are less brittle, hence less likely to be damaged during handling.

High temperature near harvest time hastens maturation and shortens the time interval during which harvest can occur. This occurs especially in cucurbits, sweet corn, and peas, and affects the majority of crops to some extent. This is either a problem or a benefit, depending on whether the grower wants to have a long or a short harvest period.

Optimum Temperature

Each kind of vegetable grows and develops most rapidly at a favorable temperature or range of temperature. This is called the ***optimum temperature range,*** within which photosynthesis and respiration occur at rates that result in the highest marketable yields. The rate of photosynthesis is high and respiration is normal, so net photosynthesis is maximum. Vegetables can be classified according to their temperature requirement in terms of their optimum temperature range (Table 3.1). However, in general, they can be grouped into whether they require low or high temperature for growth.

Temperature requirements are usually based on night temperature. Those that can grow and develop below 18°C are the cool-season crops, and those that perform best

Table 3.1. Temperature requirements of vegetables.

Temperature Range (°C)	Vegetables
7-13 (Low temperature)	Asparagus, cabbage, cauliflower, celery, garlic, leek, onion, pea, potato, spinach, lettuce
13-18 (Moderately high temperature)	Snap bean, *Capsicum* pepper, carrot, bunching onion, radish, soybean, tomato
18-30 (High temperature)	Cucurbits, mungbean, okra, ginger, sweet corn, sweet potato, taro, tropical spinach, yard-long bean, sweet corn, eggplant, lima bean, winged bean, hyacinth bean, cowpea

above 18°C are the warm-season crops. The crops that originated in temperate countries usually require low temperature, while those that originated in the tropics require warm temperature.

At high temperatures, the night temperature may influence the amount of crop yield. While photosynthesis occurs during the day, respiration occurs mostly at night. When respiration is high at night, net photosynthesis is low thus potential yield is reduced. Usually, night temperature is high during the rainy season.

Soil Temperature

Soil temperature is a major factor that determines the rate of microbial growth and development, organic matter decay, seed germination, root development, and of water and nutrient absorption by roots. The higher the temperature (up to a certain limit), the faster are these processes. The size, quality, and shape of storage organs are also greatly affected by soil temperature.

The amount of heat absorbed by the soil increases with the intensity and duration of sunshine. Dark-colored soils absorb more solar energy than light-colored ones. The capacity of water to move heat from one area to another (conduction) is greater than that of air. Heat is therefore released to the surface faster in wet clayey soils than in dry sandy soils. The lower the air temperature, the more rapid the loss. Thus, although light-colored sandy soils absorb less solar energy, less heat is also released to the atmosphere because of the low water-holding capacity of the soil.

Temperature Extremes

Vegetable crops grow well within a narrow temperature range. At 0°C plants are killed by frost, and at 40°C they are killed by heat. When temperature is colder or hotter than what the plant can tolerate, its photosynthetic, respiratory, and metabolic processes become abnormal. Many plants are permanently damaged at 10°C or even at 15°C, and most cease to carry out photosynthesis efficiently above 30°C.

The abnormalities are expressed by the slow down in growth and development and by some external symptoms. Extreme temperatures may inhibit seed germination, reduce pollen viability or germinability on the stigma, decrease fruit set, retard tuber growth or slow down development of yield components. In the tropics, heat injury rather than low temperature injury is the bigger problem.

Chilling injury. Crops requiring high temperature are very susceptible to chilling temperatures (10°-12°C or lower but above freezing). The metabolism of the crop is altered resulting in the appearance of discolored areas, poor color development, or sunken areas on the surface of the leaves or fruits (surface pitting). Chilling injury is a result of interaction between temperature and time of exposure. A short period of exposure to 5°C may cause as much damage as a long exposure to 12°C. Many chill-induced effects are related to increased ability of cells to let chemicals pass through their cell membranes (increased permeability) resulting eventually in death of cells and tissues. Membrane changes are relatively reversible, so symptoms can be prevented before permanent injury sets in, when temperature increases above chilling. Chilling injury in harvested vegetables is discussed in Chapter 12.

Heat stress. Very high temperature is potentially injurious, so it is called heat stress. Reduction of temperature on the leaf surface usually depends upon cooling by transpiration and by heat flow (conduction) to the atmosphere. When heat is not effectively removed, the temperature of leaves in full sunlight may be higher by 10°-15°C than at ordinary (ambient) temperatures; and some tissues of small fruits with a relatively small surface-to-volume ratio may have temperatures more than 15°C above ambient temperature.

Injury caused by temperature higher than what a crop can tolerate occurs gradually and is expressed as reduction in the growth rate. Its effects are seldom lethal. Temperatures above 30°C usually inhibit seed germination of celery and lettuce, increase stubby roots of carrot, and slow down fleshy root formation of radish and tuber formation of potato. Fruit set of solanaceous crops and legumes declines as day temperatures exceed 32°C. Sweet corn ears often show blank tips where pollination has failed because of hot and dry conditions.

Heat stress at fruit set or during late fruit development may cause defects that render the product unmarketable. In tomato, cracks at the stem end (catface) may appear or the fruit may be puffy (hollow inside). Onions and radish become more pungent at high temperatures; most consumers usually do not want "hot" radishes. If high temperatures occur for long periods, the leaves might develop chlorosis (leaves are light green or yellow) or show scalding effect (brown areas appear).

Heat injury can be due to starvation, toxicity, or destruction of protein structure. At temperatures above 30°C, the stomates remain closed, thus effectively preventing CO_2 from entering and 0_2 from leaving. When this occurs for long periods, starvation results since net photosynthesis is zero or less than zero. Toxicity may possibly occur when respiration is so rapid that eventually oxygen intake is reduced and the respiration process then becomes abnormal. This abnormal process eventually is called ***anaerobic respiration.*** The products of anaerobic respiration, among others, are ethanol and acetaldehyde — compounds which can damage plant cells.

The structure of proteins may be destroyed (denatured) by high heat. Destruction of the proteins causes marked chlorophyll deficiency since enzymes, which are proteins, are necessary for chlorophyll synthesis. Change in the nature of the mitochondrial membranes due to heat may also cause starvation, toxicity, or destruction of proteins since they are composed of proteins and lipids.

Cell membranes of heat-stressed plants become more porous (permeable) and thus release their cellular contents; so they become more susceptible to diseases, as the released substances serve as food for microorganisms.

Symptoms of heat injury are the appearance of dead areas in leaves of hypocotyls and young stems of legumes (heat canker), in onion leaf, in leaves of common cabbage (blight) and lettuce (sunscald). Heat injury occurs over a wide range of vegetables, depending upon the species or tissue. Vegetables normally grown in the temperate regions cannot withstand the stresses imposed by high temperatures and can rarely tolerate temperatures above 35°C.

Vernalization

The biennials and some of the cool-season vegetables (e.g. *Allium*, carrot, celery, the crucifers, garland chrysanthemum, and spinach) initiate flower formation after extended (several weeks or months) exposure to low temperature. Older plants respond better to vernalization than seedlings and transplants. Flowering in the plants mentioned above is a quantitative response to low temperature; that is, the duration of exposure needed to initiate flowering declines as the temperature decreases. The lower the temperature, the shorter the exposure to vernalization temperature is necessary. Thus, at the same exposure duration, radish will flower sooner at 5°C than at 10°C. However, if the temperature during growth is high, vernalized plants might fail to flower.

It is important to expose crops to low temperature when they are most responsive to it (inductive stage), so as to obtain flowers for seed production. However, the premature appearance of a flower stem, called ***bolting***, can cause substantial yield loss when these crops are grown for vegetables. This is particularly true in crops requiring relatively little cold exposure, like heat-tolerant Chinese cabbage. This may be a problem in low-temperature areas or during the cool months of the year at low elevation.

Light

Light from the sun travels to earth in waves. The waves are measured by their length which is expressed in nanometers (nm). Each wavelength corresponds to a certain color, thus sunlight is composed of light of different colors (as in a rainbow), though it appears white to the naked eye (Fig. 3.1).

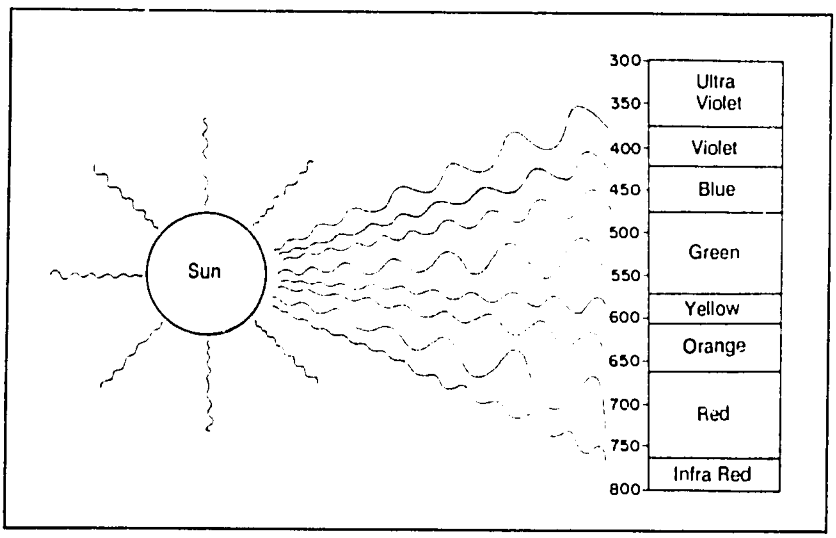

Fig. 3.1. Nature and colors of light.

Light Quality

Light quality refers to the predominating wavelength. Photosynthesis uses light in the range of wavelengths normally visible to the human eye. This light ranges from violet with a wavelength of about 380 nm, to red with a wavelength of about 670 nm. Light not used in photosynthesis is transmitted through the leaf or is reflected by the leaf.

Light in the shorter wavelengths (blue light about 450 nm) is absorbed by carotenoids and chlorophyll. In longer wavelengths (red light about 675 nm), it is absorbed by the chlorophyll only. Chlorophyll does not utilize green light but reflects it, so it appears green. Light quality becomes important only when plants are grown under artificial light. The lamps to be used should give light with the red and blue wavelengths in sufficient amounts. Otherwise, when there is a predominance of ultraviolet wavelength, the plants will be dwarfed. Low light intensity (predominance of the red wavelength) will cause the plants to be long and thin (spindly).

Light Duration

Since the earth revolves on its axis, tilts at 66°, and travels around the sun, the length of the light period varies according to the season of the year and latitude. The duration of light is measured by the number of hours from sunrise to sunset. It is called ***photoperiod*** or ***daylength.*** It varies from a nearly uniform 12-hour day at the equator (0 latitude) to continuous light or darkness throughout the 24 hours for a part of the year at the poles. In the tropics, which cover latitude 0°-23° north to south of the equator, the variation in light period is less than three hours during the shortest and longest day (Fig. 3.2). The farther the area is from the equator, the greater the difference between the shortest and longest day.

The cycles of daylength are so precise that plants which respond to light have a built-in timing mechanism that measures the duration of day or night. This, in turn, determines when a plant is going to flower. The phenomenon is ***photoperiodism.***

Some vegetable crops are qualitative in response, that is, they flower when a specific daylength threshold has been passed. Short-day plants flower rapidly when the days get shorter and long-day plants flower fast when days are longer. In reality, it is the night duration that is important; thus, short-day plants require daily prolonged darkness to induce flowering while long-day plants require shortened darkness. The classification of plants according to photoperiod is shown in Table 3.2.

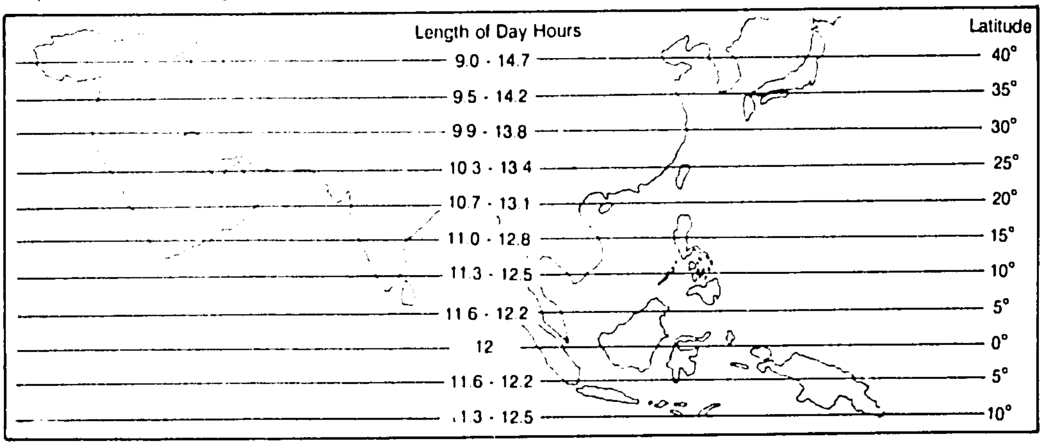

Fig. 3.2. Daylength at different latitudes.

Table 3.2. Photoperiodic reaction (for flowering) of vegetables.

Short Day	Day Neutral	Long Day
Amaranth	Corn	Spinach
Sweet potato	Cucumber	Sugar beet
Mungbean	Sweet pea	*Allium*
Cowpea	Tomato	Cabbage
Soybean	Sweet pepper	Carrot
Winged bean	Eggplant	Chinese cabbage
Tropical spinach	Artichoke	Lettuce
Garland chrysanthemum		Radish
Chayote		Spinach
		Potato

Some plants are more sensitive to photoperiod than others. Short-day plants flower within a constant number of days when the daylength is shorter than the critical photoperiod which may vary from 11-14 hours (Fig. 3.3). There is no flowering at or more than the critical photoperiod. When the length of the light period exceeds the critical photoperiod, the vegetative phase of the crop is promoted and the reproductive phase is suppressed.

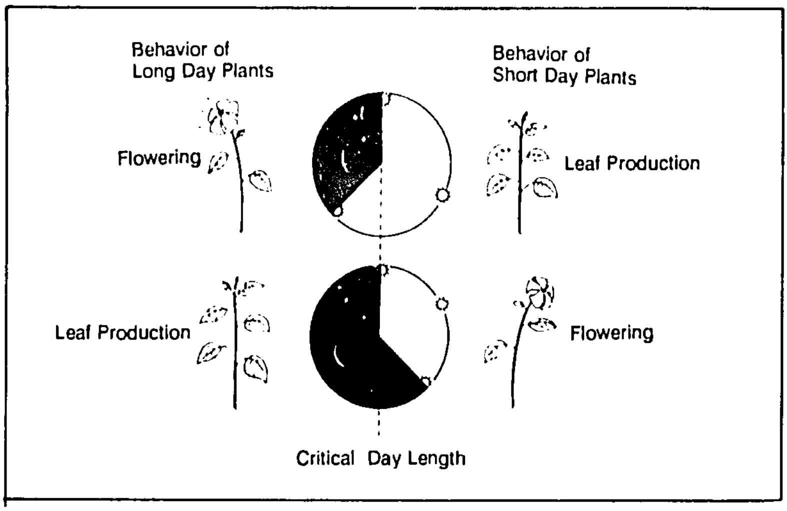

Fig. 3.3. Behavior of short- and long-day plants.

On the other hand, a long-day plant flowers within a constant number of days when the days are longer than its critical photoperiod. No flowering occurs at a shorter photoperiod in sharp contrast to the response of short-day plants. The vegetative phase of the plant is promoted and the reproductive phase is suppressed when the length of the light period is less than the critical photoperiod.

Plants which are not affected by daylength are called ***day-neutral plants.*** These plants apparently can flower under any light period.

Knowledge of the critical photoperiod of a photoperiodic plant will allow the grower to time his planting, so that flowering will occur after it has attained sufficient vegetative growth. Winged bean 'TPT-2', for example, is a short-day plant. It flowers when the daylength is less than 11 hours. If planted too early when the days are longer than 11 hours, it will produce shoots for a long period of time before it flowers. If planted when the daylength is less than 11 hours, the plant will flower after producing only a few leaves, so the yield is low.

The length of light and dark periods also influences the formation time of certain storage organs. Long days hasten bulbing in onion, short days hasten tuber formation in potato, root enlargement in sweet potato, and corm formation in taro (Fig. 3.4). In the case of cucurbits, daylength coupled with light intensity and temperature is known to influence sex expression. In general, long days and high temperature tend to keep the plants in the staminate (male) phase.

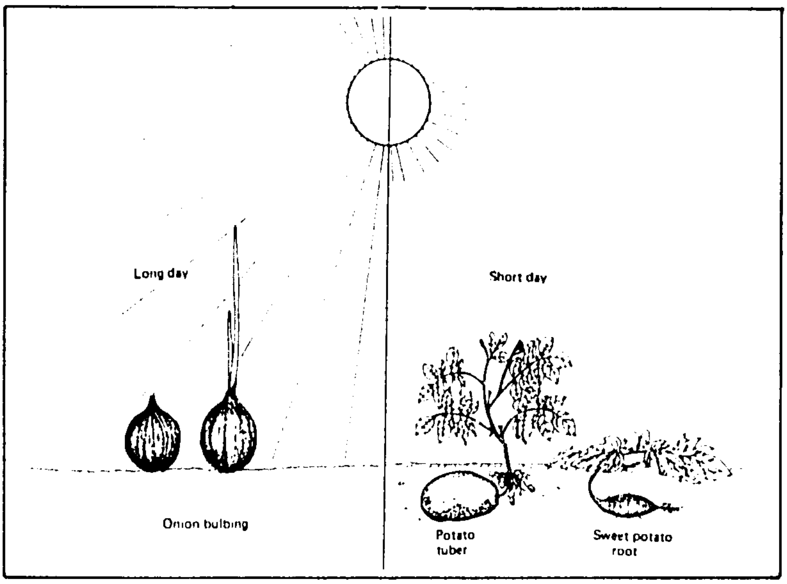

Fig. 3.4. Effect of light duration on storage organ formation.

Light Intensity

Total light energy from the sun is a net effect of the amount of light and length of the day. The amount or brightness of light, which is referred to as intensity, changes with elevation and latitude. Therefore, the highest potential photosynthesis (productivity) for the growing period of annual vegetables would be high at high latitudes (temperate region) due to long daylength. On the other hand, the greatest potential growth for perennial vegetables would be high in the low latitude (tropical region) due to longer growing periods (Fig. 3.5).

The amount of sunlight available to plants each day depends not only on the latitude but also on the season of the year. It varies with the time of day. It is measured in terms of lux or foot candles or gram calories per unit area (square centimeters) per unit time (minutes). On a clear day, light intensity varies at noon from a mountain top reading of 1.75 g cal/cm^2/min - 1.50 g cal/cm^2/min at sea level (Fig. 3.6).

Clouds, dust, smoke, or fog reduce light intensity. Photosynthesis is practically stopped at high light intensity depending on species. Normally, the amount of light available to plants is adequate and the plant will grow fast provided temperature, water, and CO_2 requirements for plant growth are met.

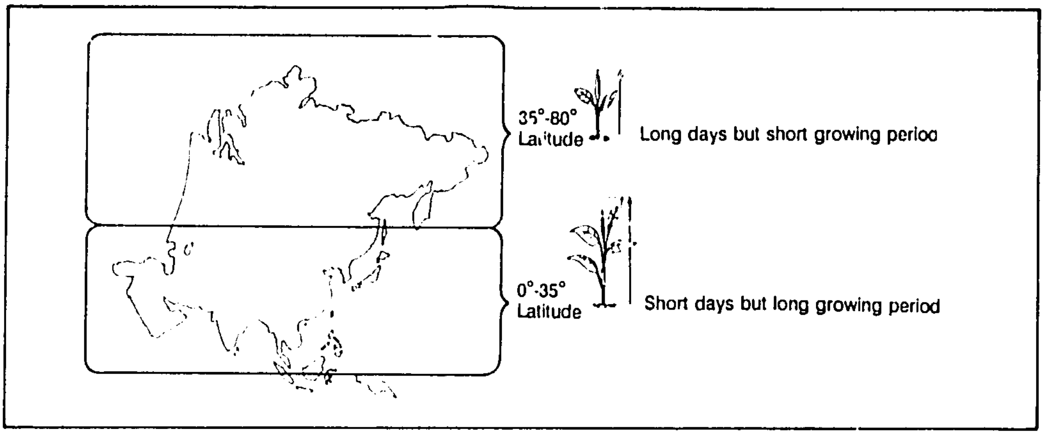

Fig. 3.5. Interrelationship of latitude, daylength, and growing period.

The reaction of a crop to different light intensities differs, depending on whether the plant is a shade or sun plant. Sun plants require high light intensities to maintain a high photosynthesis and respiration rate and consequently show lower rates of net photosynthesis at low light intensities.

Shade plants are capable of a lower photosynthetic rate than sun plants; but respiration rate is correspondingly low, so net photosynthesis is high at low light intensities. Sun plants have a higher light compensation point than shade plants; that is, the amount of light at which photosynthesis is equal to respiration is higher in sun plants.

When the amount of light received by sun plants is continuously low, so that it is always at the light compensation point, the plants will starve and eventually die. The light intensity at compensation point for most plants is around .215 g cal/cm²/min (Fig. 3.6). Above this point, photosynthesis will increase with increasing light intensity up to a certain point. At a point when photosynthesis no longer increases, the leaf is said to be light-saturated. The light saturation point determines the light requirement of plants. When the plant has a high light-saturation point, it is said to have a high light requirement. The light requirements of some vegetables are shown in Table 3.3.

Table 3.3. Light requirement of vegetables.

Light Level	Vegetable
High	Corn, cucurbits, eggplant, legumes, potato, tomato, sweet potato, yam bean
Medium	*Allium*, asparagus, carrot, celery, *Brassicas*, lettuce, spinach, taro
Low to total darkness	Ginger, bamboo shoot, bean sprout, mushroom

Light intensity is much lesser during the rainy season than during the dry season due to cloudiness. Under continuous low light intensity or when the plants are greatly shaded (although light intensity is high) plants become tall and thin (spindly), and are light green in color. This happens to seedlings which are overly protected from sunlight to prevent wilting. In the total absence of light, plants are spindly and yellowish or white (etiolated).

For the most part, plant growth depends on its ability to photosynthesize under low light conditions. On the other hand, excessive sunlight may result in little or no net photosynthesis or may even have a negative net photosynthesis. Too much sunlight for

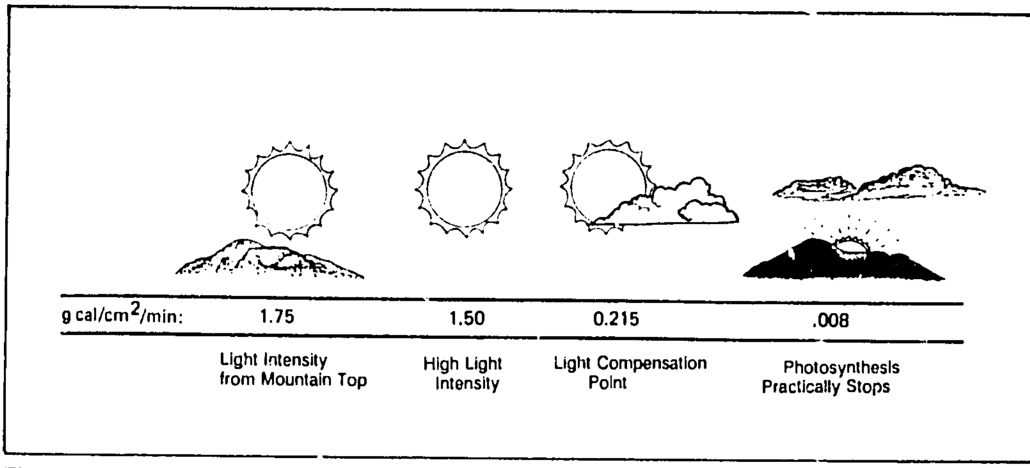

Fig. 3.6. Light intensity under different conditions.

a long period may damage the chlorophyll, inactivate enzymes, and disrupt production of high energy compounds.

Plants in full light develop several layers of palisade tissue with the corresponding amounts of chlorophyll indicating high photosynthetic activity. Conversely, plants grown in reduced light have fewer palisade layers and correspondingly lower levels of chlorophyll (Fig. 3.7). The spongy mesophyll layers have also larger intercellular spaces and generally are more succulent.

Leafy or salad vegetables, such as celery and lettuce, have generally better quality and are more tender when grown under partially overcast skies.

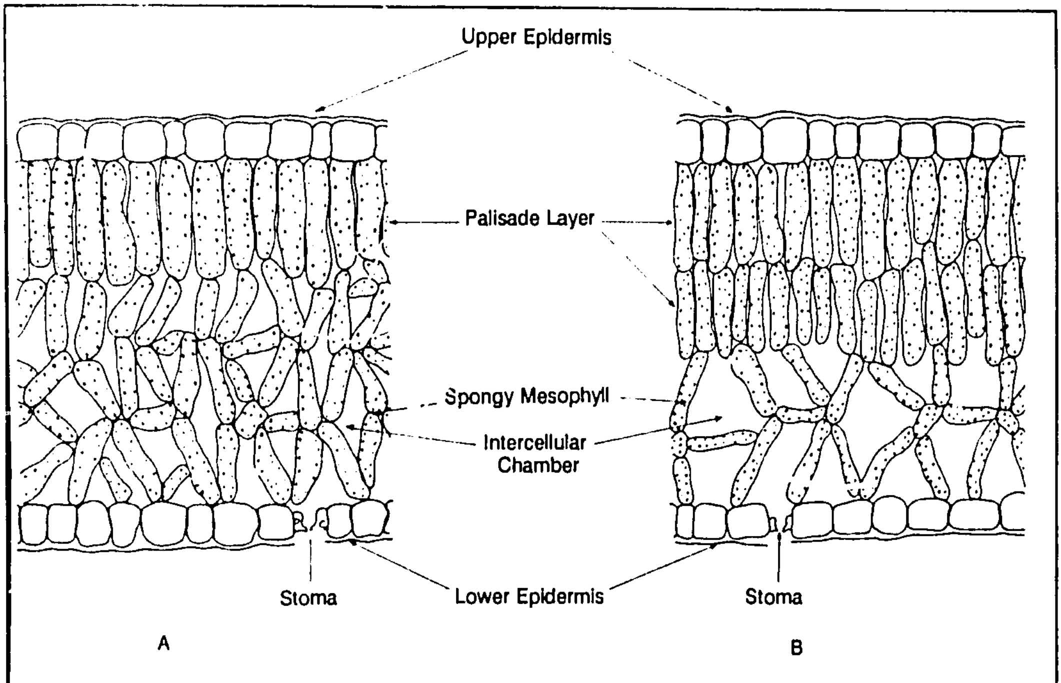

Fig. 3.7. Effect of light on leaf structure; (A) under reduced light, (B) under sufficient light.

In cucurbits, there is an interaction between light intensity and temperature in terms of the male and female flower ratio. Long days and high temperature favor male flower production while short days and low temperature favor female flower production (Fig. 3.8).

There are few vegetables that can tolerate shade, such as taro and ginger. They yield as much under partial shade as well as under full sunlight.

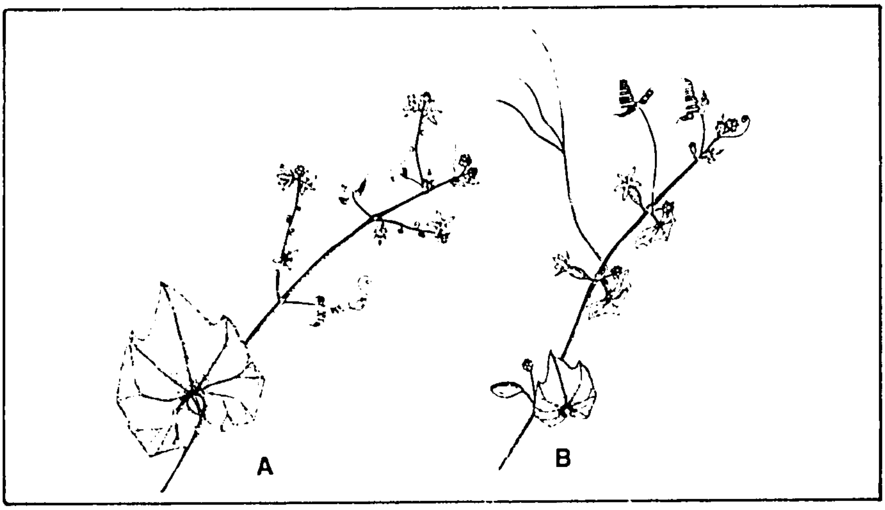

Fig. 3.8. Effect of light duration on cucurbits; (A) more male flowers at long days, (B) more female flowers at short days.

Water

Lack of water is the greatest single factor that lowers vegetable yield. Vegetables are composed of 80-95% water and they have to produce the remaining 5-20% of their weight through photosynthesis (Table 3.4). Aside from its importance for biomass, water is also essential for plant growth and development.

A plant usually absorbs several times more water than the amount incorporated in its cells. Most of it is lost through the stomates during transpiration. The water lost cools

Table 3.4. Water content commonly found in various plant parts.[a]

Plant Part	Fresh Weight (%)
Cucumber fruits	96
Lettuce head	94
Cabbage head	90
Potato tuber	79
Tomato leaves	85-95
Corn leaves	65-82
Carrot roots	88
Asparagus tips	88
Tomato fruit	94
Sweet corn seeds	85

[a]Curtis and Clark 1950 (for the first six crops) and Kramer 1969 for the last four crops.

the leaf so that it will not be too warm to inactivate the enzymes of photosynthesis and respiration. This loss through transpiration also acts as a drawing force pulling the water from the soil to the plant.

Plants get water from several sources for its growth. However, the amount of water available to plants in the tropics is primarily determined by rainfall. Dew and fog can also provide moisture for crop growth in dry areas.

During the rainy months in many areas of the tropics, there is more water than is needed. During the dry months, there is hardly any water for growing crops, thus irrigation is necessary. Drought occurs when there is too little water. Waterlogging or flooding occurs when there is too much water which does not drain fast enough. The majority of small farmers growing vegetable as a secondary crop in developing countries, still rely on rainfall for their water needs. They time their operations so as to take advantage of the presence of residual moisture to grow a vegetable crop after the main crop.

Too much rainfall causes direct damage to shoots, high incidence of pests and diseases, physical destruction of flowers, and less activity of pollinators. It also brings nutrients down to a level beyond the reach of roots (leaching). Heavy rainfall also creates flooding or waterlogging in the poorly drained soil.

In terms of water requirement, vegetables can be classified as follows:

- Great water-users with poor root penetration: cabbage, Chinese cabbage, cucumber, leafy greens, and radish. These vegetables are shallow-rooted crops and possess large leaf area and tender tissue; thus they require plenty of water.
- Economical water-users with vigorous root penetration: melons, bitter gourd, and other cucurbits. These vegetables are deep-rooted crops, possess large leaf area but with hairy lobed leaves to prevent excess transpiration, hence they are slightly tolerant to drought.
- Economical water-users with poor root penetration: *Allium* vegetables and asparagus have small and waxy leaves which reduce transpiration. However, they also have poor root systems with fewer root hairs for water uptake than most vegetables.
- Economical water-users with moderate root penetration: Solanaceous and root vegetables, and legumes which have less leaf area but with hairy leaves to reduce transpiration. They have a more vigorous root system than crucifers but poorer than that of cucurbits.
- Extravagant water-users with poor root penetration: most aquatic vegetables, such as water convolvulus, water chestnut, watercress, and some varieties of taro. They have tender shoot systems. Their root system is usually poor without any root hairs for efficient water uptake.

Waterlogging

Under waterlogged conditions, all pores in the soil are filled with water; so the oxygen supply is almost completely deprived. As a result, plant roots cannot obtain oxygen for respiration to maintain their activities for nutrient and water uptake. Plants weakened by lack of oxygen are much more susceptible to disease caused by soil-borne pathogens. Waterlogging due to lack of oxygen in the soil causes death of root hairs, reduces absorption of nutrients and water (physiological drought), increases formation of compounds toxic to plant growth, and finally retards growth of the plant.

Flooded soils usually have a high carbon dioxide (CO_2) content. The CO_2 released by respiration does not move into the upper atmosphere, because water in the soil pores restrict outward flow. At the same time, soil oxygen is used but is not replaced. The increased CO_2 content that accompanies flooding decreases permeability or the capacity of root cell membranes to take in water. In some cases, decomposition of organic matter by soil organisms that do not need oxygen (anaerobic decomposition) results in the production of methane gas, as well as some nutrient elements which may accumulate to toxic levels.

Flooding is usually more serious at high temperature than at low temperature because root respiration rate is faster, water demand is higher, and ability of oxygen to dissolve in water (oxygen solubility) is lower.

The extent of flooding damage depends upon the susceptibility of species or variety, level of water constantly present in the soil (water table), soil texture, air temperature, and presence and type of soil microorganisms. Most of the vegetables are sensitive to flooding. The different levels of sensitivity among species are presented in Table 3.5.

Awareness of the problems brought about by too much rainfall has brought about the development of practices that will minimize or eliminate them. These practices are collectively known as protected cultivation (See Chapter 7).

Table 3.5. Sensitivity to flooding in vegetables.

Sensitivity Level	Vegetable
Sensitive	Bean, *Brassicas*, broad bean, pumpkin, radish, spinach, tomato, watermelon
Moderately sensitive	Cucumber, eggplant, garland chrysanthemum, garlic, onion, pea
Moderately tolerant	Cowpea, sponge gourd, sweet potato, taro, water convolvulus, watercress

Water Balance

Although water from rainfall or irrigation may be adequate, other factors affect the plant's ability to use available moisture. Water absorption is closely linked to the rate of transpiration and water movement through the vascular system. For example, high salt concentration in the soil may limit the flow of water. When the atmosphere carries only a small amount of moisture in relation to the total amount it can hold (low relative humidity), the stomates will close and reduce the flow of water in the plant. The amount of water in a plant is the difference between the rates of water intake and water loss.

When the rate of water absorption equals the rate of transpiration (i.e., it is balanced), the guard cells of the stomata are turgid or stretched, the stomates are open, CO_2 enters rapidly into the leaves, the rate of photosynthesis is high, the rate of respiration is normal, and carbohydrates are abundant. The optimum performance of all components results in steady active growth. However, the balance becomes negative when available moisture in the soil is not enough or transpiration of water through the stomates exceeds the plant's capacity to compensate for the loss within the plant. Under this condition, guard cells lose their turgidity and stomatal opening decreases. Eventually, the rate of photosynthesis and consequently growth and yield also decrease. A plant under drought stress depends on reserve substances only. In extreme cases, the plant may either wilt or die.

Drought

Unless a plant has developed well-established root systems before the dry season sets in, it cannot survive unless it is irrigated or is drought-tolerant. A short-term drought at flowering of a determinate plant can reduce the yield significantly. Indeterminate plants flower within a longer period of time, so it may not be affected by a short-term drought. Moreover, roots of determinate plants tend to stop growing at flowering; whereas in the case of indeterminate plants, root growth still continues and can therefore absorb water from the lower depths.

Drought Resistance in Plants

Plants which can survive drought either avoid or tolerate drought. Drought-avoiders do not actually avoid drought — they avoid drying of their tissues by maintaining their water uptake and/or by reducing water loss. The plant should therefore be able to produce more roots than shoots. In addition, it has the ability to move its leaves so that only a very small leaf area is exposed to incoming radiation. It also develops hairs to insulate the leaf surface and it becomes more waxy. All these characteristics reduce light absorption, hence reduce water loss. Most of the vegetable legumes (e.g., yard-long bean and cowpea), are good drought-avoiders.

The tolerators, on the other hand, survive drought by functioning normally even with a low amount of water in their tissues. Their cells do not collapse even with low amount of water.

When plants subjected to drought are not irrigated soon enough, the stomates remain closed preventing the absorption of CO_2, thus shutting down photosynthesis and reducing the amount of assimilates formed. Should water become available before permanent wilting and cell destruction has begun, drought stress will still affect the final yield and quality of the crop. Vegetables cannot sustain prolonged drought stress without loss in yield and quality.

Most vegetable crops need water at different growth periods. When drought stress occurs during critical stages of growth, yield is directly affected; and when moisture requirements are not met the crop is permanently damaged (Table 3.6).

Wind

A slight wind is necessary to replenish CO_2 near the plant surface. During rapid growth of plants, CO_2 is rapidly depleted on the leaf surface. When there is no wind, the rate of resupplying the surface of the leaf is limited, so entry of CO_2 is too slow to maintain rapid photosynthesis. Wind also carries O_2 away from the plant. On the other hand, when there is less wind, there is less evaporation and less water requirement.

Wind is a very limiting factor in vegetable production in countries where strong winds (greater than the average wind speed of 7.2 km/hour) frequently occur. Typhoons (wind speed of 60 kph or more) are very destructive. The use of windbreaks or shelter belts will minimize damage by a relatively slow wind. A ***windbreak*** is any structure that reduces wind speed. When trees are used as windbrakes, they are called ***shelter belts.*** However, during strong typhoons, no amount of protection is adequate .

All vegetable crops, except the tree vegetables, are very susceptible to wind speeds greater than the ordinary. The deeper the root system of the crop, generally the more

Table 3.6. Critical growth stages for soil drought stress on several vegetables.[a]

Crop	Critical Stage
Asparagus	Fern growth
Bean (all)	Flowering and pod forming
Broccoli	Head forming and enlarging
Cabbage	Head forming and enlarging
Carrot	Root enlargement
Cauliflower	Frequent irrigation essential from planting to harvest
Celery	Initial stage and during rapid growth (hot periods)
Cucumber	Flowering and fruit enlarging
Eggplant	Flowering and fruit enlarging
Lettuce	Head developing
Onion	Bulbing and enlarging
Pea	Flowering and pod filling
Pepper	Transplanting, fruit setting, and developing
Potato	Any growth period from planting to harvest
Pumpkin-squash	Flowering and fruit developing
Radish	Root enlarging
Summer squash	Flowering and fruit developing
Sweet corn	Tasseling, silking, and ear filling
Tomato	Flowering, fruit setting, and enlarging
Watermelon	Flowering to fruiting

[a]Fulton 1986.

resistant it is to strong winds. Varieties that are early-maturing have a better chance of being harvested before the onset of strong winds than late-maturing ones.

Soil

The soil holds up the plant and acts as reservoir for water. It is also the main source of plant nutrient elements. Its physical and chemical characteristics greatly influence the nature and rate of plant growth. The mineral particles tend to group together so that there are spaces (the pore spaces within the soil which are partly occupied by air and partly by water).

Soil Types

The solid part of the soil is composed of a mixture of broken down rocks (mineral particles) of different sizes and the remains of plants and animals at different stages of decomposition (organic matter). The latter is only a very minor portion of the soil.

The mineral particles are clay (.002 mm or less), silt (0.05 to .002 mm), and sand (.05 mm or more). The relative proportion of these particles determines the soil texture: sandy, loamy sand, silty clay, loam, light clay, and heavy clay. Those with sand are described as coarse textured; those with clay, as fine-textured or heavy. Those with no predominant particle size are called moderately coarse-textured.

With experience, the feel method can be used to determine soil texture. The soil is first moistened then rubbed between one's fingers to feel how smooth or gritty it feels. Then it is tested whether it can be shaped, whether it is sticky,or whether it can be stretched (plastic). Using the feel method, the different textural classes can be described as follows:

Sand	-	does not stick together, is coarse or gritty
Loamy sand	-	tends to stick to each other; if shaped and handled, it will easily break.
Loam	-	easily crumbles, breaks up when rolled out into a ribbon; sand grains cannot be felt in a moist sample.
Clay loam	-	somewhat crumbly but somewhat plastic; rolls out into a ribbon between the thumb and the forefinger when moist
Clay	-	powdery when dry; tough, plastic, sticky; and rolls out into a ribbon between the thumb and the forefinger when moist.
Silty loam	-	soft and floury when dry, has smooth feel, will not form into a ribbon if rolled when moist.

Sandy soils are best suited for the root, bulb, and tuber crops provided rainfall is adequate or irrigation is available. It allows fast development and easy harvesting of storage organs. However, the soil for root or bulb crops should not be too sandy since sandy soils cannot hold much water and nutrients and therefore need fertilization. Loamy soils can hold more water and are more fertile.

Loamy soils are ideal for vegetable production. They have a good mixture of sand and clay; so they have good nutrient- and water-holding capacities and provide good aeration. Clayey soils are difficult to work when dry but have very good water-and nutrient-holding capacity. Root penetration is more difficult than in loamy soils.

Soil Fertility

When a previously forested land area is used for growing vegetables for the first time, the soil usually contains all the nutrient elements that the plant needs. However, as it is continuously used for producing a crop, the amount of nutrient elements decreases to levels which are not enough to support growth and development. Without the use of fertilizer, the yield is expected to decrease.

The nutrient elements in the soil, however, are not always immediately available. Hence, even if the total amount of nutrient elements in the soil is high, deficiency symptoms still occur. Nitrogen (N) is the most commonly lacking nutrient, followed by phosphorus and potassium; hence, they are the most common components of commercial fertilizers.

Elements Required by Plants

Plants require 16 nutrient elements, 13 of which come directly from the soil (mineral elements). Not all are required for all plants but all have been found to be essential to some, hence are termed as essential elements. Essential elements may either be required in large quantities (the macroelements) or in small amounts (microelements or trace elements).

The macroelements are nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium. The rest are microelements: boron, copper, chlorine, manganese, molybdenum, zinc, and iron. Carbon, hydrogen, and oxygen are obtained from CO_2 and water and are not mineral nutrients. The functions and deficiency symptoms of the macroelements are summarized in Table 3.7.

Nitrogen. An adequate supply of N is indicated by vigorous vegetative growth and deep green color. However, excessive quantities can prolong the growth period and delay crop maturity.

Nitrogen is a major component of proteins. Enzymes are protein bodies. The amount of nitrogen determines the amount of protein produced. The kind of protein is controlled by the genetic make up of the plant. Nitrogen is also a part of the chlorophyll molecule.

If the plant absorbed too much nitrogen, it would become too succulent. Nitrogen is absorbed mainly as nitrate but also as ammonium.

Phosphorus. Phosphorus (P) is involved in all the energy transformations as it is a component of adenosinetriphosphate (ATP) (See Chapter 2). It is also a component of other compounds involved in photosynthesis and respiration and is also present in cell membranes. Moreover, it is associated with early maturation and essential to seed formation, root growth, and disease resistance.

Potassium. Unlike nitrogen and other nutrient elements, potassium (K) does not form an integral part of such plant components as protoplasm, fats, and cellulose. Its function seems to be speeding or triggering in nature, yet it is essential to the growth and development of plants. Potassium is a mobile element which is translocated to young growing tissues when there is a shortage. Thus, the deficiency symptoms can be observed in the lower leaves first. However, yields may decrease even without visible symptoms (hidden hunger).

Lack of potassium is known to decrease plant resistance to certain diseases and the quality of some crops.

Potassium affects stomatal opening. It increases turgidity in plants and a reduction in turgidity is accompanied by a decrease in stomatal openings to conserve water. Stomatal opening is controlled by the inflow of potassium into the guard cells. It has been shown that closed stomates contain less potassium than those cells of the open stomates. Hence, uptake of CO_2 of potassium-deficient plants is less, consequently photosynthesis is lower.

Succulent vegetables like celery, lettuce, and cucumbers are of better quality when they are turgid. So,potassium which increases turgidity enhances the quality of these vegetables.

Calcium. The specific physiological functions of calcium (Ca) are not clearly defined but it is a component of the middle lamella of cells. Middle lamella cements cells together. It does not move once it is deposited in a plant part, so the leaves that are newly formed or are forming show symptoms first. In plants, like taro and amaranth, calcium is present as calcium oxalate.

Magnesium. Magnesium occupies the center of the chlorophyll molecule, hence it is very important in photosynthesis. It also activates many enzymes and is mobile, so lower leaves show the deficiency symptoms first.

Sulfur. Sulfur is a component of some amino acids which are the building units of proteins. The absence of such amino acids usually accounts for the low biological value of some legumes. It is related to the formation of oil as in soybean.

Table 3.7. Functions and deficiency symptoms of the major nutrient elements.

Nutrient Element	Function in Plants	Deficiency Symptom
N	Synthesis of proteins (including enzymes), chlorophyll, and chromosomes	Light green to yellow leaves starting with lower leaves, plants shorter than normal (Fig. 3.9)
P	Component of ATP and other reactants in photosynthesis and respiration, component of cell membrane	Leaves and stem turn purple, plants are shorter than normal (Fig. 3.9)
K	Important in carbohydrate and protein metabolism, activation of certain enzymes, promotion of growth of meristematic tissues, adjustment of stomatal movement and water relations	Yield may decrease without any visible symptoms, plants are shorter than normal; leaf margins turn brown in severe cases (Fig. 3.10)
Ca	Component of middle lamella associated with activity of certain enzymes	New leaves fail to come out or if they do, they do not unfold; they tend to stick to each other; apical roots also fail to develop; yellowing of the margins of younger leaves (Fig. 3.11)
Mg	Component of the chlorophyll molecule, necessary for activation of certain enzymes	Old leaves appear light green or yellow usually in between the veins (Fig. 3.12)
S	Component of some proteins and vitamins, activates certain enzyme required for N-fixation by leguminous plants	Plants appear uniformly yellow, light green, or thin-stemmed and spindly; plants are shorter than normal.

Microelements. Intensive cultivation of vegetable crops makes this group prone to deficiencies, not only of macroelements but also of microelements. While microelement deficiencies are relatively uncommon, their incidence if uncorrected, could severely reduce the yield and quality of vegetable crops. To help the grower in understanding the phenomenon of micronutrient deficiency, the functions of these elements and their deficiency symptoms are summarized in Table 3.8. Corrective procedures are described in Chapter 8.

Organic Matter

Organic matter represents the remains of plants and animals at various stages of decomposition. It improves drainage, aeration, nutrient - and water-holding capacities of the soil. It binds soil particles together into different sizes and forms (structure).

Organic matter also provides nutrients. It is especially a very good source of some micronutrients. However, the nutrients from organic matter are released slowly over time; so it is used to maintain or to improve good yield over a long period of time, but not to correct deficiencies.

Soils high in organic matter which are usually dark-colored are ideal for vegetable production. These soils, however, are not common.

When a soil is low in organic matter, it becomes hard and forms crusts during the summer months. In easily eroded areas (as in mountainsides) or in highly intensively cultivated areas (as in market gardens), the organic matter is easily depleted so it has to be replenished or replaced.

Soil Reaction

Soil reaction refers to the degree of acidity or alkalinity of a soil. It is measured in terms of pH. At pH 7, the soil is neither acidic nor alkaline (neutral). At pH less than 7, the soil is acidic in reaction; at pH more than 7, the soil is alkaline in reaction. The lower the pH, the more acidic is the soil; the higher the pH, the more alkaline is the soil. Specific soil classes according to pH are shown in Table 3.9.

A soil with pH 5 and pH 6 is, respectively, ten and hundred times less acidic than pH 4. Vegetables usually grow well in slightly acidic or slightly alkaline soil. Below this pH range, calcium may become less available. Above this pH range, iron and manganese may become less available. The pH range for optimum growth of certain vegetables is shown in Table 3.10. Methods of modifying the pH is discussed in Chapter 8.

Presence of Salts

Salt may be present in soils in quantities which vegetable crops may not tolerate. The salts may be soluble salts of ammonium, calcium, magnesium, potassium, or sodium. Such soils are called ***saline soils.*** Usually the salt is sodium chloride or sodium sulfate. Vegetables can be classified according to their salt sensitivity or tolerance (Table 3.11). Danger levels of salt concentration vary with soil texture. On sandy soils, 0.02% may cause damage to salt-sensitive plants; while a corresponding limit for heavy clay would be as high as 0.1%. Salt-tolerant crops are those that can tolerate 0.6% level. Table 3.12 shows the degree of soil salinity that causes 10%, 25%, or 50% decrease in yield. Beet is the most salt-tolerant among the vegetables listed but it is sensitive during germination.

Salt damage to plants which is expressed as low yield is due to excessive uptake of substances, such as chloride in toxic quantities. The symptom is the thickening and/or darkening of green tissue often with no wilting. On the other hand, a simple lack of water causes temporary or permanent wilting, reduction of the growth rate as shown by the

Table 3.8. Functions and deficiency symptoms of the micronutrient elements.

Nutrient Elements	Function in Plants	Deficiency Symptoms in Sensitive Plants
B	Cell division and development, cell wall stability, germination and growth of pollen, translocation of sugars	In cauliflower, young leaves turn yellow and tips turn brown; curd is loose and purplish-brown in color (Fig. 3.13); stem is hollow.
Cu	Synthesis or stability of chlorophyll, protein and carbohydrate metabolism, N-fixation	It is not usually a problem as the demand for Cu by plants is small.
Cl	Photosynthesis, water balance	It is not usually a problem as the presence of Cl in rain water is enough.
Fe	Chlorophyll synthesis, nitrate reduction, protein synthesis	In pepper, upper leaves turn light yellow to white with green veins. (Fig. 3.14)
Mn	Part of an enzyme complex involved in respiration, involved in the oxidation-reduction processes in photosynthesis	In peas, interveinal yellowing of leaves, formation of brown spot in the center of the seed ("marsh spot") make the pea unsuitable for food or seed. Small necrotic spots are seen on the leaves of pepper (Fig. 3.15)
Mo	Component of nitrogenase and nitrate reductase enzymes	In cauliflower. (Fig. 3.16) cupping of the leaves and interveinal chlorosis is followed by twisting and narrow elongation of the leaves ("whiptail" symptom).
Zn	Hormone synthesis, adjustment of oxidation and reduction	Deficiency of zinc is common. In field beans, leaf interveinal tissue is yellowish between green veins. Necrotic areas appear if deficiency is severe. In eggplant, leaves become mottled with interveinal chlorosis (Fig. 3.17)

Fig. 3.9. Comparison of normal (a), N-deficient (b), and P-deficient (c), pea plants.

Fig. 3.11. Young leaves of pea with yellow margins resulting from Ca deficiency.

Fig. 3.10. Cucumber leaf with brown margin resulting from K deficiency.

Fig. 3.12
Spinach with typical Mg deficiency symptom.

Fig. 3.13
Cauliflower with loose and brown curd resulting from Bo deficiency.

Fig. 3.14
Pepper leaves that turn light yellow with green veins resulting from Fe deficiency.

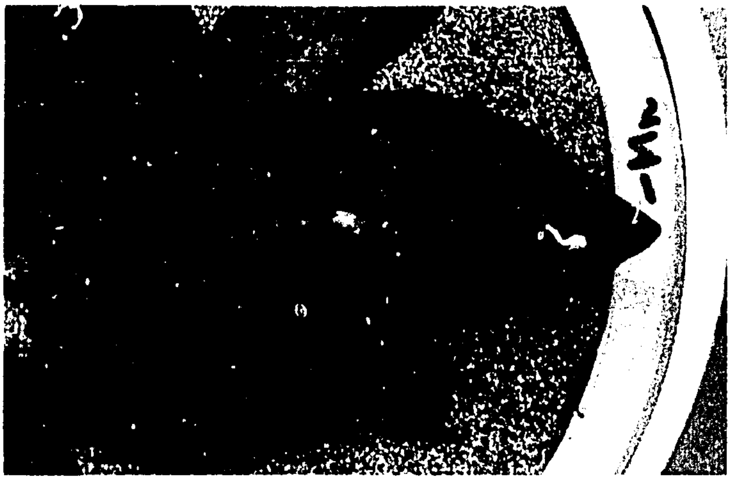

Fig. 3.15
Pepper leaves showing small necrotic spots that result from Mn deficiency.

Fig. 3.16
Normal (right) and Mo-deficient cauliflower (left) with "whiptail" symptom.

Fig. 3.17
Eggplant leaves with interveinal chlorosis and mottled appearance resulting from Zn deficiency.

Table 3.9. Soil classes according to pH.

Group	pH
Extremely acid	Below 4.5
Very strongly acid	4.5 - 5.0
Strongly acid	5.1 - 5.5
Medium acid	5.6 - 6.0
Slightly acid	6.1 - 6.5
Neutral	6.6 - 7.3
Slightly alkaline	7.4 - 7.8
Moderately alkaline	7.9 - 8.4
Strongly alkaline	8.5 - 9.0
Very strongly alkaline	9.1 +

Table 3.10. Kind of crops and their optimal range of pH.

Crop	Optimum Range	Crop	Optimum Range
Soybean	5.5-7.0	Cabbage	6.0-7.0
Hyacinth bean	5.5-6.7	Spinach	6.0-7.5
Snap bean	5.5-6.7	Eggplant	6.0-6.5
Peanut	5.3-6.6	Tomato	6.0-7.0
Sweet potato	5.5-7.0	Cucumber	5.5-7.0
Potato	5.0-6.5	Pumpkin	5.5-6.5
Radish	6.0 7.5	Strawberry	5.5-6.5
Turnip	5.5-7.0	Watermelon	5.5-6.5
Carrot	5.5-7.0	Lettuce	6.0-6.5
Taro	5.5-7.0	Cauliflower	5.5-7.0
Chinese cabbage	6.0-6.5	Asparagus	6.0-8.0

Table 3.11. Relative salt tolerance of vegetable crops.[a]

Relatively Nontolerant	Moderately Salt-Tolerant	Relatively Salt-Tolerant	Highly Salt-Tolerant
	EC range in micromhos/cm at 25°C		
200 - 400	400 - 600	600 - 800	800 - 1200
Lima bean	Tomato	Garden beet	Asparagus
Green bean	Broccoli	Kale	
Celery	Cabbage	Spinach	
	Pepper	Okra	
	Lettuce		
	Sweet corn		
	Onion		
	Pea		
	Watermelon		
	Cantaloupe		
	Squash		

[a]Adopted from USDA Agricultural Handbook 60. US Salinity Laboratory.

darkening of leaves, and sometimes formation of a thick, waxy coating on the leaf surface.

Increased salts in the soil water also reduce the amount of water available to plants, so crops grown in saline soils need more frequent irrigation than the same crops in normal soils.

Table 3.12. Percent yield decrease of selected vegetable crops due to soil salinity (the higher the number, the more tolerant is the crop to soil salinity).

Crop	Percent Yield Decrease 10%	25%	50%
	soil salinity (EC_e)[b]		
Beets *Beta vulgaris*	5.1	6.8	9.6
Broccoli *Brassica oleraceae*	3.9	5.5	8.2
Tomato *Lycopersicon lycopersicum*	3.5	5.0	7.6
Cucumber *Cucumis sativus*	3.3	4.4	6.3
Muskmelon *Cucumis melo*	3.6	5.7	9.1
Spinach *Spinacia oleraceae*	3.3	5.3	8.6
Potato, Irish *Solanum tuberosum*	2.5	3.8	5.9
Sweet corn *Zea mays* var. *saccharata*	2.5	3.8	5.9
Sweet potato *Ipomoea batatas*	2.4	3.8	6.0
Pepper bell *Capsicum annuum*	2.2	3.3	5.1
Lettuce *Lactuca sativa*	2.1	3.2	5.2
Onion *Allium cepa*	1.8	2.8	4.3
Carrot *Daucus carota*	1.7	2.8	4.6

[a]Adopted from Hartman 1988.

[b]EC_e means electrical conductivity of the saturation extract of the soil reported in mmhos/cm at 25°C. It measures degree of soil salinity. The higher the value, the more saline the soil. For crops that are sensitive to salinity at germination, e.g. garden beets and sugar beets, EC_e should not exceed 3 mmhos/cm.

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CHAPTER 4

Variety Development and Testing

Definition and Types of Varieties

A variety is a group of plants that share common qualities which are distinct from other groups of plants of the same species. Strictly, a variety must meet three criteria: ***distinctiveness, uniformity***, and ***reproducibility***. The latter means that the essential characteristics of the variety are maintained even with repeated seed increase. In popular usage, the term "variety" is used interchangeably with the more accurate term "cultivar" (which means cultivated variety, to differentiate it from botanical variety).

A distinction is often made between ***traditional*** and ***improved varieties***. Traditional varieties are those that have been used by many generations of farmers. They usually started as a farmer's selection, then reproduced and maintained by the farmers themselves. Some traditional cultivars, particularly those that have been used for hundreds of years, are so variable that they could not satisfy the rigid criteria. These are technically called ***land races***.

Improved varieties, on the other hand, result from systematic plant breeding work and seed multiplication usually by trained personnel. Many commercial seeds are those of improved varieties which usually, but not always, pass the criteria of a variety. The seed quality of an improved variety depends on the skill of the plant breeders who develop them and the seed producers who multiply them. In many instances, these are two independent groups.

Among seed-propagated crops, traditional varieties are seed-produced by natural pollination through successive generations; hence, they are described as ***open-pollinated varieties*** (OP). Many improved varieties of vegetable crops also fall in the same category. Another type of improved variety, ***hybrids***, have been increasingly used worldwide in recent years. An indication of this is the listing of varieties offered for sale by various seed companies (Table 4.1). In Japan, according to Takayanagi (1984), the percentages of hybrid varieties in cabbage, Chinese cabbage, and radish productions were 94%, 91%, and 37%, respectively. In the Philippines, the percentages of hybrid varieties in cabbage, Chinese cabbage, and bulb onion productions were 18%, 27%, and 20%, respectively (Mabesa 198[illegible]).

Hybrids are varieties that result from controlled pollination involving two (F_1 hybrid), three (three-way cross), or four (four-way or double cross) parental lines. Most of the commercial hybrids of vegetable crops are F_1 hybrids. Commercial F_1 hybrids are preferred by some growers because they produce vigorous seedlings which are easy to establish in the field and they are highly uniform which makes management easier. These traits are common to many hybrids and can be used to distinguish a hybrid from an open-pollinated variety.

Among vegetatively-propagated crops (e.g., garlic, shallot, sweet potato, and potato) varieties are ***clones*** — the progeny of one plant propagated without passing through the sexual phase. These are uniform and stable. In rare cases, such as in white potato, a crop that is normally propagated by vegetative means may also be propagated commercially by seed (open-pollinated or hybrid). Thus, in the same crop, there may be clonal, as well as open-pollinated and hybrid varieties.

Table 4.1. Number of cultivars of vegetable crops (by category) listed in 18 commercial seed catalogs from seven countries.[a]

Crop	No. of Cultivars		% Hybrid
	OP	Hybrid	
Solanaceous vegetables			
Tomato			
Fresh market	142	151	52
Processing	45	14	24
Pepper			
Sweet	72	61	46
Hot	45	13	22
Crucifers			
Cabbage	66	170	72
Chinese cabbage	6	50	89
Radish	35	32	48
Cucurbits			
Watermelon	109	87	44
Melon	102	72	41
Slicing cucumber	49	76	61
Pickling cucumber	38	61	62
Squash	32	26	45
Bulb onion	102	114	53
Total	843	927	52

[a]1986 data.

The above description of types of vegetable varieties does not indicate which type is superior. In fact, only variety tests to be discussed later in this chapter, can lead to this judgment. Improved varieties are not always better than traditional varieties, and hybrids are not necessarily better than open-pollinated varieties.

Strains

In the seed trade, there may be several 'strains' of the same variety, with minor differences but possessing the same basic qualities identified with that variety. Strains develop in old open-pollinated varieties when these are subjected to selection under different conditions. Prominent examples of varieties with strain differences having been demonstrated are Red Creole variety of onion, California Wonder variety of bell pepper, and Grand Rapids variety of lettuce.

There is no clear criterion to determine how much difference should be demonstrated to merit the designation of "strain" nor in deciding if a variety is sufficiently similar to another to merit being given the same name. For marketing considerations, commercial seed may have exactly the same name (usually a popular type) but may be very different from each other in economically important traits. This point is illustrated in the case of the Grand Rapids variety of lettuce. Awareness of strain differences is of crucial importance to commercial growers who are unwilling to shift to new varieties, either because these are not available or the market preference for the established variety is so specific that it may be too risky to try an entirely new variety.

Even among commercial F_1 hybrids, farmers sometimes complain that the hybrid they used to plant several years ago have apparently changed. The difference may be imagined or real, but the farmer has no way of checking unless he has saved remnant seeds. It is possible that the parental lines changed over many generations of maintenance, and the change is translated into differences in hybrid performance. All these complications suggest the continuing need of sensitivity to differences, not only between varieties, but also within varieties.

Origin of Varieties

Varieties are developed through a process called ***plant breeding*** which is defined as the science and art of genetically improving plants for the benefit of man. It is an art because it involves the selection of plants which conforms to a desired ideal in the mind of the plant breeder. Like a painting, a desired plant is first drawn in the mind of the breeder, then translated to reality through skillful application of scientific principles.

As a science, plant breeding depends on the principles of genetics to explain how traits are transmitted from parents to offsprings. Modern plant breeding also relies on the scientific disciplines of plant physiology, pathology, entomology, biochemistry, statistics, biotechnology, and others which provide the breeder with a deeper understanding of his work and the tools to make his work easier and faster.

Plant breeding is also regarded as controlled plant evolution, hastened and directed by man to benefit himself. Without man's intervention, the plant would evolve to benefit itself, resulting in the development of traits that have limited value to man. Thus, traditional varieties, most of which developed through the forces of natural selection, tend to be variable, vegetative, and late maturing. They also tend to be seedy. These traits are needed for the survival of the plant under natural selection pressures.

Improved varieties tend to have a high proportion of edible to nonedible plant parts (harvest index), short growing period, and less seedy fruits. These traits make it easier and more profitable for the farmer to grow the crop commercially. However, these traits may not allow the plant to survive natural environmental pressures. Improved varieties are meant to be cultured — they rarely survive on their own.

On the other hand, most traditional varieties easily adapt to their native environment. They usually give a reliable performance with little help from the farmer, but their yields feed only the farmer and a few other people In short, they are ideal for a primitive situation of subsistence farming but inadequate for a modern society that requires its farmers to feed hundreds of other people who are engaged in nonfarming pursuits.

Characteristics of Improved Varieties

The objective of plant breeding is to create a variety which conforms to the concepts established by the plant breeder himself based on prevailing farm and market standards. To be accepted by farmers, the new variety must satisfy their preferences, as well as those of the traders (who buy the farmers' produce), and ultimately those of the consumers (who buy from the traders).

In some cases, the plant breeder may create a variety which is totally new and unfamiliar to his clientele. This is a gamble and does not guarantee success. However. there are sufficient cases of varieties developed through plant breeding that were quickly adopted because they showed overwhelming advantages over traditional varieties. Prominent examples are 1) determinate tomatoes which replaced indeterminate tomatoes, and 2) white spine cucumber which eventually replaced the black spine types after some resistance from the consumers. On the other hand, there are also examples of failures, such as the effort to popularize the high Vitamin A tomatoes, which did not gain consumer support because the fruits were yellow.

The pressure of modern society to produce more high quality foods by less farmers has guided the plant breeder in developing new varieties of food crops. Plant traits that have been modified or changed in the process are productivity, adaptability, stability or reliability of performance, and quality.

Productivity

One of the most remarkable achievements of the modern plant breeder is the improvement of crop productivity. Yields per unit area per unit time, and per unit fertilizer were increased with the development of varieties with high yield potential, early maturity, improved plant architecture, and high harvest index. The new varieties of processing tomato which are early-maturing, highly determinate, and capable of yielding 140 t/ha or more illustrate the achievement. In the case of leguminous vegetables, such as yard-long beans, the requirement for nitrogen fertilizer was reduced with the use of varieties having improved N-fixing ability.

Adaptability

Normally, plant species have their own environmental confines within which they are adapted. Thus, cabbages and potato which evolved under cool climates are generally unadapted to a warm climate. In the tropics, these crops are traditionally grown only in the cool highlands. Tomatoes which originated from cool and dry climates would not be profitable to grow in the warm and humid tropical environment. It has been difficult to expand production of these crops outside the limits of their environment.

The situation, however, has changed considerably in recent years because varieties with wide adaptation were developed by plant breeders. In cabbage, production areas have been shifting gradually to the warm lowlands, which can now grow cabbages throughout the year using heat-tolerant varieties. Tomatoes can now be grown successfully in the lowland tropics even during the warmest and wettest part of the year with the use of improved varieties.

Reliability

Another important accomplishment of plant breeders is in ensuring that, year after year, crops would perform reliably. To achieve this, plant breeders develop varieties which possess stress resistance and tolerance. Drought tolerance, for example, reduces the adverse effects of abnormally dry conditions in some years. Resistance to diseases prevents total crop loss during epidemics. Genetic resistance to pests also provides an effective alternative to the widespread use of chemical pesticides. Chemical pesticides are not only expensive but also damaging to the environment. Moreover, genetic resistance is the only effective way to control some diseases, such as bacterial wilt caused by *Pseudomonas solanacearum.*

Quality

In vegetable crops, quality is the most important factor that determines acceptance of a variety. New varieties, to be successful, must conform to the prevailaing market standard. The farmer may be keen on productivity, adaptability, and stability of performance; but the consumer, the ultimate judge, does not even get to see the crop and buys the product, whether or not it comes from a low-yielding, sickly, unadapted plant. Thus, a vegetable breeder treats quality ahead of other plant traits.

Considerable breeding gains have been achieved in the color and firmness of tomato, sweetness of sweet corn, dry matter of onion, nonbitter flavor of cucumber, seedlessness of watermelon, and many others.

Special Traits

With increasing mechanization in agriculture, plant breeders and engineers have joined hands to make the new cultivars and the new agricultural machines complement each other. In highly developed countries many vegetable crops, including tomatoes and potatoes, are already harvested by machines. In processing tomatoes, machine harvesting is possible because of the development of varieties with the following traits: concentrated fruit set and ripening, compact growth habit, and firm fruits.

In cucumbers and tomatoes, cultivars with restricted vine types (dwarf) were developed specifically for home gardens. Many seed catalogs have special sections on home garden varieties.

The Plant Breeding Process

Variability: The Raw Material in Plant Breeding

Like a painter who needs different colors to create a work of art, a plant breeder needs differences (variability) in his subject plant to create a new variety. If all tomatoes were identical, a plant breeder cannot create a new variety of tomato.

Fortunately for the plant breeder, all plant species with few exceptions have variability. Thus, in tomatoes there are tall and dwarf types, small- and big-fruited types, and many other kinds of differences in fruit character (Fig. 4.1). There are sufficient raw materials for plant breeding. A typical plant breeding job might, for instance, consist of developing a new variety of tomato which is dwarf and large-fruited. Using two varieties (one tall and large-fruited, the other dwarf and small-fruited) as starting materials, the plant breeder would cross these varieties to create new combinations of traits which may not have existed before.

The process by which variability is manipulated to create and choose new desirable combinations is the essence of plant breeding. The key to the whole process is the breeder's ability to spot differences. The application of this ability is called ***selection***. A plant breeder must be able to tell the real differences among plants of the same species.

Types and Causes of Variability

Differences among individuals may have various causes. Not all types are useful, however, for plant breeding. The appearance of an individual (phenotype) results from the influence of its genetic constitution (genotype), from the effects of the immediate environment where the individual lives, and the combined effects (interaction) of these two factors.

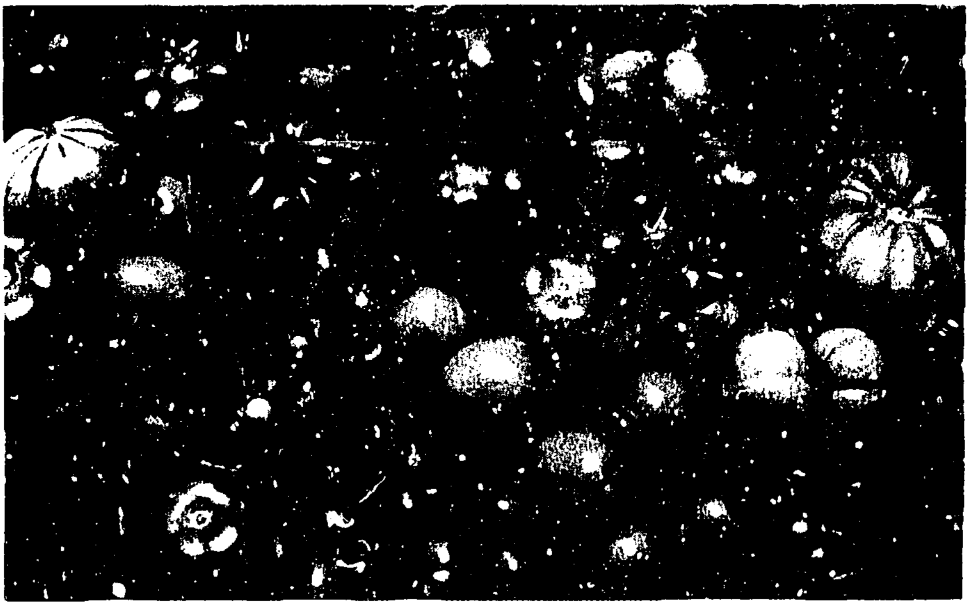

Fig. 4.1. Variability of fruits in tomato.

If P symbolically represents the phenotype, G the genotype, E the environment, and I the interaction of G and E, we can express the above relationship in a simple equation as:

$$P = G + E + I$$

Based on this relationship, the size of a tomato plant may be determined by its genetic constitution which is inherent to the particular variety of tomato, the level of fertilizer applied during its cultivation, and the combined effects of fertilizer and variety. Some varieties are more easily affected by fertilizer than others.

Contrary to some beliefs, the effects due to environment are not transmitted to the offspring. This was clearly demonstrated in the classic experiment where mice whose tails were cut with a knife (environment) produced offsprings with tails. On the other hand, the genetic constitution of the individual is passed to its offspring, through physical units in the sperm or egg cells called ***genes***, during the reproductive process.

Among a population of plants, variability is caused by both environmental and genetic factors. However, only the variations caused by the latter are useful in breeding because this is the only component of variability that could be imparted to the succeeding generation. The environmental effects, on the other hand, are only temporary in nature as in the case of the experiment on cutting the mouse's tail.

From the given equation, it is clear that if the environmental effect is zero, the interaction I is also zero and P is equal to G, i.e., the appearance of an individual reflects its true genetic value. To further explain this, visualize a situation where a plant breeder is looking at two adjacent plants in the field, one of which is taller than the other. Assuming that the two plants are genetically identical (that is, G is zero in the above equation) and that the height difference was mainly due to the high soil fertility where the taller plant stands, then any selection for tall or short stature will be ineffective since the difference between the two individuals was due entirely to the environment. The effect of high soil fertility on plant height is only true in the present generation. Seeds harvested from the two plants will produce a new generation of plants with similar heights, on the average, if planted under exactly similar conditions.

Genetic variation may also be classified according to the extent of its effects on the individual. When the differences among individuals are very large and easily perceived, the variation may be classified as ***qualitative***. Traits exhibiting this type of variation are not highly masked by environment (the E effect in the previous equation is low or zero). Examples of this type of variation are the differences in spine color on the fruits of cucumber (which may be black or white) and seed shape in peas (which may be round or wrinkled).

Differences among individuals may be small and there are many intermediate types. This type of variation is classified as ***quantitative***. Variations in yield, maturity, and seed size are examples of quantitative variation. In the case of yield, levels such as 1.0, 1.2, 1.21, or 1.217 t/ha and intermediate readings are possible, depending on the accuracy of yield-measuring instruments. In contrast to qualitative variation, quantitative variation is highly influenced by the environment, and therefore, selection for quantitative traits is normally very difficult.

Sources of Genetic Variability

Genetic variability may be naturally occurring or artificially generated. The naturally occurring variation, especially evident on land races, originates from the following processes: ***spontaneous mutation, admixtures***, and ***outcrossing***. Artificially produced genetic variation comes from human-mediated hybridization and from artificially induced mutation. These processes are further described below.

Mutations are sudden heritable changes which occur naturally (spontaneous mutation) or because of artificially applied physical and/or chemical factors, known as mutagens, which change the genetic constitution of the individual (induced mutation). The causal factor(s) for spontaneous mutation is not known. Induced mutation can be effected by radioactive rays, such as X-ray and gamma rays; or by chemical mutagens, such as ethyl-methyl-sulfonate (EMS).

The changes resulting from mutation may be easily perceptible, thus they are called ***macromutations*** (e.g. changes in flower color); or inconspicuous, thus they are called ***micromutations*** (e.g., changes in quantitative characters). Spontaneous mutations occur infrequently but over time, these changes may accumulate in natural plant populations and contribute significantly to genetic changes. The selection of desirable mutations from the accumulated spontaneous changes greatly helped man to domesticate plant species from the wild.

Physical admixtures, such as when seed of variety A is accidentally mixed with variety B, may become a source of genetic variability in variety B if variety A's genes are integrated into variety B by outcrossing. Even without outcrossing, the physical mixture per se of varieties A and B is itself a form of variability. Strictly, the mixture can neither be called variety A nor B.

Outcrossing occurs when a group of plants, such as in a variety, is pollinated by another distinct group by wind, insects, or other natural agents of cross-pollination. Outcrossing is a very powerful mechanism for generating natural variation and offers plant species capable of it with a system to constantly adjust to the ever-changing environments. Indeed, many natural populations, even of species with perfect flowers, are capable of outcrossing. Apparently, the individuals that do not have this ability and do not mutate fast enough in the right direction, become extinct when the environment becomes too harsh for their native ability to cope with.

Nature's way of creating variability may be too slow and inappropriate for man's needs; thus, the plant breeder usually has to resort to artificial ways of producing it. This is done through artificial hybridization or induced mutation. Artificial hybridization is the crossing of two or more parents, often chosen for carrying desirable characters, in order to generate variation from which desirable progenies may be selected. This purposeful or planned hybridization dominates the modern-day breeding of agricultural crops. In contrast to natural outcrossing which is fairly random, artificial hybridization is controlled.

Managing Variability: Development of Open-Pollinated Varieties

Plant breeding is a long and tedious process, most of which is spent in ***selection***, a process of searching for the desired type in a variable population of plants. Selection can be as simple as looking for a pure black seed in a pile of multicolored seeds, or as sophisticated as isolating a cell line resistant to salinity stress in a callus culture previously subjected to mutagenesis. The principle in both cases is the same, only the technique varies. The selection methodology may be elegant; but, in vegetable breeding, it always eventually ends up in the research farm with the plant breeder walking through the rows of crops, looking for the plant that meets his breeding objective.

The method of selection may vary according to three categories of crops: 1) seed-propagated, self-pollinating crops, 2) seed-propagated, cross-pollinating crops, and 3) vegetatively propagated crops. The method of selection is also influenced by the nature of variation: whether it is naturally existing or artificially generated.

The common vegetable crops are listed below by category:

- Seed-propagated, self-pollinating crops

Tomato	Yard-long bean	Garden pea
Eggplant	Cowpea	Lettuce
Capsicum pepper	Common beans	Mustard

- Seed-propagated, cross-pollinating crops

Cabbage	Radish	Squash
Chinese cabbage	Pak-Choi	Luffa gourd
Cauliflower	Watermelon	Bottle gourd
Broccoli	Cantaloupe	Bitter gourd
Kale	Cucumber	Onion

- Vegetatively-propagated crops

Garlic	Ginger
Shallots	White potato

Since this chapter is only an introductory topic designed to give an overview of plant breeding, this section will emphasize the selection process only in self-pollinated crops. Further information on the other crops may be obtained from Allard (1960). The technique for self-pollinated crops may apply equally to cross-pollinated ones, if these are artificially self-pollinated in the selection process.

Many of the crops listed under the self-pollinating category also undergo a fairly high degree of natural cross-pollination in certain environments; thus, some plant breeders find it necessary to subject them also to artificial self-pollination.

Selection from naturally existing variation. Individuals belonging to the old ***land races***[1] of self-pollinated crops tend to be a mixture of pure lines resulting from many generations of self-fertilization[1]. Technically, a ***pure line*** is defined as "the progeny of a single, homozygous, self-fertilized individual". Because the pure line is homozygous[2], its progenies remain true-to-type and uniform. Genetic variation among the progenies of a pure line is practically absent. Therefore, any measurable within-line variation is largely due to the effects of the environment. Selection within a pure line is ineffective and should not be practiced.

In a land race, genetic variation exists between individuals, each of which is likely a pure line, having arisen from a homozygous parent in the previous generation. Selection from within this mixture of pure lines is effective. Two methods of selection are possible to improve the old land races: ***mass-selection*** and ***pure line selection***.

Whenever land races of a crop are still in use, the first step in improving them is through mass-selection. In its simplest form, mass-selection is done by roguing or weeding out the off-types and bulking or gathering the seeds to be used from the remaining individuals. The process is also called ***negative mass-selection*** (Fig. 4.2). The resulting bulked seed lot is devoid of inferior types, but the variability of the population, which probably contributed to its stable performance, is kept intact.

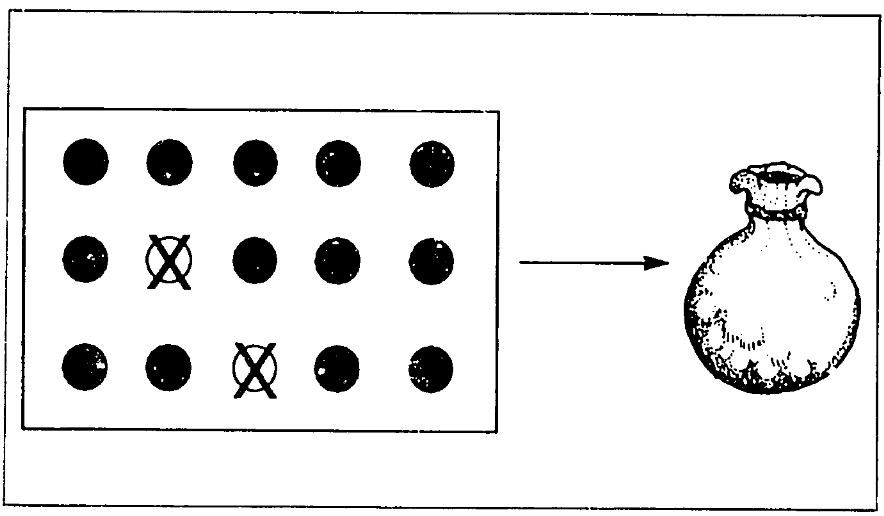

Fig. 4.2. Negative mass selection. Off types (o) are rouged out of the field and seeds from remaining plants are bulked.

[1] Land races of crops have three unique features. They have been grown in an area for a long time, often going back to hundred of years; they are a mixture of various types, and they are well-adapted to the area. In self-pollinated crops, the individuals composing the mixture will be mostly homozygous.

[2] The term "homozygous" refers to a genetic condition in which the two alleles (in the case of diploid species) are not contrasting. For example, given the simplest case of a single gene, designated as gene *A*, controlling a character, the homozygous conditions would be ***AA*** and ***aa*** as contrasted to the heterozygous condition, ***Aa***. Upon self-fertilization, ***AA*** and ***aa*** will remain true-to-type; whereas, **Aa** will give progenies which are either ***AA***, ***Aa*** and ***aa***. In other words, ***Aa*** will segregate in the following generation.

Positive mass-selection is a more powerful method for improving a land race (Fig. 4.3). However, it is more laborious than negative mass-selection. It is commonly practiced by modern-day seedmen to preserve the characteristics of established varieties of cross-pollinated crops. The technique not only improves cross-pollinated crops but may even lead to a new strain.

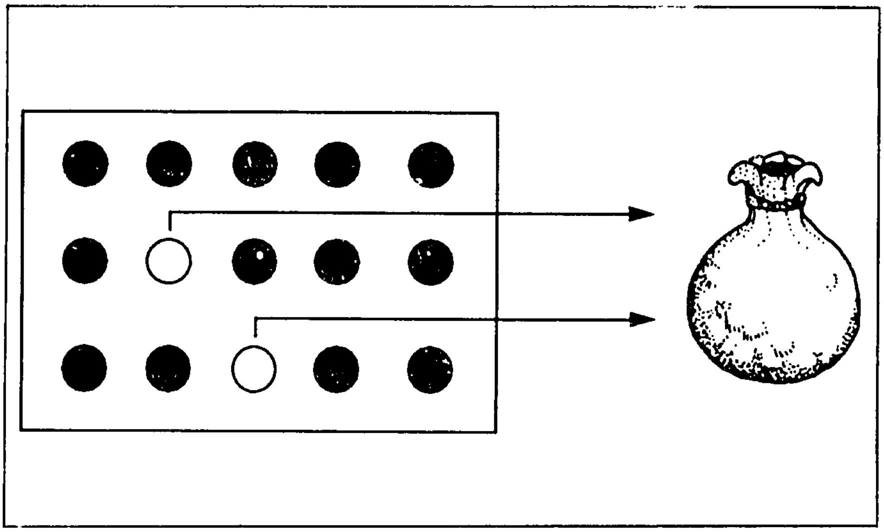

Fig. 4.3. Positive mass selection. Superior plants (o) serve as the source of bulked seed for the next generation.

For cross-pollinated crops that lose vigor when seeds are produced through pollination of closely related parents (such as crops belonging to the *Brassica* family), it is important that at least 50 plants are selected for the traits that typify the variety. This practice improves the chance that seeds in subsequent generations are produced through the mating of unrelated plants. This requirement means that a minimum population size for selection purposes should always be more than 50. It also means that selection can be more strict as the number of plants to select from is increased. A high percentage of selection indicates that the population subjected to selection is fairly uniform, or that the selection process is not very rigid. Selected plants are harvested in bulk.

Further improvement of a land race variety may be achieved through pure line selection (Fig. 4.4). In this case, a new type may arise by selecting a uniquely different individual (likely a pure line) within the land race. For example, the selected pure line may be earlier maturing, more uniform, and higher yielding than the source variety itself. This outstanding pure line may then be released as a new variety.

In practice, pure line selection is carried out by selecting from the source variety a number of distinct and desirable individuals. The number of individuals to select depends upon the extent of usable variability within the source population. It may range from a few to several hundred selections. These are then harvested individually and planted in separate rows for observation and further selection. A series of tests for yield, quality, or other appropriate selection parameters may be conducted by the plant breeder before an outstanding pure line may be ready for release as a new variety.

In contrast to mass-selection, pure line selection includes selection through progeny test. This makes it possible to discover small differences of characters which become more apparent between progenies than between individual plants in the field.

Selection from artificially generated variation. Selection from artificially generated variation in a self-pollinating crop is not drastically different from selection from naturally existing variation. As a matter of fact, if the variable population arising from controlled hybridization or from other means of generating variability is brought to a high level of homozygosity through several selfing generations (that is, most individuals are practically pure lines), the schemes for selecting the outstanding pure lines are equivalent. This is evident especially if the ***bulked method*** is used to manage the variability created by hybridization (see below for details of this method).

The ultimate goal of selection in self-pollinated crops, regardless of the source of variation (natural or artificial), is the selection of superior pure lines. Mass-selection is rarely, if ever applied in developing new varieties from artificially generated variation.

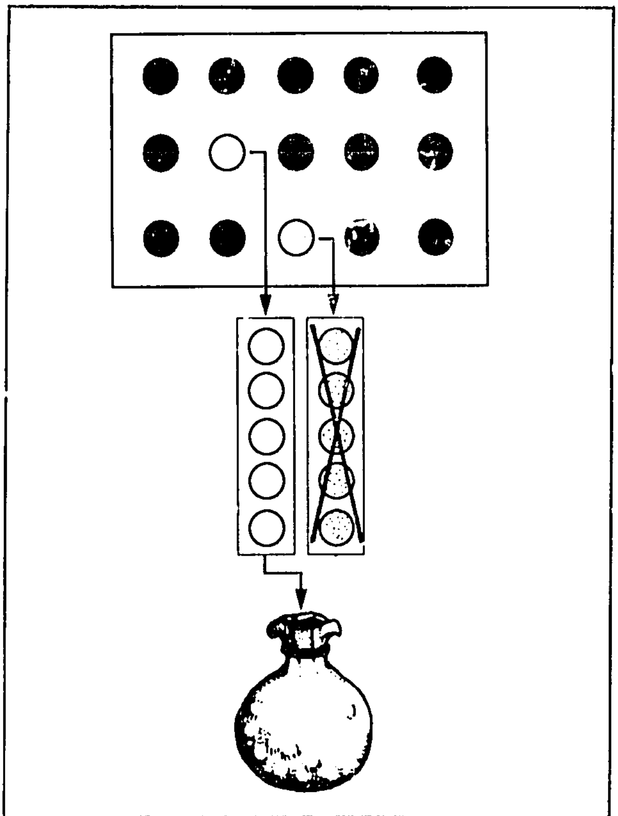

Fig. 4.4. Pure line section. Selected plants (o and • are harvested individually and planted in separate rows for observation and further selection. Seeds of the selected line (o) are bulked.

Natural populations differ from artificially generated variation in the way their inherent variability is managed. In natural populations, variations from chance outcrossing and spontaneous mutations are continually sampled, generation after generation, by natural selection to preserve individuals that are adapted to the environment.

In the case of genetic variation artificially created for breeding purposes, the plant breeder applies the selection pressure to drive the population towards the desired types. In this process, the plant breeder applies two basic techniques to bring the variable population to a sufficient level of homozygosity before the best pure lines are finally selected.

The first and the simplest technique is the ***bulk method***. In this method, the variable population that arose from a planned cross is grown generation after generation en masse before individual plants (pure lines) are selected. The number of bulking generations depends upon the nature of the cross or upon the plant breeder.

Some breeders prefer to start single-plant selection as early as five selfing generations after the original cross; whereas, others prefer to wait until the seventh or eighth generation of selfing when individuals in the population are at a higher level of homozygosity. If the parent stocks used in hybridization are not widely different, the number of bulking generations could be less.

Without selection by the plant breeder, only natural selection acts upon the bulked population to weed out the weak individuals. For example, susceptible tomato plants may not survive if planted in a field with a high natural population of virulent bacterial wilt pathogens. Sometimes, however, the plant breeder may choose to apply negative selection in each generation. This procedure is called ***modified bulk*** or ***modified mass method***.

The other system of handling hybrid populations is through the ***pedigree*** method. As the name implies, it involves keeping a record of the line of descent of all individuals and lines in the population. In addition to pedigree record, relevant notes on each selected individual or line are kept for use in further selection. These may be notes on vigor, disease resistance, apparent quality, general performance, and other information that may not be obvious from measured data taken on the line, if any. Both the pedigree record and the cumulative notes are important when deciding which lines to keep for final evaluation.

In the pedigree method, the changing genetic structure of the hybrid population in self-pollinated crops dictates the selection approach to be applied by the plant breeder. The maximum range of genetic variation for the cross is expressed in the first segregating generation (usually termed as the F_2). With further selfing, there is a rapid approach to uniformity among the progenies of each selection (genetically, this is due to the increase in the level of homozygosity): differences are more accentuated, however, between lines or families. In the pedigree method, the plant breeder emphasizes, therefore, the selection of superior single plants in the early generation and outstanding lines or families in the later generations.

Hybrid Variety Development

The process of developing hybrid varieties differs from that of developing open-pollinated varieties in the following manner:

- Regardless of mode of natural pollination, ***all*** selected plants are self-pollinated (by artificial means if necessary) and evaluated in progeny rows as in pure line selection, until they reach a high level of homozygosity. The final product of this process is called the ***inbred line***. Genetically, it is the equivalent of a ***pure line***. However, the inbred line is not intended as a variety by itself but only an intermediate step.
- The inbred lines are tested for ***combining ability***, that is, the ability to give an acceptable progeny in a hybrid combination with other inbred lines. The combination with the best performance becomes the candidate for commercial hybrid variety.

These two steps constitute an added cost to variety development and partly explain why hybrid seed is always more expensive than open-pollinated seed. In addition, hybrid seed production is more expensive. This is best illustrated in the case of hybrid tomato seed production which involves the following added costs (in comparison with production of open-pollinated seed):

- The "male" (plants used as pollen source) to "female" (plants used as seed source) ratio is 1:6; this means that one out of every 7 ha in hybrid seed production is nonproductive,

- One hectare of hybrid seed production requires 40-60 workers for 30 days to do the manual pollination work. These workers are not needed in production of seed of open-pollinated varieties.
- The need for constant movement of pollinators in the hybrid seed production field requires a reduction of plant population. This results in lower seed yield per unit area.

The superior characters of F_1 hybrid plants, unlike that of open-pollinated varieties, cannot be maintained by saving their seeds for growing the next crop. The uniformity, vigor, and overall performance of the hybrid is lost during seed multiplication. Therefore, growers need to buy seeds from the seed producer every time they want to plant. The seed producer maintains the inbred lines and controls the seed production of the hybrid seed.

Variety Evaluation for Farmer Adoption

A farmer who wants to grow a good variety will have a hard time choosing from the large number of varieties available. As mentioned in the early part of this chapter, there are hundreds of varieties for every crop worldwide. Counting the possibility of strains, the number increases even more. Only one of these is best-suited to the farmers' needs and conditions. This section describes the process by which the choice of variety or strain can be made methodically.

Sources of Varieties

The closest sources of varieties for testing are the farmers who have used these themselves. Some of them produce their own seeds. The farmers are also excellent sources of information about the characteristics of varieties that they are using.

Secondly, it is likely that there are several local seed traders. In developing countries, commercial seeds are usually imported. A few traders may sell locally produced seeds, but in some cases these are not identified by variety name. Many traders sell seeds but cannot give accurate information on the performance of varieties that they are selling. Information about varietal characteristics of commercial seeds can be obtained directly from the seed company that developed the varieties. This is in the form of leaflets or seed catalogs and are given free. It will help farmers select the varieties they want to use or evaluate. Reputable seed companies have trained technical staff who can provide information about the adaptation and performance of their varieties. In addition to providing information about variety performance, many seed companies also give free seeds for trial purposes upon request.

Another source of varieties for testing is government institutions, such as universities and the Department of Agriculture, which are involved in variety development. Promising breeding lines may be obtained from these institutions and evaluation can be done with their cooperation. These institutions usually provide a comprehensive description of their varieties.

Lastly, international agricultural research centers such as the Asian Vegetable Research and Development Center (AVRDC), have both germplasm and advanced breeding lines that are distributed free for evaluation. Annual reports, newsletters, technical bulletins, and other publications describe the availability of such seeds from these centers.

It is not advisable for untrained personnel to import seeds indiscriminately, as these are potential carriers of pests. All importations must pass the local quarantine service as required by law.

Types of Variety Tests

Variety tests are done for several reasons. Plant breeder performs these routinely to evaluate materials that may be useful in his breeding work or to compare his advanced lines with commercial varieties preparatory to release. Government research institutions and extension workers perform variety tests to obtain information necessary for making variety recommendations to farmers. The farmer himself must do it, because the final decision about varieties is his. He is also the one who will suffer the consequences.

There are two main categories of variety tests: ***on-station*** and ***on-farm***. The former, as the name suggests, is performed in an experiment station and supervised by technical personnel. The latter may or may not be supervised by technical personnel and usually involves only one or two new varieties. Ideally, the elite varieties coming out of the on-station trial (nearest station) should be tested in the on-farm trial.

Procedure for On-Station Trial

Selection of varieties to be evaluated. The chance for success in a variety trial is determined by the choice of varieties to be included in the trial. There is always the temptation to try every variety that a researcher can get hold of. The choice of trial entries must be based strictly on the objective of the trial. For example, if the purpose is to identify heat-tolerant tomatoes with bacterial wilt resistance, it is necessary to look for these characters in the variety description.

If there are no descriptions, one should inquire from the source of the variety, who should be able to provide information. This will reduce the number of trial entries considerably because there are very few varieties that possess a combination of heat tolerance and bacterial wilt resistance. There are also many types of tomatoes: determinate and indeterminate growth habits, for fresh market, for processing, etc. In the same manner, the researcher must be aware of the distinction between long-day and short-day onion, pickling and slicing cucumber, muskmelon and cantaloupe, summer and winter squashes, etc.

A researcher who knows exactly what type of variety he wants is likely to succeed. It is much better to test ten varieties that are known to possess the desired characters than to test 100 varieties picked at random. In any case, only a maximum of 20 varieties should be included in routine variety evaluation where yield measurement is important. At least, one (or more) of the entries, should be a popular local variety of the type being tested.

Selection of trial environment. The most important consideration in choosing the trial environment is that this should be representative of the conditions under which the variety will be used. Prevailing temperature, rainfall, photoperiod, soil type, and cropping pattern must be as close as possible to the conditions under which the variety will be used. Very few varieties have wide adaptation; but all varieties, if grown in the environment for which they are bred, should perform well. It is not recommended to test for wide adaptation, i.e., testing for both dry and wet seasons in the tropics if the variety will be used only for the dry season.

In the same manner, it is not recommended to test under upland soil conditions if the variety will be used in a postrice paddy-field environment. Determining the range of adaptation of a given variety, such as that obtained in a multilocation, multiseason trial is a good academic exercise; but its practical value is very limited. Improperly interpreted, it can also lead to mistakes in judging the variety's worth. If at all, a multilocation, multiseason trial must be done within the range of conditions under which the crop is actually being grown or may be potentially grown.

Principles of variety trials. The simplest way to compare varieties is to plant them side by side, one row of each variety, in the same field at the same time. This simple trial is adequate for the purpose of observing qualitative traits such as plant type, fruit color, or sex expression. However, a lot of information on qualitative traits can be obtained even without performing a trial, simply by looking at catalogs or interviewing farmers. Thus, the more important objective of a variety trial is to observe genetic differences in quantitative traits, such as yield. However, observed differences in field trials are not entirely due to genetic differences. As discussed earlier in this chapter, these traits result from genetic as well as environmental influences.

Differences in growing conditions may alter the relative performance of varieties, making it difficult to measure genetic differences. If the growing condition for one variety is better than that of other varieties, then it is not possible to conclude that this variety is genetically better even if the observations indicate so. The variety in question may, in fact, be genetically inferior; but its performance is simply boosted by the favorable environment in which it is grown.

For example, if variety A is given fertilizers and variety B is not, then the superior performance of A over B can simply be a fertilizer effect rather than the genetic superiority of A over B. To avoid this complication, a number of principles must be observed in conducting variety trials.

1. **Treat all varieties uniformly.** This refers to the whole range of conditions, other than the genetic qualities, that affect the crop. The more important of these are the following:

- Seed quality – Ideally, the seed must be of comparable high quality. Physical seed mixtures and seed-borne diseases must be avoided. The physiological age of the seeds must be approximately similar. Seed treatments, if used at all, must be applied to all varieties under test.
- Management practices — From sowing to harvesting, the varieties must receive exactly the same management input. Sowing must be done in the same soil mix, in the same nursery facility, and on the same day. Water, fertilizers, and pesticide treatments must be exactly similar. The trial field must have uniform fertility, water supply, and other biological and physical factors that can potentially affect the performance of the crop. Harvesting must be done on the same maturity index.
- Competition between adjacent varieties — If one variety produces a big canopy, it may adversely affect the performance of the next variety by shading. To avoid this and other competition effects, multiple-row plots may be used, discarding outer rows.

The first principle of variety trial, to treat all varieties uniformly, is the single most important principle to observe. However, it is often violated, because of factors beyond the control of the researcher. For example, it is almost impossible to find two spots in the same field that are exactly similar in fertility. Between two adjacent varieties, one may be so susceptible to diseases that it is unable to survive to maturity. In this case, its adjacent variety, if resistant, may have the advantage of more space and less competition over other varieties that happen to be planted beside equally resistant varieties. Thus, errors cannot be totally eliminated in the course of a variety trial. ***Error*** is the fraction of the observed differences among varieties that is not due to genetic effects.

The next two principles deal with the subject of managing error to improve the reliability of the experiment. This is the next best thing to do, if error cannot be minimized by controlling the conditions of the experiment. By proper management of error, reliable estimates of variety performance can be made.

2. **Plant each variety in duplicate (replication).** This permits a more accurate measurement of quantitative traits by balancing out effects of location in the experimental field. For example, the yield of variety A may be 10 units in one portion of the field and 12 units in another portion. If the first measurement erred on the low side and the other measurement erred on the high side, then the average of the two measurements may be closer to the true yield of variety A. Obviously, the confidence on the closeness of the average to the true yield increases as more replications are used.

However, confidence in the average of all measurements can only be obtained if one is assured that variety A is neither consistently given the better environment in all the replications nor consistently given the poor environment. The same thing is true with all other varieties in the trial. Thus, it is important to observe the next principle.

3. **Randomization.** By assigning varieties to random positions in the field, the researcher avoids the mistake of consistently putting some varieties in favorable or unfavorable conditions across replicates. In essence, the concept of randomization is related to the first principle of variety trials. By randomization, each variety has an equal chance of being assigned to a particular portion in the field as all other varieties. In this manner, the varieties are being treated uniformly.

Experimental design. Before setting up the variety trial, a researcher must plan the design for the experiment. This refers to the scheme of planting each variety across replicates following the principles described above, and to the corresponding scheme of analyzing data that will be obtained from the experiment. It should be emphasized that the experimental design is decided before, not after, conducting the experiment. An experimental design must address the basic question: Considering the inevitability of error, how confident can a researcher be in making conclusions about varietal differences? The science of statistics gives the researcher a very powerful tool for answering this question.

Through the use of appropriate statistical methods and experimental design, errors are measured and sorted out according to whether these can be explained or not. The errors that cannot be explained (***residual errors*** or more commonly, ***residual effects***) are then used as a basis for testing the validity of varietal differences. If the residual effect is very large in relation to the measured differences among varieties, the level of confidence of the researcher in making conclusions about varietal differences is considerably diminished. Thus, under conditions of large residual effects, only big differences among varieties can be detected by statistical test.

On the assumption that the bulk of error in a field experiment is due to differences in soil conditions, the variety trial is usually planted in such a way that each complete set of varieties (replicate) is planted together in one block of the field that is so carefully selected that difference in soil conditions within the block is minimal. In this manner, there are as many blocks as there are replicates. This method of planting assures that varieties planted in every replicate are exposed to approximately the same soil conditions. However, there can be large differences in soil condition among replicates. These differences alter varietal performance and can be considered as a portion of error. The trial design makes it possible to 'isolate' this error, because it can be explained as block differences, reducing the unexplained residual effect component and facilitating the detection of varietal differences. The variety trial design just described is commonly referred to as ***randomized complete block design*** (RCBD). The term is descriptive of the procedure followed; that is, a complete set of varieties under trial is randomly assigned to equal plot sizes in every block. An RCBD experiment involving six varieties is illustrated in Fig. 4.5.

Analysis and interpretation of data from an RCBD experiment. From the experiment illustrated in Fig.4.5. yield data may be summarized as shown in Table 4.2.

I	II	III	IV
–1———————4——	–7———————1——	–13———————5——	–19———————3——
–2———————5——	–8———————4——	–14———————6——	–20———————1——
–3———————3——	–9———————3——	–15———————2——	–21———————5——
–4———————2——	–10——————6——	–16———————4——	–22———————4——
–5———————1——	–11——————2——	–17———————1——	–23———————6——
–6———————6——	–12——————5——	–18———————3——	–24———————2——

Fig. 4.5. Plan of a variety trial with six varieties in four replications. The plot number is shown at the left and the variety number at the right of each plot. Replicates are designated Roman numerals. Note that the varieties are randomly assigned to plots in every replicate.

Table 4.2. Yield per plot and means per variety and block.

	Replication (Block)				Variety
Variety No.	I	II	III	IV	Mean
1	85	90	93	112	95
2	92	90	85	121	97
3	91	104	90	119	101
4	106	108	101	117	108
5	89	98	89	120	99
6	89	104	94	113	100
Block Means	92	99	92	117	100

Looking at the variety mean column, it is clear that variety 4 has the highest mean among the six varieties. However, this superiority does not seem to be generally valid, because in block IV, varieties 2, 3, and 5 are better than variety 4.

To understand the situation better, the data from each block can be examined. It appears that blocks 1, 2, and 3 are almost identical in mean values, but the block 4 mean is abnormally high. Also, in block 4 all the varieties gave higher yields in relation to the first three blocks. Thus it may be inferred that block 4 is a better environment. To determine why this is so, the researcher may review his procedure to find out if it is possible, that block 4 is more fertile. It may be further hypothesized that variety 4 tends to decline in performance under high soil fertility condition. However, for the purpose of this trial, it is not necessary to know why block 4 gave a higher yield. The aim of the research, comparison of the six varieties, is not directly influenced by it.

Further examination of the data from the 24 plots in four blocks of six varieties shows a wide variation. Since the experiment is a variety trial, it is logical to attribute these differences to unequal productivity of the varieties. Table 4.3 shows the means across four blocks of the six varieties. The same table shows the deviations from the variety mean of each plot. These deviations vary widely.

Table 4.3. Variety means and deviation from variety means.

Variety	Variety Means	Deviations from Variety Means			
		I	II	III	IV
1	95	-10	-5	- 2	+17
2	97	- 5	-7	-12	+24
3	101	-10	+3	-11	+18
4	108	- 2	0	- 7	+ 9
5	99	-10	-1	-10	+21
6	100	-11	+4	- 6	+13

From the trial design, there is another explanation for the differences among plot yields: the blocks. Deviations due to blocks (block effects) can be subtracted from the individual deviations from variety means of Table 4.3, to give the residual effects or residual error shown in Table 4.4, for which there is no apparent explanation.

Table 4.4. Components of yield: general mean, variety effects, block effects, and residual effect.[a]

	Block	I	II	II	IV
	Block Effects	-8	−1	-8	+17
Variety	Variety effects	Residual Effects			
1	−5	−2	−4	+6	0
2	−3	+3	-6	−4	+7
3	+1	−2	+4	−3	+1
4	+8	+6	+1	+1	-8
5	−1	-2	0	−2	+4
6	0	-3	+5	+2	−4

General Mean = 100

[a]Effects are calculated as the difference between the means (block or variety) and the general mean.

Of course, the main interest in the trial is variety effects. These are also subject to chance variations. For example, the mean of 108 attributed to variety 4 cannot be obtained exactly, even if the trial is done simultaneously in a neighboring lot or repeated in the same lot. However, variety means will also show consistent systematic differences if there are indeed differences among varieties.

In the statistical analysis of the data shown above, the magnitude of differences among varieties is assessed against the magnitude of differences in residual effects. To make this assessment possible, the variations are expressed in units called ***variance,*** which is simply a measure of variability. Thus, the analysis is called ***analysis of variance***. The theory and detailed calculations involved in this analysis are found in every book on statistics, so these will not be presented here.

It is sufficient for our purpose that the hypothesis of equality among varieties is tested by determining the ratio of variance among varieties to the error (or residual effects) variance. The ratio is called ***calculated F value***. Higher ratios indicate that the chance is high that variance among varieties did not occur by accident, thus the hypothesis may be rejected. This chance can be determined exactly by referring to a table of F values and comparing the calculated F value with tabular F values.

If the calculated F value is less than or equal to the tabular value, the variance among varieties can be regarded as entirely accidental; so that, the differences in variety means may also be entirely due to chance. If, however, the calculated F value is greater than the tabular F value, then this is an indication that the variety means in the trial show real as well as chance differences.

Such calculated F value and the differences among varieties that gave rise to it are considered ***significant***. By convention, the term significant is understood to mean that there is still a possibility of one in twenty (5% probability level) that variety differences described as significant, are entirely due to chance. In the case of a highly ***significant*** difference, another conventional term, the possibility is only one in one-hundred (1% probability level).

- For a fixed area in a variety test, smaller plots and more replicates give more precision.
- For a fixed number of plots, larger plots give more precision.
- For a fixed size of plot, more replicates increase precision approximately in proportion to the square root of the number of replicates.
- The best compromise between plot size and number of replicates depends on the relationships between cost (which is proportional to the area in the experiment and number of plots) and size of residual error (which is inversely proportional to the plot size within certain limits). The best combination of plot size and number of replicates minimizes both cost and experimental error.

The application of these guidelines can be seen from Table 4.5. In the case of fleshy fruits, like tomato, the cost of the trial can be minimized if only five plants per plot and three replicates are used. However, this design can only detect differences of 50% among varieties and with only 50% chance of obtaining statistically significant differences.

To detect a 10% difference with 50% chance of obtaining significant differences, a variety trial on tomato will require a plot size of 25 plants if 20 replicates will be used. The table illustrates the principles and serves as a rough guide. In practice, variety trials are conducted with only three to four replications; the plot size (number of plants) is dependent on spacing of plants. Crops that are grown with close spacing, such as mungbean, are tested with more plants per plot than crops with wider spacing, such as tomato and Chinese cabbage (Table 4.6).

Table 4.5. Number of replications and plants per plot for trials of 10 or more varieties that can allow detection of yield differences of increasing value.[a]

Number of Plants Per Plot	Assumed Differences Among Varieties: 10%		16%		20%		30%		50%	
	Discriminating Power of the trial									
	50%	90%	50%	90%	50%	90%	50%	90%	50%	90%
Fleshy fruits										
5	n	n	20	n	12	n	6	12	3	5
10	20	n	14	20+	8	17	5	9	3	4
25	20	n	10	20	6	12	4	6	2	3
50	14	N	7	15	5	9	3	5	2	3
100	11	20+	6	11	4	7	3	4	—	2
Cole crops										
10	15	n	8	15	5	9	3	5	2	3
25	10	20	5	10	4	6	3	4	—	2
50	8	12	4	8	3	5	2	3	—	2
100	6	11	3	6	3	4	2	3	—	2
Head lettuce										
10	7	13	4	7	3	4	3	4	—	2
25	5	9	3	5	2	3	—	2	—	—
50	4	7	3	4	2	3	—	2	—	—
100	3	5	2	3	—	3	—	2	—	—

n = far more than 20; 20+ = slightly more than 20

[a]Mimeographed handout for the International Seed Technology Training Course, University of the Philippines at Los Baños. Unpublished.

Table 4.6. Number of rows, row length, spacing, and plot population in variety trial at AVRDC for different crops.

Crop	No. of Replications	Row: No.	Row: Length (m)	Spacing: Row (cm)	Spacing: Plant	Plot Population (No. of plants)
Chinese cabbage	4	4	4.8	50	50	40
Mungbean	4	4	6.0	40	10-15	160-240
Soybean	4	6	6.0	45	10	360
Sweet potato	4	3	5.0	100	25	60
Tomato	3	2	4.8	100	40	24

Finally, although the randomized complete block design is generally used for number of entries not exceeding 20, the total number of plots in the trial should not be less than 20. For example, if there are only five entries, the number of replicates should be at least four. If the total number of plots is less than 20, the residual error is estimated from insufficient data and the chance of obtaining significant differences is correspondingly reduced.

Reducing the size of residual error is of general interest in variety trials. With less error, plot size and number of replicates can be reduced without sacrificing the chance of obtaining significant differences, even when the true differences among varieties are small. Two steps can be done to reduce the size of residual error:

- Avoid errors in setting up the experiment by scrupulously observing the principles of conducting variety trials. ***Treat all varieties uniformly.*** The field must have uniform soil conditions or nearly so, plot sizes must be equal, planting and other cultural management operations must be done at the same time, and fertilizer rates must be similar.
- Differences among varieties that may have arisen during seed production and are not heritable can be reduced. Seeds can be sorted to eliminate abnormal and undersize seeds. For transplanted crops, more seedlings can be grown to allow selection in the seedbed. This is important in hybrid varieties of crucifers where occasionally, inbred parents are mixed with hybrid seed because of imperfections in the self-incompatibility system. Inbreds can be spotted in the seedbed because they tend to grow very slowly.

Stand, missing plants or plots. A good variety trial must have a perfect stand in all plots following the principle that all varieties and plants must be treated uniformly. However, this is not easily achieved. A common problem in variety trials is missing plants or plots. This is seen immediately after planting, when missing plants or plots result from poor germination of some varieties. In this case, replanting should be done as soon as possible (within five days as a general rule) to avoid any complication arising from differences in age of the plants.

Missing plants maybe avoided by testing germination before sowing and by overseeding, i.e., sowing more seeds per hill than usual. Thinning to the desired population should, however, be done immediately to avoid competition effects among plants in the same hill. Another method of avoiding missing hills is to practice transplanting instead of direct-seedling.

Differences in stand also result from differences in mortality. Mortality may occur at any time during the season and should be regularly monitored by the researcher. If it happens early enough, then the neighboring plants can benefit from the space left by the missing plant and in many cases, can compensate for the yield loss by producing a higher yield. In this case, there is no need to perform corrections on the plot yield.

If the loss occurs just before harvest, however, there may not be enough time for the neighboring plant to compensate for the yield loss. In this case, correction for the yield per plot can be made according to the ratio between the number of plants. In extreme cases when missing plants are too many and unmanageable, it may be necessary to express yield in two forms: plot and plant bases. In interpreting these data, it should be remembered that the former is probably an underestimate, while the latter is an overestimate.

In all cases, the cause of mortality should be diagnosed. If the cause is varietal, such as when a variety is highly susceptible to soil-borne diseases, then the mortality can be considered as normal for the variety affected and should not be corrected at all.

The question of either rejecting whole plots or whole replicates should be considered when the unusually poor stand or performance of the plot or even an entire replicate is clearly due to nonvarietal causes, such as water logging (which may affect only one or a few plots). Missing plots can be filled up with the use of statistical procedures. A plot that looks "bad" should not necessarily be rejected.

Cultural management practices. As a rule, a variety trial is done for the sole purpose of comparing variety performance. It should not be complicated by combining the variety test with an experiment on management practices, such as fertilizer level or pest control. If the response of a particular variety to these factors needs to be studied, a separate experiment should be designed.

The management practice for the variety trial must be uniform for all plots. If the trial is being conducted to test varieties that are being prepared for release as a commercial variety, then the set of management practices must conform with the accepted commercial practice.

Management practices should be so planned that these are done by replicates; so that, a complete set of varieties receive the treatment at about the same time. For transplanted crops, replication may start in the seedbeds. This is an assurance against loss of an entire variety in case of disease outbreak or other problems that may affect only one of a few seedbeds. For large trials where several personnel are involved, one person may be assigned to each replicate.

Consistency of management practices across several trials facilitates comparison and interpretation of results. At AVRDC, for example, a standard set of management practices is followed for every crop.

It is also important to determine if the variability of results obtained in the trial is comparable to that obtained by other researchers working on the same crop and the same character. Such a comparison is possible by calculating the ***coefficient of variation*** (CV), which is the ratio expressed in percentage of the sample ***standard deviation***(s) (another measure of variability), and the grand mean. The CV is a relative measure of variation, in contrast to the standard deviation, which has the same unit as the observations.

For data from different experiments of the same nature, the mean and standard deviation often tend to change in the same proportion, so that CV is relatively stable or constant. Abnormally high CVs, in relation to that of similar experiments, indicate that the results may be unreliable (the magnitude of error is too high). Low CVs, on the other hand, indicate that the magnitude of chance variation is kept low, hence the experiment is reliable.

Significant differences among varieties, as suggested by the F values, do not necessarily imply that every variety in the trial is significantly different from every other variety. It is possible that only one variety is significantly different from all the others, and that all the others are not significantly different from each other. To clarify this situation, the ***least significant difference*** (LSD) is calculated. LSD makes it possible to do paired comparison, usually between the check variety and the experimental variety.

In case the F test shows that varietal differences are not significant, does this mean that the varieties are similar or that there are no differences among the varieties? No; such conclusion is wrong. Another, perhaps larger, trial (with more replicates and larger samples) may show significant differences. It is possible that the true differences among varieties are so small that the trial design was inadequate to show this.The chance of demonstrating significant varietal differences in a field trial, if differences of a certain size among varieties exists, is called the ***discriminating power*** of the trial.

When only small differences exist among varieties, there is less chance of finding significant differences in the trial than when large differences exist. Hence, it is advisable to carefully study the objective of the trial before conducting an experiment. If, for example, tomato is intended for processing, it does not matter if a variety matures one week earlier or later because the price per kilogram is fixed at a certain level by the processing company.

However, if it is intended for the early dry-season fresh market, a few days' difference can be very important to a farmer because prices tend to drop drastically in a very short time. Thus, the trial design may need to be adjusted to fit this requirement to detect small differences. It may be necessary to increase the number of replicates, with or without increases in plot size. However, this need has to be balanced with the need to keep the cost of running the trial low.

Reducing the cost of the variety trial. The cost of conducting a variety trial is determined primarily by the number of entries, plot size, and number of replicates as these determine the size of the experiment. A minimum number of replicates and plot size must be used, without sacrificing the "discriminating power of the trial". In the early part of this chapter, we discussed the importance of carefully selecting entries to keep the size of the trial small and to make sure that the entries are chosen according to the objectives of the experiment. In the case of plot size and number of replicates, the following guidelines may be observed:

Data to be collected. The set of data to be collected from a variety trial varies from one crop to the other. Even within one species, the evaluation criteria may vary depending on the intended use of the crop. For example, the criteria for evaluating tropical off-season fresh-market tomato are different from those for processing tomato (Table 4.7). Heat tolerance is important for off-season tomato because this is grown during the time of the year when night temperatures are higher than 21°C. Bacterial wilt resistance is equally important because the tomato is planted in upland soils where bacterial wilt is a problem. On the other hand, heat tolerance and bacterial wilt resistance are not important for processing tomato because this is grown during the cool season in paddy fields (postrice) where bacterial wilt is not a problem. Processing tomato has specific requirements for quality that can be met by using the plant and fruit characteristics enumerated in the Table.

Emphasis should be made on characters that are relevant to the objectives of the trial. Usually, these pertain to aboveground parts of the plant, such as growth habit, earliness, and fruit yield. Equally important is the root system. This is particularly important on leguminous crops, whose ability to fix nitrogen should be evaluated by examining the root nodules. Evaluation should extend to the postharvest stage when the harvested product is evaluated for handling, cooking, and processing qualities.

Plant characters may be classified as 1) type character, 2) performance character, 3) quality factors, and 4) special traits. The ***type character*** is not influenced by environmental factors and is useful in establishing variety identity. In a replicated trial, it is useful for checking if planting was done correctly; i.e., if the seeds were planted in the correct plots. It is not necessary to subject this kind of character to quantitative analysis. Examples of type characters are netting in melons, shape of cabbage head, growth habit of tomato, and calyx color in eggplant. Data recording of these traits is done in a descriptive manner.

Performance characters, on the other hand, are subject to environmental influences even in the small area of a trial field. These characters need to be measured carefully in every replicate. The data are analyzed with the Analysis of Variance (ANOVA). Examples of performance characters are number of fruits, weight of fruits, and resistance to pests.

Quality factors are traits that are highly subjective in importance, and their evaluation may vary from one researcher to another. Examples of these are flavor, texture, and overall appearance. These are difficult to quantify and are usually measured with a rating scale.

Special traits are those that may need considerable time (several years or seasons) before evaluation is completed. Examples are dependability and local acceptance by farmers, traders, and consumers. Evaluation is highly subjective and may need special experimental designs.

Before initiating a trial, the researcher should plan the set of data to be collected and prepare a blank table (Figs. 4.6 to 4.12). However, some flexibility must be allowed during data collection. For example, if the plan is to evaluate for field resistance to downy mildew in Chinese cabbage, but the condition turns out to be unfavorable for the development of the disease, all varieties may obtain a resistance rating if data for resistance will be taken.

On the other hand in the course of the trial, meaningful differences may be observed in the field which were not anticipated. For example, conditions may become favorable for fruit cracking in tomato; so that, it is possible to score for crack resistance even if it was not originally planned to do so.

Methods of description and recording of data. Observations from the experiment can be recorded according to several methods: 1) measurement and counting, 2) giving numerical scores, as judged by the eye, 3) verbal description, and 4) taking pictures, drawings, or preserved specimen.

Measurement and counting are the most accurate methods of observation. Weights, linear dimensions, instrument reading (such as pH and soluble solids) are common measurements in a variety trial. One should not go beyond 1% accuracy but should not round numbers lower than 20 to units. In most cases, three figures are sufficient. For example, the root weight of radish can be expressed alternatively as 0.3 kg. 325 g, 325.15 g, or 325.150 mg. Among these, 325 g (three figures) is the most appropriate. Avoid recording fractions as 1/4 instead of 0.25 because the former can cause difficulty when the data are entered in data processing machines.

Counts such as number of plants that remain on the plot after seedling mortality, number of fruits per cluster, and number of days to first flower are also commonly obtained. In many cases, it is not the count that is important in interpretation of data but the fraction that is derived from count data. This is true in the case of bolting, which is obtained from count data on number of plants that flower and total number of plants. Individually, these counts may be meaningless; therefore, one should also record the total number.

In taking measurement and count data, all blanks should be filled up, including those that correspond to plots where data cannot be obtained. For example, if insects are being counted and one plot does not have a single insect, then zero (0) is entered in the data sheet. If another plot is empty (all plants died), then a dash (-) is entered in the data sheet.

Numerical scores or ratings are used to convert descriptive information or visual estimates to numerical records. This method, when used properly, allows a fast evaluation of a large trial. For example, a researcher may choose to give numerical scores of plant height in okra instead of doing actual measurements. He may choose a scale of 1 to 5, where 3 is the height of the check variety or the estimated average of all the plants in the trial.

Plots with visually estimated plant heights which are more than that of the check variety are given scores of either 4 or 5, depending on how much taller these plots are.

Fig. 4.6. Data sheet for AVRDC tomato yield trial.

PLACE :______________________________ Date sown:______________________________

Date planted:______________________________

		1	2	3	4						5	6					7	8				9	
Plot No.	Entry	Date flwd	Growth habit	Fruit set rating	Disease rating						Insect rating	Fruit traits					No. of plants	Weight & Number Markbl		Cull		Total	
					Gls	Lm	Eb	Lb	TMV	B		Co	Sh	Cr	Br	Ber		No.	Wt.	No.	Wt.	No.	Wt.

Gls = gray leaf spot
Lm = leaf mold
Eb = early blight
TMV = tobacco mosaic virus
B = bacterial wilt
Co = color
Sh = shape
Cr = cracks
Br = blotchy ripening
Ber = blossom end rot

Fig. 4.7. Data sheet for AVRDC mungbean yield trial.

Replication No. ____________

Name of cooperator: ____________

Date of Planting: ____________

Entry No.	AVRDC acc. or cross #	Varietal name or pedigree	1 No. of plants/sq m	2 Yield: first 3 harvest (kg/ha) 1st	 2nd	 3rd	Total harvest (kg/ha)	3 Days to 1st flower	4 Plant ht (cm)	5 Pods/plant	6 Seeds/pod	7 1000-seed wt (g)	8 Diseases virus	 PM	 CLS	9 Days to 1st pod	10 Lodging	Remarks

PM = powdery mildew. CLS = cercospora leaf spot

Fig. 4.8. Snap pea and/or snap bean cultivar trial data sheet.

Name ______________________________ Date Sown ______________________________

Institute ______________________________ Expt. Site ______________________________

Address ______________________________ Elevation (m) ______________________________

Plot No.	Entry	Rep. No.	Total Stand (TS)	Harvest sequence							MPN	MPY (g)	TY (t/ha)	MY (t/ha)	PL			PW			Diseases/pests		Remarks
					1st	2nd	3rd	4th	5th	Total					1	2	AVE	1	2	AVE	Rust	Insect damage	
				DH																			
				PN																			
				TPW (g)																			
				MPW (g)																			
				DH																			
				PN																			
				TPW (g)																			
				MPW (g)																			
				DH																			
				PN																			
				TPW (g)																			
				MPW (g)																			
				DH																			
				PN																			
				TPW (g)																			
				MPW (g)																			
				DH																			
				PN																			
				TPW (g)																			
				MPW (g)																			

DH = Date harvested; PN = No. of pods harvested. TPW = Weight of pods harvested; MPW = Weight of marketable pods after removing defective pods; MPN = Mean pod no. per plant = Total PN/Total stand; MPY = Mean pod yield per plant = Total TPW/Total stand; TY = Total yield = $\frac{\text{Total TPW (g)}}{\text{Plot size (m}^2\text{) x 100}}$

MY = Marketable yield = $\frac{\text{Total MPW}}{\text{Plot size (m}^2\text{) x 100}}$; PL and PW = Pod length and pod width, respectively. Measure length and width of randomly chosen ten pods at optimum harvest and take their mean. Diseases/pests damage: Score the severity with scales 0 = no damage to 9 = most serious damage.

Fig. 4.9. Radish cultivar trial data sheet.

Name ______________________ Date Sown ______________________

Institute ______________________ Expt. Site ______________________

Address ______________________ Elevation (m) ______________________

Plot No.	Entry	Rep. No.	Total Stand	Harvest Sequence				Days to Maturity	Total harvested hills	Harvest rate (%)	Plant weight (g)		Root weight (g)		Market-able Root wt. per plot (g)	Yield (t/ha)	Diseases/pests				Remarks
					1st	2nd	3rd				Total	Mean	Total	Mean			Soft rot (%)	Virus	Downy Mildew	ID	
			(1)					(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	
				DH (2)																	
				NH (3)																	
				TW (4)																	
				RW (5)																	
				MRW (6)																	
				DH																	
				NH																	
				TW																	
				RW																	
				MRW																	
				DH																	
				NH																	
				TW																	
				RW																	
				MRW																	
				DH																	
				NH																	
				TW																	
				RW																	
				MRW																	
				DH																	
				NH																	
				TW																	
				RW																	
				MRW																	

(2) DH = Date harvested, mostly once-over harvest is possible in each plot; (3) NH = No. of plants harvested; (4) TW = Total plant weight including leaves and roots; (5) RW = Total root weight harvested; (6) MRW = Total marketable root weight; (7) No. of days to 50% harvest from sowing; (8) Summation of NH; (9) 100 x Item (1); (10) Summation of TW; (11) Item (10)/Item (8); (12) Summation of RW; (13) Item (12)/Item (8); (14) Summation of MRW;

(15) $\frac{\text{Item (14)}}{\text{Plot size (m}^2\text{) x 100}}$; (16) 100 x No. of infected plants/Total number of plants (1); (17) - (19) Severity scoring with scales 0 for no symptom to 9 for the totally damage; ID = inset damage

Fig. 4.10. Mustard cultivar trial data sheet.

Name ____________________

Institute ____________________

Address ____________________

Date Sown (Transplanted) ____________________

Expt. Site ____________________

Elevation (m) ____________________

Plot No.	Entry	Rep. No.	Total Stand (1)	Harvest sequence				Days to Maturity (6)	Total Hills Harv. (7)	Harvest Rate (%) (8)	Growth		Marketable Weight/plot (g)		Yield (t/ha) (13)	Diseases/pests (%)			Remarks
					1st	2nd	3rd				Total (g) (9)	Mean (g) (10)	Total (11)	Mean (12)		Soft rot (14)	TuMV (15)	ID (16)	
				DH (2)															
				NH (3)															
				TW g (4)															
				MW g (5)															
				DH															
				NH															
				TW g															
				MW g															
				DH															
				NH															
				TW g															
				MW g															
				DH															
				NH															
				TW g															
				MW g															
				DH															
				NH															
				TW g															
				MW g															

(2) DH = Date harvested, mostly once-over harvest is possible in each plot; (3) NH = No. of plants harvested; (4) TW = Total top weight harvested; (5) MW = Weight of marketable leaves; (6) No. of days to 50% harvest from sowing; (7) Summation of NH; (8) Item (7)/Item (1)] x 100; (9) Summation of TW; (10) Item (9)/Item (7); (11) Summation of MW; (12) Item (11)/Item (7); (13) $\frac{\text{Item (11) (g)}}{\text{Plot size (m}^2\text{) x 100}}$

(14) - (16) [No. of severely damaged plants/Item (1)] x 100; (16) ID = Insect damage.

Fig. 4.11. Broccoli and/or cauliflower variety trial data sheet.

Location ______________________
Name ______________________
Institute ______________________

Date Sown ______________________
Date Transplanted ______________________
Expt. Site ______________________
Elevation (m) ______________________

Plot No.	Entry	Rep No.	Total Stand (TS)	Harvesting Sequence (Use separate sheet if more than 5 harvests)	1st	2nd	3rd	4th	5th	Days to Maturity (5)	Total Hills Harvested (6)	Plot Curd Yield g (7)	Yield (t/ha) (8)	Harvest Rate (%) (9)	Mean Curd Weight g (10)	Curd Width (cm) (11) 1	2	AVE	ACD (%) (12)	Pest/Diseases BR (%) (13)	SR (%) (14)	MV (15)	ID (16)	Remarks
				DH (2)																				
				NH (3)																				
				CW g (4)																				
				DH																				
				NH																				
				CW g																				
				DH																				
				NH																				
				CW g																				
				DH																				
				NH																				
				CW g																				

(2) DH = Date harvested; (3) NH = Number of curds harvested. (4) CW = Total weight of curds harvested. (5) = No. of days to 50% harvest, from items (2) and (3). (6) = Summation of NH (7) = Summation of CW.

$$(8) = \frac{\text{Item (7) (g)}}{\text{Plot size (m}^2\text{)} \times 100}; \quad (9) = 100 \times \text{Item (6)/Item (1)}; \quad (10) = \text{Item (7)/Item (6)};$$

(11) Measure ten random sample curds and take the mean of them. (12) ACD = 100 x Number of abnormally developed curds/Item (1); (13) BR = Black rot; (14) SR = Soft rot; (15) - (16) MV = Mosaic virus and ID = Insect damage. Score severity with scales 0 for no symptom to 9 totally destroying damage.

Fig. 4.12. Eggplant and/or pepper (hot and sweet) cultivar trial data sheet.

Name ______________________ Date Sown ______________________

Institute ______________________ Date Transplanted ______________________

Address ______________________ Expt. Site (Elevation) ______________________ (m)

Plot No.	Entry	Rep. No.	Total Stand (TS)		1st	2nd	3rd	4th	5th	6th	Total	TFY (t/ha)	MFY (t/ha)	Fruit Character											Damage rating				Remarks
														Color	MUFW (g)	MFL (cm)			MFD (cm)			FWT (mm)			Virus	SB	BW	ID	
																1	2	AVE	1	2	AVE	1	2	AVE					
				DH																									
				FN																									
				TW (g)																									
				MFN																									
				MFW (g)																									
				DH																									
				FN																									
				TW (g)																									
				MFN																									
				MFW (g)																									
				DH																									
				FN																									
				TW (g)																									
				MFN																									
				MFW (g)																									
				DH																									
				FN																									
				TW (g)																									
				MFN																									
				MFW (g)																									

DH = Date harvested; FN = Total fruit no. harvested. TW = Total fruit weight harvested; MFN = No. of marketable fruits after removing malformed and damage fruits; MFW = Weight of marketable fruits;

$$TFY = \text{Total fruit yield} = \frac{\text{Total TW (g)}}{\text{Plot size (m}^2\text{)} \times 100}; \quad MFY = \text{Marketable fruit yield} = \frac{\text{Total MFW (g)}}{\text{Plot size (m}^2\text{)} \times 100};$$

MUFW = Mean unit fruit weight = Total MFW/Total MFN. MFL = Mean fruit length. Measure length of ten randomly chosen fruits at optimum harvest stage and take their mean; MFD = Mean fruit width. Measure width of ten randomly chosen fruits at optimum harvest stage and take their mean. FWT = Mean fruit wall thickness. Measure the thickness on the above fruit samples and take their mean. Damage rating = 0 for no symptom, 9 for totally destroying damage; [illegible]burn; SB = Sunburn; BW = Bacterial wilt; ID = Insect Damage

Plots with visually estimated plant heights which are less than that of the check variety are given a score of 2 or 1. In this scale, 5 is given to the tallest plots in the trial, and 1 to the shortest. The scale of 1 to 5 is a very convenient scale and is sufficient for many needs.

To avoid confusion, the higher scores should be given to desired traits. Thus, 5 should be given to the most resistant plots and 1 to the most susceptible plots. If taller plants are desired, then 5 is given to the tallest plants and 1 to the shortest. However, if short plants are preferred, 5 is given to the shortest plants. Zero (0) and (-) have the same meanings in this method of scoring as in measurements and counts.

If more detailed comparisons are needed, an expanded scale of 0-9 may be used, adopting the same convention of assigning higher numbers to desired characters. In this scale, 5 is assigned to an average (borderline) case. The lowest score (worst case) is 2, while 1 and 0 have special meanings. The score of 1 is used to mean that the entry is disqualified, i.e., not to be evaluated because of some factors which make evaluation impossible, such as when insect damage to the growing point makes plant height evaluation unreliable. The score of 0 is used for missing plants or plots.

Numerical scores is a substitute system, if measurement or counts are either too difficult to do or impossible to accomplish considering manpower limitations. Measurements and counts are objective records, and they allow easy comparison with data from other experiments.

Verbal description is entered under the column "Remarks," which is usually the last column on a data sheet. It is a very convenient method of recording impressions that certainly cannot be captured in other forms of record keeping. Impressions may range from strongly negative, such as "junk", to strongly positive, such as "a winner". Verbal description may be more detailed, too, such as "not good as a commercial variety but definitely useful as a parent for improving fruit color".

Pictures, drawings, or preserved specimen are worth a thousand words or data, to borrow a popular saying. These are used when dealing with observations that are difficult to describe because these are unusual. Since these are expensive methods of recording, they should be used sparingly.

Pointers in record keeping. Raw data sheets should be of good quality paper that are not easily damaged by water or humidity. To avoid damage or loss, they should be returned to a bound record book (such as a ring binder) when not being used. Avoid using water soluble ink for recording. Write legibly so that another person can easily understand the record. Avoid manual copying of raw data; this is not only time-consuming but may also be a source of error.

On-Farm Trial and Promotional Testing

Strictly, on-farm trials and promotional tests are not research activities but rather an interface of research and extension. On-farm trials are performed on varieties that are in the final stages of testing, having passed the on-station trials, but not yet officially released by the breeding institution. The objective is to compare the new prospective variety with popular varieties in the farmers' fields.

The farmer cooperator must be one who has been growing the crop for years, not one who is just starting, or one who has been growing a different crop. Preferably, he should be a regular participant in on-farm trials. This requirement is crucial for the success of the test, because the farmer is an active participant in the evaluation process. He must be able to give insights on variety performance, considering his experience with the crop, his own variety, and other experimental varieties that he has tried before.

The test is done preferably with supervision from the breeder. The number of test varieties is normally limited to a maximum of three, including the farmer's variety and a leading commercial variety as checks. The on-farm trial is as simple as planting a few rows of new variety in the middle rows of the farmer's own crop, using exactly the same management procedure that the farmer traditionally uses for his crop.

On-farm trials have the following inherent limitations:

1. Direct measurements of yield are difficult to obtain. These are usually given by the farmer in number of baskets of fruits harvested or similar measures.
2. The number of entries cannot be too many because these may create confusion.
3. Detailed observation by the breeder is not possible because he cannot visit the trial very often. Usually, the observations are descriptive rather than quantitative.

Promotional trials are done on varieties that are officially released and in the process of mass-production. The objective is to convince the farmer to use the variety. Practically anyone who is interested and willing to participate can do so. However, one should avoid farmers who are growing the crop for the first time. They have a tendency to blame the variety for a crop failure, or give credit entirely to the variety for success.

The number of entries is restricted to two: the new variety and the farmer's variety, preferably grown in equal parts of the farm. The new variety should not be planted in a plot so small that the farmer will not give it enough importance. For example, if a new variety is early maturing, the farmer may not harvest it if the plot is so small. Instead he may wait for his own variety to mature so that harvesting of the two varieties is done at the same time. Under this situation, the new variety will have a lot of culls of overripe fruits. The marketable yield will be underestimated.

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CHAPTER 5

Vegetable Seed Production Technology

Good quality seed is one of the main factors that determines the success of a crop. In developing countries, the unavailability of good seed is a major problem which is related to the absence of good varieties, inadequate technology for seed production, poor quality control, postharvest seed handling, inadequate marketing, and the farmers' indifference to improved varieties.

Seed programs have received different levels of support in developing countries. The support ranges from the direct introduction of improved varieties (which are frequently not adapted to the new environment of the importing country) to breeding and seed production of selected improved varieties by local public institutions and private seed companies. Many farmers, however, still use their own seed because commercial seed is either unavailable or not the right variety for their needs.

Seed Requirements for Vegetables

Seed requirements vary with different production systems. The nutrition gardens need a small amount of seed per variety but from many varieties/species. The demand for seed is year-round, and the species and varieties required vary with the season and location. Farmers usually save seeds from their own crops for the next planting. Some buy mature fruits from the local market and use the seeds for planting. Commercial enterprises usually meet the demand for large amounts of seeds from fewer varieties/species that meet the market requirement. Seed supply, therefore, is easier to organize and is often handled by the private sector.

Seed Production Technology at Farmer's Own Field

Seed production at the farm level by the farmer himself is still the most common source of seeds for the small vegetable farmers and home gardeners in developing countries. Very often the seeds produced are of poor quality. Frequently, the fruits harvested for seeds are those that were missed during harvesting for fresh vegetable and those left over at the end of the production season. No positive selection is carried out to choose the best plants and fruits for seed production (See Chapter 4). The plants are weak at the end of the production season, thus, producing seeds that are not physically and physiologically fully mature.

The correct varietal isolation distance is not usually followed to prevent cross-pollination. The plant population then becomes genetically mixed in succeeding plantings. Because the planting is continuous, disease infection particularly by viruses may become a problem. The weakened infected plants produce poor seeds; and if the virus is seed-borne, it will be carried into the next generation. The seed produced may come from a wet season crop which is exposed to fungal and bacterial disease infection. Again this allows seed-borne pathogens to infect the next crops. Moreover, the seeds are not properly extracted, processed, and stored. All these contribute to the use of inferior seeds by many vegetable gardeners.

Suggested Production Guide

Production from fresh vegetable plots. The best plants in terms of growth and yield (depending on the parts of the plant being used for vegetable) and the best fruits should be selected for seed production. Any plant or fruit with suspected symptoms of disease and pest attack should be excluded. One or two fruits should then be allowed to mature fully, either on the plant or during postharvest incubation before seed extraction. The mother plants would, therefore, continue to be productive.

Separating the seed production plots. When the farmer needs to produce more seeds, he should allocate a separate area for seed production. The plot should be the best piece of land in terms of accessibility and water supply. It should also be relatively free of disease and pest problems. Off-types and crop volunteers (seeds that were accidentally left in the field by the previous crop) in the seed production crop should be rouged or pulled out as often as possible by using the negative selection technique (See Chapter 4).

Any disease and insect infection should be controlled more rigorously than in the case of fresh market production. Crop management and crop rotation practices are essentially similar to that for fresh market production. Some additional cultural management practices are needed, however, because the seed crops stay longer in the field.

For some biennial vegetables (e.g., radish and cabbage), special treatments have to be done and/or planting time has to be adjusted to induce flowering and seed setting. These vegetables need lower temperatures and/or longer days for flower initiation. Because of these special requirements, these crops are best seed-produced by specialized seed growers.

Maintaining the variety. To prevent species/varietal mixture, it is important to harvest and process the different varieties separately, lot by lot. All the seed cleaning, drying, and processing equipment and seed containers should be cleaned and free from seed of another variety. The seed containers should be labeled clearly with the name of the species, kind, variety, and the date of storage.

In cross-pollinated species, if the genetic purity of a variety is to be maintained, the buds for seed collection should be bagged with paper envelope before anthesis or flower opening to prevent pollen contamination from other nearby varieties of the same species. The bagged flower bud should then be pollinated artificially during flowering with pollens collected from the same variety. If unbagged, cross-pollination takes place which gives rise to segregating populations in the succeeding crops. If the varieties are grown at a sufficient distance from each other then bagging is not done. The recommended isolation distances for some vegetables are presented in Table 5.1.

In a newly introduced variety, the new environment may be favorable for the expression of potential variation. When harvesting the seeds, certain morpho-physio-, or patho-type may be consciously or unconsciously selected, forming new variants (strains) of the variety.

In an F_1 hybrid variety, the seed collected will not be true to type because it segregates in the F_2 generation. It usually loses its uniformity, quality, and vigor. F_1 hybrid seed is common today. If multiplication is continued, a new variety may be selected and fixed (Chapter 4).

Table 5.1. Mode of pollination, isolation distance, and maturity indices of some vegetable crops.

Vegetables	Pollination	Isolation Distance (m)	Maturity Indices
Garden bean	Naturally selfed, cross by insect	45-60	Pods mature and yellow
Cowpea	Naturally selfed, cross by insect	130	Two-thirds of pods turn brown
Dolichos bean	Partially selfed, and cross-pollinated	180-360	Pods dry and yellow
Pigeon pea	Partially selfed, and cross-pollinated	180-360	Pods start to dry
Garden pea	Normally self-pollinated	Minimal	Seeds fully developed and hard
Chick pea	Normally self-pollinated	Minimal	Seeds fully developed
Pepper	Partially selfed and cross-pollinated	45-360	Red ripe
Tomato	Normally selfed with crossing by insects	30-60	Ripe or ripening
Eggplant	Partially selfed, and cross-pollinated	400-900	Beyond edible stage
Lettuce	Naturally selfed-pollinated with cross-pollination by insects	30-60	White fluff (30-50%) on heads
Cabbage	Largely cross-pollinated by insects, with self-pollination	300-1000	Seeds dark brown in color
Cauliflower	Largely cross-pollinated by insects with self-pollination	300-1000	Pods turning brown
Watermelon	Partially selfed, and cross-pollinated	400-1000	Edible maturity
Cucumber	Partially selfed, and cross-pollinated	400-1000	Fruit pale yellow/golden

Harvesting and Processing

The seed crops of vegetables can be grouped according to the state of the seed at harvest:

- Dry seed. The seeds are not harvested when the fruits ripen but are left to dry on the plant. Examples of vegetables under this group are the beans, *Brassicas*, *Luffa* species, okra, onion, lettuce, carrot, and sweet corn.

- Seeds of fleshy fruits. There are two types of seeds under this group.
    - Seeds with mucilaginous coating — Examples: tomato and cucumber.
    - Seeds without mucilaginous layer — Examples: pepper, eggplant, melon, and squash.

Seed drying on the plant. At physiological maturity, when the development of the embryo and accumulation of storage material are almost complete, the moisture content of the seed is about 50% wet basis. The seeds then start to lose moisture while they are still attached to the mother plant because of the sun and the wind. Soon they are harvested and further dried by natural or artificial means, depending on the system available.

Harvesting dry vegetable seeds. Beans and other leguminous vegetables are usually allowed to dry on the vines and harvested before the pods start to shatter. Likewise, the pods of *Brassica* crops are harvested when 70% of the inflorescence are ripe (i.e., the seed turns brown or black) and before the pods shatter. The fruits of *Luffa* species are also left on the plants to dry before harvesting. Other vegetables with seeds harvested dry are okra, onion, kangkong, sweet corn, lettuce, and carrot. Table 5.1 shows the maturity indices of some vegetables for seeds.

Drying of the pods/fruits. In tropical countries with much wet weather, it is not advisable to allow the fruits to dry on the plants. The physiologically mature fruits must be harvested and air-dried immediately under the shade or under the sun whenever possible. Hanging the wet fruits/pods above the wood stove can help hasten drying and may prevent insect pest infestation. Sometimes it may be necessary to split the wet, mature, green legume pods to remove the seed so they can be dried faster. In this case, however, the seeds should be handled carefully because they are susceptible to damage by bruising.

When drying with artificial heat, the temperature must not be above 30°C when the seeds still have a high moisture content greater than 20% (usually after harvest) to avoid heat injury. The drying temperature can be increased later in the drying period to 35°-40°C.

Threshing and Processing of Dry Pods/Fruits

Because the volume is small, the dry pods/fruits can be threshed manually after harvesting by beating with a stick or rubbing and splitting by hand. Threshing is easier and more efficient if the harvested pods/fruits are first dried directly in the sun to make the pods more brittle. The trash is then removed by winnowing. A windy day is best for winnowing. A household fan can be used to facilitate the winnowing process. Poor seeds (diseased, wrinkled, split, etc.) and pieces of inert matters are hand-picked.

The clean seeds are further dried to about 8% moisture content (MC) directly in the sun on a tray, drying mat, or any suitable container. The seeds should be spread out in a thin layer to hasten drying. The drying place must be well-ventilated and the seeds turned from time to time. Drying time will depend on the moisture content of the seeds which can be determined by its hardness/brittleness. When bitten or crushed with a stone, a dry seed of about 8-10% moisture content is hard and brittle. The drier the seed, the harder and more brittle it becomes. It cracks or shatters with a characteristic popping sound. Wet seed is elastic and therefore will not crack/break.

Extracting and Processing Seeds of Fleshy Fruits

Seeds with mucilaginous layer. In tomato, seeds of the fully ripe fruits can be extracted right after harvest. The fruits are cut and crushed in a noncorrosive plastic bucket or wooden container. The crushed fruits in the form of a slurry are left to ferment in the shade away from direct sunlight and rain. The pulp should be stirred regularly to help release the seeds and to prevent mold growth from discoloring the seeds. Fermentation is completed when the bubbling activity (CO_2 released due to fermentation) is reduced, the slurry cools down and decreases to the initial volume, and the supernatant of the slurry clears up. A more practical indication is the sinking of the seeds to the bottom of the container.

Natural fermentation takes one to two days at a pulp temperature of 22°-27°C, and two to four days at 15°-22°C. If fermentation is sufficient, no mucilaginous matter is left on the seeds and the floating pulp can be easily separated. The seeds are then washed and cleaned and dried in the same way as seeds of the dry fruit seeds.

In cucumber, the field-ripened fruits may be allowed a postharvest incubation indoors in a dry place for about 10 days before extracting the seeds. If the fruits are already soft, however, seeds may be extracted without incubation. The fruits are cut into halves lengthwise, and the seeds with the attached core tissue are scooped into a plastic or stainless container to ferment as in tomato. The rest of the processing is the same as in tomato.

Seeds without mucilaginous layer. Seeds are extracted directly without fermentation. Sweet pepper seeds are extracted by splitting the fruit lengthwise and removing the seeds manually with any suitable tool. The fruit wall is separated from the core of the fruit and the seeds are rubbed off manually or washed out by rubbing in ample water. The clean, wet seeds are then spread out to dry.

The eggplant fruit should be allowed to mature beyond the edible stage when harvested for seed. Seeds in fruits that have not reached edible maturity continue to mature if not removed from fruits for some days. Change in color and softness is a good indication for determining harvest time. The fruit is cut, crushed, or macerated; and the seeds are separated from the pulp by washing.

Melon, watermelon, squash (pumpkin), and wax gourds are split into halves, usually longitudinally; and the seeds are separated manually or washed off from the pulp.

Farm-Level Packaging and Storage

When the seeds are already dried and cleaned, they have to be stored properly before planting. The seeds are placed in an appropriate package or container and stored until planting. They should be packed and stored properly to maintain high viability until planting time. Seed moisture content and temperature are the two important factors that affect seed viability in storage. When these factors are too high, the seeds deteriorate rapidly.

Packaging

The material for packaging is a major factor in regulating the moisture content of stored seeds. Seed moisture attains equilibrium moisture content with the relative humidity (RH) of the air surrounding it. The moisture content of the seed during storage will either be low or high, depending on the RH of the surrounding air and on the permeability of the packaging material to moisture. This is significant if one takes into account the general rule for predicting storage life of seeds which states that seed life is doubled or halved with every 1% decrease or increase of seed moisture content (Harrington 1972). This rule applies to storage between 15-70% RH, 0°-30°C, and 4-14% seed moisture content. The nature of the packaging material, therefore, is very important in this regard. Table 5.2 shows the characteristics of different packaging materials.

Table 5.2. A comparison of barrier properties of some common flexible packaging materials.[a]

Material	Property (resistance to)			
	Water vapor	Gas transmission	Water	Oil grease
Kraft paper	0	0	2	0
Sulphine paper	0	0	2	0
Glassine paper	0	3	3	4
Waxed glassine paper	4	5	5	6
Cellulose	0	6	5	10
Cellulose acetate	1	2	6	6
Polyvinylchloride (PVC)	2	5	10	8
Mylar	4	6	10	8
Polyethylene (PE)	7	3	10	5
Polyvinyldichloride (PVDC)	9	8	10	8
PE coated paper	7	3	6	5
PVDC coated paper	8	8	6	8
PE coated cellulose	8	8	6	6
Aluminum foil (9 micron)	10	10	10	10

[a]Source: Klaasen 1983. Qualities are graded from 0-10, where 10 is the highest grading and 0 signifies that the quality is nonexistent.

The temperature of the seeds to be packed is one factor to consider. Warm seeds heat up the surrounding air and increase the capacity of the air to hold water vapor. If the seeds are tightly sealed inside and then cooled down, the excess water vapor in the sealed container condenses; and a significant portion of this is reabsorbed by the seeds. This in turn increases the seed moisture content of the previously dried seed.

In serious situations, the seed may become wet enough for fungi and insect pests to grow. This is especially critical if the ambient relative humidity is high, and the air space in the container is much larger than that occupied by the seeds (i.e., too big container for too little seed). It is, therefore, advisable to choose a container which can be packed as full as possible with the amount of seeds available.

Apart from packaging materials, the packaging procedure is also very important. Some of the most suitable and readily available seed containers for vegetable gardeners are small glass bottles with a good rubber-gasket screw top, e.g., baby food, soft drink, soya sauce, and wine bottles. The bottle stoppers should be sealed with molten wax or candle after being tightly secured. Small tin cans with air-tight lid, (tea or coffee cans, health drink containers, etc.) may be used. It may also be useful to wedge a layer of plastic sheet between the lid and the container.

The seeds may also be kept inside a thick polyethylene (PE) packet which is fastened or sealed as tightly as possible before being packed in the metal container. The PE packet is properly sealed by heat, preferably by an electric heat sealer. An alternative procedure is sealing over a candle flame, although this is not so reliable. The bag may also be fastened by tying it as tightly as possible. For extra protection, another plastic bag may be used to contain the bag with the seeds.

Many other containers can be used, such as paper bags, cardboard boxes, cotton bags, bottle gourd containers, wooden boxes, porous jars without glaze, plastic or glass bottles without rubber-gasket stoppers. These containers however are not moisture proof. They can be used in places with low relative humidity or when storage period is very short. If the seeds are stored by hanging them above an open wood stove, as is done in some places, these containers could store seeds for a longer period.

If blue silica gel (silica gel with cobalt chloride as color indicator) is available, it can be used as an indicator of leakage when a transparent bottle or plastic bag container is used. Dry silica gel is blue and the wet gel is pink. A small perforated PE bag of this type of silica gel can be packed with the seeds. During storage if the silica gel stays blue, then the seal is perfect; and if it starts to turn pink, then there is leakage and the container has to be tightly sealed.

Storing

Dry seed sealed very tightly at around 8% MC is easy to store. It can be kept for a year without much problem if the initial quality of the seed lot is good even in normal, tropical, indoor, ambient temperature of around 30°. However, once the container seal is opened and not resealed properly leakage occurs and the remaining seeds start to reabsorb moisture from the atmosphere and begin to deteriorate. The most important point is to keep the container tightly sealed all the time, so that seeds are kept dry.

If the seed is to be stored for a longer period, the sealed package/container can be kept in the household refrigerator or freezer. In this case, the condition is equivalent to the standard set by the International Board for Plant Genetic Resources (IBPGR) for germplasm storage. Seeds can be stored easily for more than 10 years. If parts of the seed lot have to be taken out for planting from time to time, the package including the seed inside should be rewarmed to room temperature before the hermetic seal is opened. This will prevent atmospheric water vapor to condense on the remaining seed which could then be repacked safely for further storage.

It must be noted, however, that storability of different vegetable seeds differs even under similar storage condition as shown in Table 5.3.

Table 5.3. Mean germination of six kinds of vegetable seeds grown in different years and stored under different conditions (°C - RH%).[a]

Kind of Seed	Year	Init. Germ[b] (%)	Storage Conditions 32°-90% 3 mos. (%)[a]	32°-70% 12 mos. (%)	21°-70% 15 mos. (%)	21°-50% 48 mos. (%)	10°-50% 60 mos. (%)
Bean	1958	93.0	25.1	4.7	90.7	93.6	95.4
(Phaseolus	1959	96.0	45.4	71.4	99.9	100.5	101.0
vulgaris)	1960	89.0	26.6	92.0	98.9	94.6	97.3
Pea	1958	93.6	72.5	52.3	97.4	100.8	101.2
(Pisum	1959	94.0	76.5	81.5	98.9	92.1	99.8
sativum)	1960	94.8	60.8	77.7	90.9	86.7	96.2
Watermelon	1958	89.5	43.2	44.6	87.6	96.0	97.7
(Citrulus	1959	99.0	67.4	43.5	95.6	97.5	97.6
lanatus)	1960	92.7	6.7	65.4	87.9	96.8	99.4
Cucumber	1958	95.5	16.4	25.6	84.9	94.6	96.9
(Cucumis	1959	97.6	59.0	69.3	96.6	99.1	99.9
sativus)	1960	96.6	0.5	82.7	95.8	97.1	100.3
Tomato	1958	89.7	50.2	69.9	91.0	98.0	98.9
(Lycopersicon	1959	87.5	76.9	83.4	92.1	94.5	98.5
lycopersicum)	1960	96.6	6.1	85.2	93.8	95.6	96.9
Sweet corn	1958	89.2	0.3	0.3	83.5	97.5	100.6
(Zea mays)	1959	95.2	14.2	8.4	97.4	93.6	100.5
	1960	98.4	0	52.5	97.8	95.5	98.5

[a]After James et al. 1967.

It is best not to treat the seed with agrochemicals before and during storage if the seed is clean and healthy, and the seed packages have to be kept in the kitchen or in a household refrigerator/freezer. Recommended seed treatment can be done just before planting. This will prevent food contamination and danger from accidental consumption of treated seeds. If storage insects (weevils) cause any problem, pack the seed with napthalene (moth ball).

If small quantities of many species and varieties are to be stored, a home-made desiccator can be used. It can be made from any large-mouth glass jar with a good rubber-gasket top, (e.g., food preservation bottle, or small airtight metal biscuit tin with a good lid). Among the desiccants that can be used are silica gel, calcium chloride, quick lime, cooled-down fresh wood ash, and dry charcoal. Silica gel and calcium chloride can be reactivated for reuse by heating. The former is inert and the most hygroscopic (readily taking up and retaining moisture). It changes from blue (dry) to pink when wet (RH above 45%) — an objective indication of the status of the storage environment.

The set-up is similar to that of the laboratory desiccator. At the bottom of the jar, a layer of desiccant (e.g., silica gel), which is about 10% of the container space, is put. This is followed by a porous layer of paper, wire-mesh, or perforated metal plate as base for the seed packages to stand on. The seed packages should not be airtight, so that there will be free exchange of moisture between the seeds and the desiccant. Suitable materials for packaging in this case are paper, cotton, and nylon netting. Plastic-based bags should not be hermetically sealed; so that moisture from the seed can diffuse out and be absorbed by the desiccant.

In the past, soybean seeds in Taiwan were stored in clay jars with a layer of fresh wood ash at the bottom and at the top before the jar was finally sealed. Fresh wood ash acts both as a desiccant and as a repellent against insect pests. With this technique, soybean seed viability can be maintained from one season to another without any problem. See Fig. 5.1 for a similar set-up, using charcoal instead of wood ash.

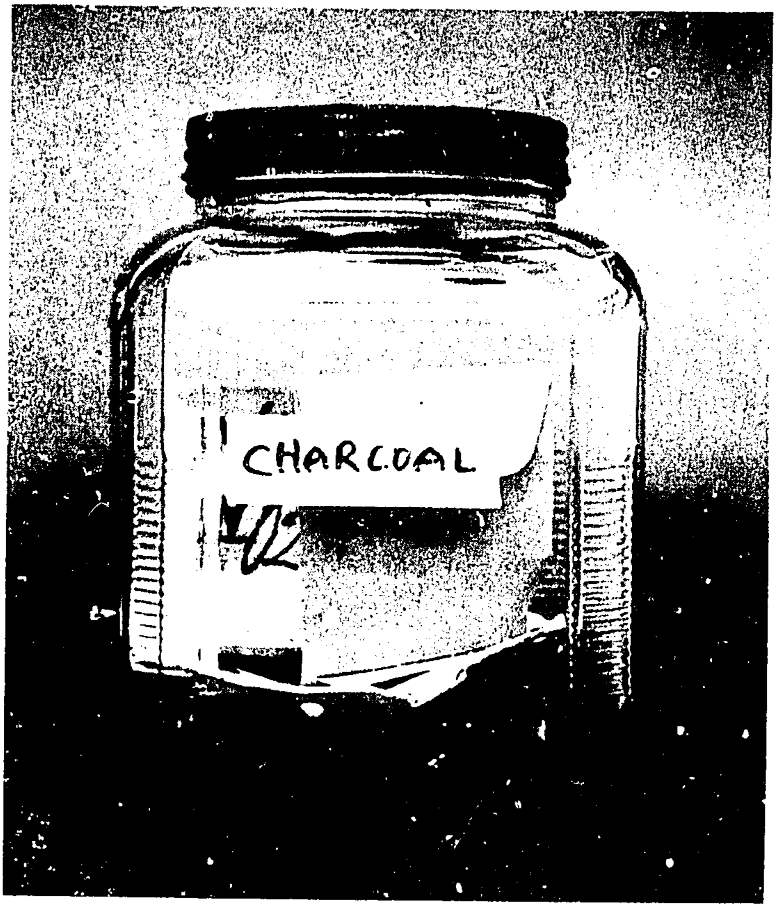

Fig. 5.1. Storing seeds with the use of charcoal.

The homemade desiccator can also be used to dry small amounts of seed to a very low seed moisture content of 5%-6%. AVRDC's slow seed dryer operating at 15°C and 15% RH makes use of this principle to dry seeds to 5% moisture content for long-term germplasm storage.

Specialized Large-Scale Seed Production

The principles involved in specialized large-scale production of vegetable seeds are similar to those applied at the farmers' level. The main difference is the highly technical skill needed and instrumentation used in the different phases of commercial production to ensure quality. Another vital factor is the aspect on seed distribution and trade.

To ensure the production of quality seeds, a seed-certification program which can be official (voluntary/compulsory) or self-imposed must be implemented. Seed certification encourages the production and distribution of superior seeds and propagating materials that adhere to high standards of genetic identity, physical purity, and other desirable attributes. It assures the close supervision of every production stage from the development of a new variety by the breeder to the final step, planting in the farmer's field, processing, and quality control. In the multiplication program, certain international and national standards must be prescribed for each crop and for each step.

In developing countries, the national seed programs are usually concentrated on cereal and grain legumes which may have seed certification programs already imposed. For vegetables, the large number of species involved would make a fully operational seed certification system too costly to establish and maintain. Often there is no vegetable seed industry, and if available, it is poorly organized. The function of any seed certification system in vegetable seed production should be to promote the availability of high quality seeds and should not hamper improvement and innovation. Therefore, in developing countries, a certification system should be optional and voluntary (self-imposed).

In the private sector, the certification program is usually self-imposed because the reputation of a company depends on the ability to consistently produce and market high quality seeds. All seed producers should adapt this attitude.

Seed Generations

Generally, the certification program classifies seed generations into: (1) breeder seed, (2) pre-basic seed, (3) basic seed, and (4) certified seed.

Breeder seed. It is the purest quality seed of a named variety produced by the breeder or the breeding institute which released the variety. To maintain purity, positive selection is carried out during every seed production cycle, and only a few of the best plants that are true to type of the variety are selected. Pollination is under strict control. Occasionally, vegetative propagation of a few nuclear stock plants is done.

Pre-basic seed. Several generations of multiplication may be carried out as for breeder seed, to build up the population of basic seed. The generation between the breeder seed and the basic seed is the pre-basic seed. This step may be by-passed if a large quantity of breeder seed can be produced, stored, and released gradually as needed.

Basic seed. Basic seed is produced from breeder seed or proven basic seed. Quality control is stringent through strictly controlled pollination and rouging. The breeder or the breeding institution should be involved in the supervision. Depending on the multiplication rate of the species concerned, this seed may be used directly for the production of certified seed. This is equivalent to the Foundation Seed in non-European classifications.

Certified seed. Certified seed can be produced from basic seed or an earlier generation of certified seed under a certification scheme. The breeder normally has no control at this stage. The seed produced from basic seed is known as ***certified seed, first generation*** (C_1). Seed produced from the latter is known as ***certified seed, second generation*** (C_2), and so on. Seed from any one of these multiplied generations is used for commercial crop production. However, due to the number of generations for large-scale production, the variety may lose its genuineness. The number of regenerations of certified seed should, therefore, be controlled. This will allow new basic seed to be injected into the certified-seed multiplication program.

An example of the certification of vegetables on the Pai-tsai group including Chinese cabbage and edible rape in Taiwan is as follows.

A. Standards for Field Inspection

1. General standards:
   a. Only one variety of the same crop may be grown for seed production on a farm.
   b. The crop should not be grown on lands where vegetables of Brassicaceae were grown during the previous crop season.
   c. In case the land is infested with soil-borne diseases, it should be planted with non-Brassicaceae plants for three years before it can be used again for seed productions of the Pai-tsai group.
   d. Compost applied on the seed farm should not contain residues of Brassicaceae plants.
   e. Field inspection should be made during bolting and harvesting stages.
   f. Isolation (minimum). The isolation between varieties is 1,000 m for stock seed farms and 800 m for extension seed farms.
   g. During field inspection, the facilities for harvesting and storage should also be inspected.
   h. The certified seeds must be properly stored in bags or in other containers.
   i. Clearly marked signboards should be erected on the farms.
2. Specific standards:

Item	Foundation Seed Farm	Stock Seed Farm	Extension Seed Farm
Other crop/variety (max)	None	0.2%	0.5%
Soft rot, virus diseases, *Sclerotinia* rot	Very slight	Slight	Slight

B. Standards for Laboratory Seed Analysis:

Item	Foundation Seed (%)	Stock Seed (%)	Extension Seed (%)
Moisture content (max)	10.5	11.0	11.0
Pure seed (min)	99.4	98.7	97.7
Other crop/variety seed (max)	-	0.2	0.5
Weed seed (max)	0.1	0.1	0.3
Inert matter (max)	0.5	1.0	1.5
Germination (min)	85.0	80.0	75.0

Note: The weight of each submitted sample is 20 g.
- = None.

A Viable Seed Production Program

A seed production program can be set up successfully under two conditions. First, there should be a need for the seeds (varieties) for local or for export market. Secondly, quality seed of the species should be produced in the country profitably. With these two conditions, a successful multiplication system can be established as described earlier for each variety. The responsibility of different agencies dealing with the different stages of multiplication should be clearly defined. Also, when the system is not working smoothly, the cause of the problem can be pinpointed.

The supervising agency taking care of seed quality control (including field inspections, sampling, and laboratory tests) should be an independent body. Usually, the International Seed Testing Association (ISTA) rules are applied. However, appropriate allowance (i.e., relaxation on some of the rules) should be provided, depending on the maturity of the national seed program. This will promote further progress in seed activity rather than create an obstacle if the national seed program does not have sufficient means to follow the strict rules set up by ISTA.

Advance vegetable seed production technology is available in many developed countries, including Taiwan. The private sector has successfully adopted this technology. The steps in seed production technology include the following:

1. Maintenance of stock seed
2. Field-scale production
3. Harvesting
4. Drying and threshing
5. Processing and cleaning
6. Seed treatment and packaging
7. Storage
8. Seed quality control
9. Marketing and distribution

To grow a good seed crop, the grower should know how to grow the crop well. This includes suitable crop rotation, good seedling production, and proper management practice, such as seed-bed preparation, fertilization, irrigation, and pest control. Reference should, therefore, be made to the respective chapters in this manual. A seed crop is harvested at a stage when seed quality is best and the harvest loss is minimal. The seed is conditioned after threshing to remove the undesirable materials, upgrade seed quality, treat seed with agrochemicals, and pack seed into desired containers.

The undesirable materials include: trash, dust, hulls, leaves, stems, dirt, mud balls, weed seeds, other crop seeds, other cultivar seeds, undesirable seeds of the seed crop (broken, immature, shrivelled, insect-damaged, moisture-damaged, mold-damaged, diseased, etc.). The aim of any seed processing is to completely separate the undesirable materials, minimize seed loss, upgrade seed quality, and prevent loss of seed quality in the most efficient manner. The steps followed in sequence are receiving, drying, precleaning storage, precleaning, basic cleaning, upgrading, treating, bagging, storing, and shipping.

Crop management, harvesting, and seed conditioning are carried out depending on the crop species. The following references are recommended for a more detailed discussion of the operations: George 1980, 1984; Grubben 1978; Salunkhe 1987; and Shinohara 1981.

Finally, each member of the seed production team, from grower to technician, should know their duties and perform them efficiently. A competent, dedicated, conscientious, self-motivated, and dependable staff is the most important asset for the success of any seed production program.

Seed Production Environment

The seed producer should know the environmental factors which affect the production of seeds. The selection of the seed production site is influenced by climatic and soil factors. The site should have a suitable day-night temperature regime, a relatively low RH (60%), a good water source for irrigation, a good soil drainage, and a minimal disease and insect pest problem. Vegetables need intensive crop management practices. Ecological and soil-related factors can be modified by cultural practices which should be technically feasible and profitable.

The most important climatic factors of seed production are temperature, daylength, rainfall, relative humidity, and wind.

Temperature. Temperature affects flowering especially on biennial vegetables like cabbage, onion, and carrot. These crops will not flower until they are exposed to low temperatures during certain stages of their development for a period of time. The ability to flower and to develop seed through low temperature treatment is known as ***vernalization*** (Chapter 7). This is acquired under natural conditions in temperate countries.

Under tropical conditions, these vegetables can be vernalized artificially. Chinese cabbage, for instance, can be artificially vernalized at the germination stage to make the plant flower later. In carrot, the mature roots have to be harvested, selected, and kept in cold storage (2°-5°C) before planting again for seed production in the cool season. These practices are costly and also more liable to create management problems during handling.

Some annual vegetables are also affected by temperature during the reproductive stage. Tomato, a relatively warm-season crop, sets fruit very poorly when night temperature is high. The optimum for this crop is a night temperature range of 15°-18°C.

Daylength. The relative length of light and dark periods (photoperiod) is very important in the flowering and fruiting of some vegetables. Soybean, pea, and winged bean are examples of vegetables which are sensitive to photoperiod. These vegetables do not flower if the daylength is more than what is required. These vegetables normally begin to flower towards the shorter days of the year starting at the latter part of September in the Northern Hemisphere.

Rainfall and relative humidity. The significance of these environmental factors on seed production is their effect on the fruiting stage. Pollination may be adversely affected when there is too much rain. Rain during the fruiting period also promotes high relative humidity which enhances the growth of foliage and disease incidence. A dry period at fruit maturity is favorable for the harvesting and processing of the seeds.

Wind. Pollination and seed ripening are favored by air movement through the crop. The crop also dries faster, so that harvesting and threshing can be done conveniently. Continuous strong winds, however, may cause some problems, such as shattering, which results in some loss of seeds.

Additional information on vegetable production in the tropics is summarized in Table 5.4.

Table 5.4. Provisional data on seed production of vegetables in the tropics.

Vegetable Types	Fertilization[a]	Pollen Agent[b]	Day-Length[c]	Weight/ 1000 Seeds[d] (g)	Seed[e] (kg/ha)	Duration[f] (months)	Seed Yield Normal	(kg/ha)[g] High
1. Solanaceous vegetables								
Sweet pepper	mixed	insects	n	5.5	0.4	4	60	100
Hot pepper	mixed	insects	n	3.3	0.5	9	200	600
Tomato	self	—	n	3.3	0.4	5	80	150
African eggplant	mixed	insects	sh	3.3	0.6	10	120	150
Eggplant	mixed	insects	sh/n	4.0	0.8	7	200	300
2. Cucurbits								
Wax gourd	cross	insects	n	70	2	5	250	400
Watermelon	cross	insects	n	70	3	4	250	400
Melon	cross	insects	n	25	2	4	300	600
Cucumber	cross	insects	n	25	3	4	300	800
Pumpkin (squash)	cross	insects	n	170 (70)	2	4	500	800
Bottle gourd	cross	insects	n	150	3	6	400	600
Loofah	cross	insects	n	90	3	6	250	400
Bitter gourd	cross	insects	n	60	5	4	250	400
3. Leguminous vegetables								
Pigeon pea	mixed	insects	sh/n	125	15	9	1200	3500
Sword bean	mixed	insects	sh	4000	60	9	1300	2500
Hyacinth bean	self	—	sh/n/l	330	40	9	900	2000
Soybean	self	—	sh	670	50	4	1300	3000
Lima bean	self	—	sh/n	400-800	50	9	1000	2500
Mungbean	self	—	sh/n	30	5	4	500	1200
Common bean	self	—	n	290	100	4	800	2000
Pea	self	—	n	170	120	3	1500	2500
Winged bean	self	—	sh	500	20	7	1100	2500
Yard-long bean	self	—	sh	270	20	6	500	1500
Cowpea	self	—	sh/n	220	20	5	700	2500
Voandzou	mixed	insects	sh	670	80	4	600	2000
4. Crucifers								
Chinese cabbage (pak-choi)	cross	insects	n/l	3	0.6	5	500	800
Chinese cabbage (pet-sai)	cross	insects	1	3	0.6	6*	500	800
African cabbage	cross	insects	n/l	2	1.0	5	600	900
Turnip	cross	insects	1	3	1.5	9*	600	1200
Mustard	cross	insects	n/l	2	1.0	6	600	900
Kale, borecole	cross	insects	n/l	2	1.0	9*	600	900
Cauliflower	mixed	insects	n	3	0.3	6*	150	300
Broccoli	cross	insects	sh/n	3	0.3	6*	500	800
White cabbage	cross	insects	n	4	0.6	9*	600	1200
Radish	cross	insects	1	10	10	6	800	1200
5. Tropical leaf vegetables								
Amaranth	mixed	wind	sh/n	0.3	1	4	500	1500
Basella	self	—	sh	40	10	6	1200	200
Celosia	cross	insects	sh	1	1	5	400	700
Jew's mallow	self	—	sh	2	1	5	300	400

Table 5.4. Continued.

Vegetable Types	Fertilization[a]	Pollen Agent[b]	Day-Length[c]	Weight/ 1000 Seeds[d] (g)	Seed[e] (kg/ha)	Duration[f] (months)	Seed Yield Normal	(kg/ha)[g] High
Kangkong	self	—	sh	40	5	5	500	—
Nightshade	self	—	n	2	1	6	100	—
Talinum	cross	insects	sh	0.3	1	6	200	300
New Zealand spinach	self	—	sh/n	65	10	6	400	800
6. Hot-season types								
Okra	mixed	insects	sh/n	50	6	6	400	1000
Roselle	self	—	sh	30	6	6	200	400
Sweet corn	cross	wind	n	150	15	4	1000	2000
7. Cool-season types								
Onion	cross	insects	n	3.0	4	9*	400	800
Japanese bunching onion	cross	insects	l	2.9	4	9*	300	600
Leek	cross	insects	l	2.5	3	12*	200	600
Celery	cross	insects	l	0.3	0.3	9*	300	500
Asparagus	cross	insects	n	40	4	3 (years)	400	1000
Beet	cross	wind	l	16	10	9*	800	1200
Endive	self	—	1	1	1	9	200	300
Carrot	cross	insects	1	1.2	1	9	300	1000
Lettuce	self	—	1	0.8	0.3	6	125	200
Spinach	cross	wind	1	10	20	6	600	1200

[a]Fertilization mainly by self-pollination, cross-pollination, or mixed.
[b]Main pollen agent for cross-pollination.
[c]Daylength reaction (photoperiodism): neutral = n, long day >13h = 1 or short day > 13th = sh.
[d]Weight of 1000 seeds approximately, in grams.
[e]Seed needed for 1 ha of seed growing.
[f]Average period in months between sowing and harvesting.
[g]Seed under suitable climatic conditions; *require a cold period for bolting.
Source: Grubben 1978.

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CHAPTER 6

Seed Quality Testing

Since seed is the basic input for vegetable production, its quality is a major factor which determines the economic success of the crops. Poor quality seeds give few and uneven plant stand from the very start, and they may be sources of inoculum for some seed-borne diseases. With the use of good seeds, one gets better results with less effort and expense.

A true botanical seed is a fertilized mature ovule with a very small plant (embryo) usually with a food storage tissue and a protective coat or coats. Sometimes the term ***"seed"*** is used for vegetative parts of plants, such as tubers, bulbs, etc., which are used for asexual propagation. The seed referred to in this chapter is the true seed.

True botanical seed can be classified into two classes: 1) orthodox seeds - those that can be dried to low moisture levels for storage at low temperature and 2) recalcitrant seeds - those that do not survive drying and freezing. Most vegetables have the orthodox seeds. A few, such as chayote (*Sechium edule*), have recalcitrant seeds.

Characteristics of High Quality Seeds

High Analytical Purity

The seeds must be free of seeds of other species and varieties, weed seeds, and other impurities. Pure seed may be separated from these impurities during seed processing. In many cases, however, varietal mixture is more difficult to distinguish. This varietal mixture can be minimized by using superior stock and preventing crossing between varieties. A knowledge of the mode of reproduction of the crop will enable the seedman to determine the right isolation distance between varieties (See Chapter 5).

Good Vigor and Germination Capacity

The seed is at its peak vigor and germination level at maturity, usually just before harvest, after which it starts to decline. Vigor and germination can be greatly affected by the following important factors.

Growing of the crop. The conditions in the field where the crop is grown can affect the germination of the seeds produced. Improper growing conditions, such as inadequate water and nutrients may result in poor development of the endosperm, thus giving rise to light or shriveled seeds which germinate poorly.

Seed maturity. Generally, immature seeds have less germination ability and vigor than mature ones. This poor germination performance may be due to the limited amount of food reserves in the immature seed. Thus, immature seeds may germinate well after harvest but lose their viability after a few months of storage when the limited food reserves may have been exhausted. Another reason is the inability of immature seeds to absorb water and oxygen which are important for germination.

Moisture and temperature. These factors are important when seeds are stored before planting. The higher the moisture content and temperature during storage, the faster is the respiration process, consequently, the faster the viability of the seeds is lost. A general rule on the effect of these two factors states that for each drop of 1% of moisture content and for each drop of 5.6°C, the lifetime of the seed is doubled.

Seed damage. Seed injury may affect the embryo or the radicle, the food storage, or the pathway of food to the embryo. Seed vigor and germination are reduced. It also makes the seeds susceptible to the attack of microorganisms.

Free from Seed-Borne Disease

The disease is either on the seed surface or in a deep-seated tissue of the seed. One infected seed can infect many plants in a seedflat or seedbed before they are transplanted to the field. A few infected plants in the field can provide the source of inoculum to spread the disease to other plants. Examples of seed-borne diseases are tomato mosaic virus, halo blight in beans, and mosaic virus in lettuce and cabbage.

Seed regulations exist in many countries to protect the seed buyer. These regulations prescribe the minimum quality standards for seed lots. The International Seed Testing Association (ISTA), to which many countries are associated, has formulated the International Rules for Seed Testing (ISTA 1985) which prescribes testing methods but does not set standards for seed lots.

Seed Germination

The process of germination has been discussed in Chapter 2. There are two kinds of germination: epigeal, where the cotyledons are lifted above ground; and hypogeal, where the cotyledons remain below the soil surface. Examples of epigeal germination are those of the common bean, soybean, cowpea, Chinese cabbage, pepper, tomato, and onion. Hypogeal germination is demonstrated by sweet corn, adzuki bean, broad bean, and pea. The different types of germination are shown in Fig. 6.1.

Requirements for Germination

Biological factors. The seed is physiologically mature and not dormant. Dormancy is described in detail later in this chapter.

Environmental factors. The following environmental factors are important considerations in the germination of the seed:

- Water — This is essential for softening seed coat and swelling of the seed causing the seed coat to rupture. It facilitates gas exchange through the wetted cell wall, promoting enzyme activation and translocation leading to the assimilation of the reserved storage materials. Seeds germinate at a range of 30-55% moisture.

  The process by which water enters the seed is called ***imbibition*** and is affected by the following factors: ambient temperature, moisture availability and its osmotic pressure, permeability of the seed coat, chemical composition of the seed, and

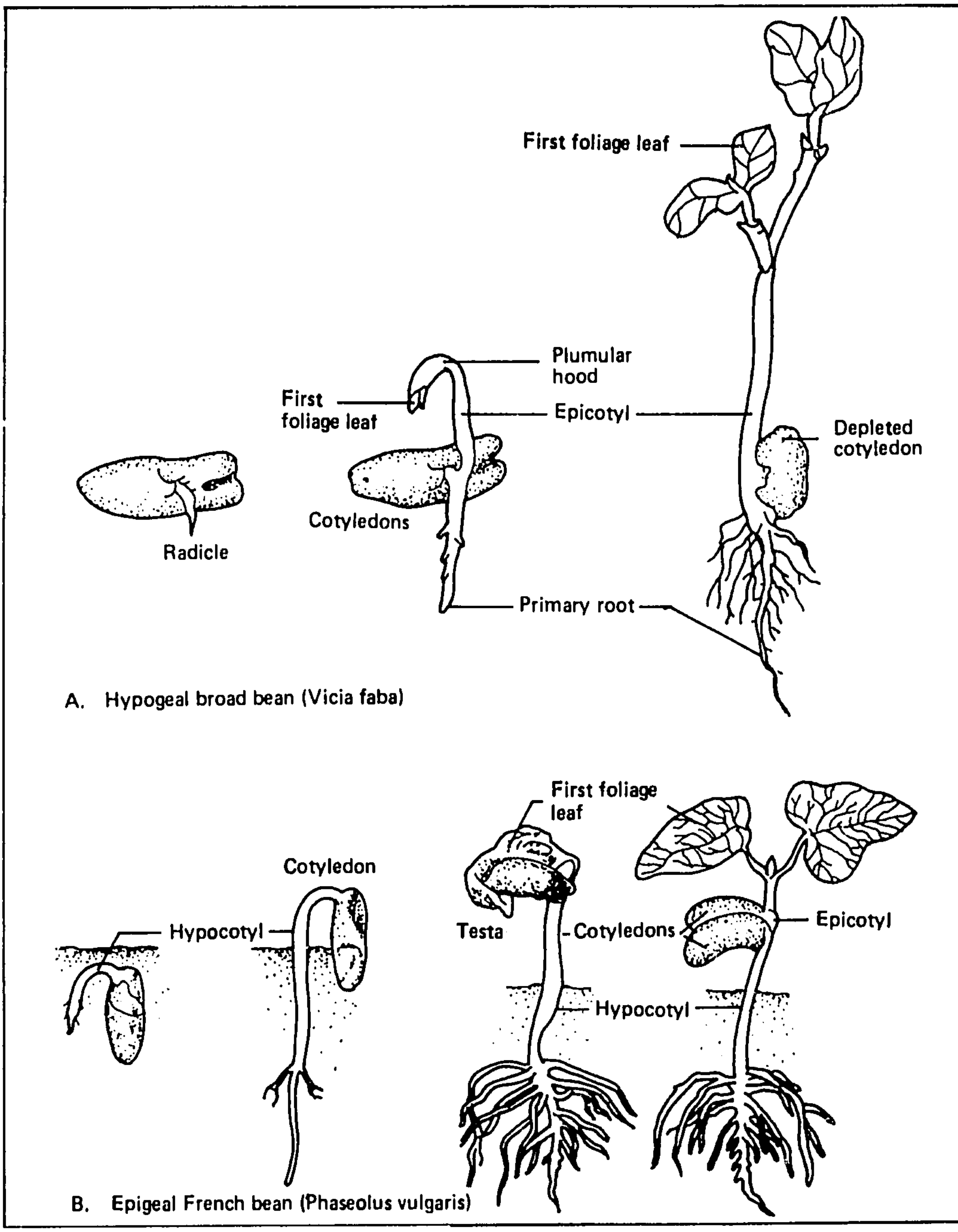

Fig. 6.1. The hypogeal and epigeal type of seedling development shown by two species in which the cotyledons are the storage organs.

duration of exposure. Water imbibition creates pressure due to absorption of water by seed storage protein, cellulose, pectic colloidal particles, etc. of the seed tissue, causing the seed to increase in size. Imbibition is a physical process and has no relation to seed viability. A dead seed also imbibes.

The relationship between dry weight of different embryonic organs during germination is illustrated in Fig. 6.2.

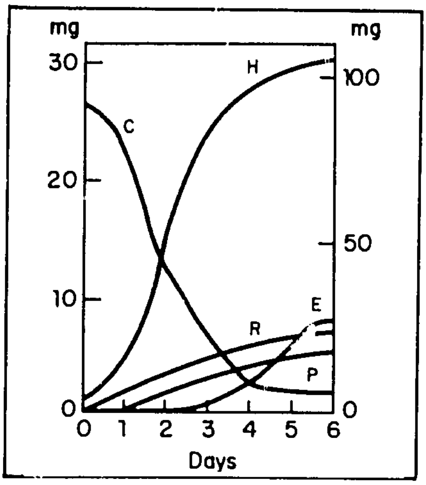

Fig. 6.2. Changes in dry weight of embryonic organs of *Vigna sesquipedalis* during germination.

- Oxygen — This is required in aerobic respiration which produces the energy needed in the germination process. Most vegetable seeds germinate at 20% oxygen.
- Temperature — This requirement for different species varies. Germination will take place between 5°-45°C with the optimum around 20°-30°C. Some seeds require alternating low and high temperatures for germination; others may require chilling temperature. The range of temperatures for germination of some vegetables is presented in Table 6.1.
- Light — This is usually optional in most cultivated species, although enhanced germination in light has been observed in freshly harvested seeds of lettuce. The intensity and quality of light also affect germination.

Table 6.1. Optimum temperature ranges for vegetable germination.

Temperature (°C)	Vegetable Species
10-15	Celery, lettuce, peas, spinach
15-20	Bunching onion, carrot, Chinese cabbage, onion, radish
20-30	Asparagus, cucumber, eggplant, mungbean, snapbean, soybean, sweet corn, tomato
30-35	Asparagus bean, cucurbit

The light sensitivity of seeds can be affected by the following factors:

1. Age of seeds — Seeds are more sensitive when freshly harvested but become less sensitive later.

2. Period of imbibition — After one hour of imbibition, lettuce was found to germinate better when exposed to light for two minutes.

3. Temperature at imbibition — Seeds become more sensitive to light when they are first exposed to a higher temperature, then returned to the optimum temperature.

4. Chemicals -- Some chemicals, like potassium nitrate, when used for moistening the media can reduce or completely eliminate light requirement. Gerrnination is promoted by gibberellic acid, thiourea, and kinetin.

5. Other factors—These factors are osmotic pressures and hydrogen ion concentration (pH) of the water medium (pH range 4.7-6), presoaking, low temperature (i.e., stratification) and radiation (e.g., gamma), and mechanical damage at harvesting, processing, and handling.

Seed Dormancy

Dormancy is the inability of seeds to germinate under favorable conditions. It may be due to a physical or physiological condition of a viable seed. In agriculture, seed dormancy affects crop establishment, growth, and harvest, and uniformity of seed development and maturation. The ungerminated dormant seeds that remain in the soil for many years will produce unwanted volunteer plants in future plantings.

In some crops, dormancy may be desirable when it prevents preharvest and postharvest sprouting during wet weather, thereby, maintaining seed quality. Dormancy protects the entire crop stand against total loss during drought, and insect and disease infestations.

Seed dormancy is caused by the following factors:

- Immature embryos, e.g., *Pinus* spp., *Lactuca sativa* (some vs), need after-ripening
- Seed coats impermeable to water (sweet potato and mungbean) and/or gases (cucumber, beet, lettuce)
- Presence of germination inhibitors such as phenolic compounds, e.g., abscissic and caffeic acids (beet)
- Physiological immaturity, e.g., absence of some growth substances or more inhibitors than growth substances (though morphological growth is complete)
- Light sensitivity
- Mechanical restriction to seedling growth by seed coats, e.g., *Amaranthus retroflexus,* probably seedless watermelon.

Impermeable seed coat is caused by impervious substances deposited in the testa, pericarp, or nucellar membranes. In wild soybean, it may be the presence of a strophiolar cleft of the seed coat in the micropylar region. During the final stages of ripening, weather and soil conditions are important in inducing hard seed formation. The breakdown of hard seedcoats with time in natural environment is due to the following processes: a) wetting and drying, b) freezing and thawing, c) forest fires, d) passage through digestive tracts of animals, e) action of natural soil acidity, and f) attack by microorganisms.

Inhibitors are substances that stop the metabolic succession of events during germination, e.g., endogenous chemical germination inhibitors. It is difficult to locate inhibitors in the seed. They can be in the embryo, endosperm, pericarp, and wall of fruits. The chemical nature of inhibitors consists of simple organic compounds of relatively low molecular weight. Some of the natural inhibitors are cyanide and ammonia compounds, mustard oils, alkaloids (caffeine, cocaine), organic acids, abscisic acid (ABA), unsaturated lactones (coumarin), essential oils, phenolic compounds, and synthetic growth retardants, e.g., c.c.c. (chlorocholine chloride).

Inhibition is accomplished through blocking of the production of processes needed for respiration, e.g., from storage starch to simple sugars by amylase, from storage proteins to amino acids and amides by protease, from storage fats to fatty acids by lipase, etc.

Phytin, the main source of the seed's inorganic P needed in the energy-rich phosphate bonds which provide the energy for germination is inhibited by coumarin. Germination can be prevented by chemical inhibition, osmotic inhibition, or a combination of the two, e.g., ferulic acid inhibits the germination of tomato seeds inside the fruit.

Physiological immaturity may involve the entire root-shoot axis or only the plumule or radicle. Some species require a low-temperature pretreatment (3°-10°C) known as ***stratification***, but others need high temperature (40°C) treatment to induce germination. The treatment time also depends on the age of the seed. Light intensity, wavelength, and photoperiod also affect physiological immaturity, e.g., lettuce dormancy is broken by red light and continuous white light inhibits both onion and leek seeds.

Environmental factors such as water supply, mineral nutrient especially nitrogen, seed moisture content during seed development, maturation, and harvesting also affect dormancy. Age of seed and storage conditions also affect seed physiological immaturity. For example, higher temperature breaks dormancy.

Methods to overcome seed dormancy are the following:

1. Use of suitable temperature regime:

   a. the correct optimum
   b. alternation of temperatures, e.g., 8 hours at 30°C and 16 hours at 20°C
   c. prechilling moist seeds at 5°-8°C

   The effectiveness is attributed to the hastening of postharvest maturation, promotion of gas exchange, and alteration of growth regulations and other reactant in the germination processes [reduction of ABA (abscisic acid) and increase of GA (gibberellic acid)].

2. Modification of seed coats by:

   a. cutting
   b. milling to remove adherent appendages
   c. scarification by abrasion or chemicals such as acetone, alcohol, hydrogen peroxide, sulfuric acid, hydrochloric acid, and sodium hydroxide (Try to avoid excess because it will cause injury.)

   The effectiveness is attributed to the removal of inhibitors or facilitating their leaching (washing down) from various components of the seed, promoting gas exchange, and improving water absorption.

3. Removal or neutralization of inhibitor by leaching seeds in water solutions of promotor or placing them on activated carbon

4. Chemical treatment with:

   a. potassium nitrate (KNO_3)
   b. thiourea
   c. hydrogen peroxide (H_2O_2)
   d. plant growth regulators like gibberellins, auxins, cytokinins, and ethylene

The effectiveness of the chemical treatment depends on the species involved. Generally, a combination of promotors gives better results. The mechanism is attributed to the influences on the enzyme systems involved in the various metabolic phases of the germination process. Gibberellins play a primary role in regulating germination and in breaking dormancy. The effect of inhibitors, such as abscisic acid and cytokinins, is secondary because they depend on the presence or absence of gibberellins. Without gibberellins, the seed will not germinate; and with gibberellins, the seed remains dormant only when an inhibitor is present in the absence of cytokinin.

Germination Test

A germination test is done to determine the field planting value of the seed lot and to obtain results which can be used to compare the value of different seed lots. The results on the same seed lot should be uniform and reproducible between different tests and laboratories. To accomplish this, laboratory germination test with recommended fixed testing conditions and seedling evaluation standard for different species was developed by International Seed Testing Association (ISTA) for international use.

Usually, the recommended test conditions provide the best growing environment for the seed to germinate. The germination test will provide an indication of the quality of the seed lot, that is, if it is well cleaned and not dormant. One should remember that germination result is not a precise prediction of field-emergence because the field conditions are different from the test conditions. However, comparison between results of two seed lots will give an indication of their relative field-emergence ability.

Vigor test predicts field emergence better. The test is to be done on seeds from the pure seed fraction of a purity test. The seed shall receive no pretreatments except those recommended by ISTA (ISTA 1985).

Sampling

The objective of sampling is to obtain a sample of a size suitable for seed tests, in which the same constituents are present as in the seed lot and in the same proportions. Steps to get a representative sample is described in detail in the ISTA rules (ISTA 1985).

Representative primary samples are obtained from the seed lot by taking small portions at random from different positions in the lot and then combining them to form the composite sample. From this sample, smaller samples (submitted samples) is obtained by one or more stages. Similarly, a working sample are obtained from the submitted sample. At each stage, thorough mixing is followed either by progressive subdivision or by the abstraction and combination of small portions at random (Fig. 6.3).

The instruments and methods used in sampling the lot are the stick or sleeve-type trier, nobbe trier, and hand sampling.

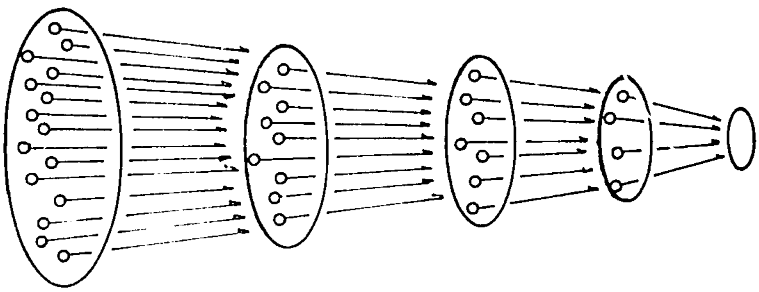

Fig. 6.3. Diagrammatic representation of successive stages in taking a sample from a seed lot.

The sampling methods used in the laboratory to reduce the submitted sample to the size of a working sample are the following:

1. Mechanical divider method
   a. Conical divider
   b. Soil divider
   c. Centrifugal divider
2. Random cup method
3. Modified halving method
4. Spoon method

The mechanical divider method is briefly presented here. A special machine which divides the sample into almost equal parts is used to mix the samples. The sample is passed through the divider, recombining the two parts, and passing the whole sample again two or three times. To reduce the quantity of the sample, half of the sample is removed in the succeeding run through the machine. This process is continued until a working sample of approximately (but not less than) the required size is obtained. The ISTA rules specify the size of samples to be submitted and the working samples of different species. (Fig. 6.4 shows a conical divider.)

General Method

From the working sample (pure seed fraction) 400 seeds in replicates of 25, 50, or 100 seeds are arranged and spaced uniformly on or in the substrate and maintained at a favorable moisture level under conditions of temperature and light indicated in the ISTA rules (Table 5a) (ISTA 1985). The uniformly spaced seedlings will facilitate germination evaluation and prevent the spread of disease infection. A good strategy is to include a recommended treatment to break dormancy for the species under testing, e.g., using potassium nitrate on half of the total number of replicates. Contaminated seeds may be sterilized or treated with fungicide.

Fig. 6.4. Conical divider.

Seed of each replicate can be counted by hand, with counting boards, or vacuum seed counters. If counting is to be done by hand, the pure seed lot should be divided into representative and equal subsamples corresponding to the number of replicates required for germination test (usually four replicates) with the use of the halving technique. The required number of seed for each replicate is then counted from each subsample.

When using a counting board, the holes should be slightly bigger than the biggest seed in the seed lot to prevent exclusion of the big-seeded portion of the seed lot. When using a vacuum counter, the entire head of the counter should be filled with seed before the vacuum is applied. This will prevent nonrandom sampling of the sample lot. The seed lot has to be mixed again before the next replicate is obtained. Never draw samples by facing the head down and sucking the seed directly from the seed lot because this will suck up mostly the lighter seeds. The size of the board and vacuum plate should fit the size of the germination tray, so that the exact number of seed in the replicate is directly placed on the tray at a uniform spacing.

Procedures

Methods using paper. The type of paper selected should be porous, thick to hold enough water, and fine in texture to prevent roots from growing through the paper. The removal of seedlings during counting may damage other younger seedlings that are not yet ready for counting if roots grow through the paper substrates. The common materials used are filter paper, blotter paper, paper towel, and cloth towel. The substrate should be free from contamination of microorganisms and phytotoxic compounds and have pH of 6.0-7.5 The two methods are as follows:

a. Top of paper (TP) — Seeds are germinated on top of one or more layers of paper.

b. Between paper (BP) — Seeds are germinated between two layers of paper. It can be flat on the tray, rolled up to stand on the tray or "pleated" in the tray. The "pleated" paper is most suitable for pelleted seeds.

Methods using sand. This substratum is most suitable for testing big seeds, such as sweet corn, soybean, common bean, and broad bean. The two methods are as follows:

a. In sand (S) — Seeds are planted on a uniform layer of loose moistened sand and then covered to a depth of 10-20 mm with sand which is left loose.

b. Top of sand (TS) — Seeds are pressed into the surface of the sand. The sand should be between 0.05-0.8 mm in diameter. The sand is washed and sterilized before use in order to kill microorganisms and weed seeds. During the testing period, the sand is maintained at a water-holding capacity of 50%-60%, and pH of 6.0-7.5. The top and bottom moist sand layers should be raked loose in order to provide good aeration.

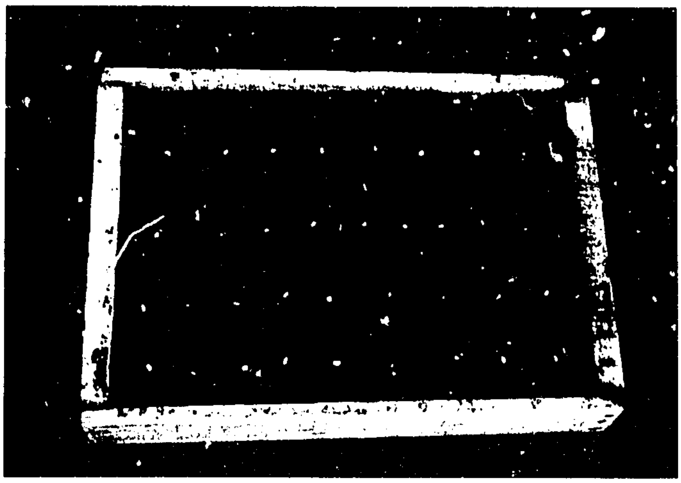

Fig. 6.5. Germinating seeds on top of the sand.

Methods using soil or an artificial compost. As in sand, the method includes "in soil" and "top of soil" schemes. The standardization of this substratum is more difficult, hence, it is not recommended normally. However, it has the advantage of absorbing some of the phytotoxic compounds in the seed, allowing normal seedling growth. When compost potting mixture is readily available, this method may be used.

Conditions for Germination Test

Moisture. The substratum should not be so wet that a film of water forms around the seeds because this will limit aeration. The initial quantity of water should be such that no additional water is required later on. Addition of water creates variability between replicates and tests. When a low moisture level is recommended, the moist substratum should be pressed against a dry absorbent surface, such as dry paper towel or blotter, to remove excess water.

Temperature. Where alternating temperatures are indicated, i.e., for seeds suspected to be dormant, the lower temperature should be maintained for16 hours and the higher one for 8 hours. The temperature from an artificial light source should not exceed the level prescribed.

Light. Many species will germinate equally well in light or in darkness. However, in the light, seedlings are more well developed (no etiolation) and, therefore, less susceptible to disease infection. In addition, any seedling with chlorophyll deficiency can be identified. When light is prescribed, it should be illuminated for at least eight hours every 24 hours during the high temperature period at an intensity of approximately 750-1,250 lux. Light can be either natural or artificial.

Intensity should be even over the entire testing surface. Any heating from the light source should not raise the temperature above the prescribed limit. Cool, white fluorescent lamps are recommended because they have a relatively low emission in the far-red and a high spectral emission in the red region which tends to promote germination.

Germination Apparatus

The three main types of germination equipment are germination cabinet, room germinator, and bell jar or Jacobsen apparatus (Copenhagen tank). The germination cabinet can control temperature only or both temperature and relative humidity (RH). The former is equivalent to a standard laboratory incubator. The latter is generally called a germinator. There are timers for both temperature and light controls; so that, high and low temperature cycle as well as light and dark cycle can be regulated. A room germinator is essentially a large walk-in germination cabinet.

The Jacobsen apparatus, also known as Copenhagen tank, is a specialized equipment for germination. It consists of an upper table for setting round paper substrate (e. g., filter papers) and seeds with the use of the TP method. Each replicate is then covered with an inverted transparent cone with a small hole at the tip for ventilation. The paper substrates are connected to a lower water tank with paper wicks. The germination temperature is controlled by regulating the water in the lower tank.

The selection of equipment depends on the availability of funds and the species to be tested. A germinator with both temperature and RH control is usually recommended if funds are available. Germination cabinets are more suitable if the species to be tested are many and small-seeded. When the sand methods have to be used, the room germinator is more convenient because of available space. However, if it breaks down, a lot of germinating space will become redundant. In addition, the flexibility to set different smaller cabinets at different temperature and light regimes for different spaces will be too costly in a room germinator.

In general, the specifications required in a germination equipment are the following:

- Working temperature range is between 5°-35°C
- Temperature variation is maintained at ±1°C.
- Change of one temperature to another (when alternating temperature is required) should be less than an hour between 10° and 30°C.
- Humidity control should be high (close to 100% RH) and consistent.
- The light source should not affect temperature and light control.
- Control should be automatic.
- It should be easy to clean and repair.

Breaking Dormancy for Retesting

If some fresh but dormant seeds remain at the end of the standard germination test, the following methods may be tried out to retest the seed lot. Recommended treatments for different species are given in the ISTA rules (ISTA 1985):

1. Prechilling—Do this at 5°-10°C for an initial period up to seven days before moving to the recommended temperatures for germination test.

2. Predrying—Do this at a temperature not exceeding 40°C with free air circulation of up to seven days before germination test.

3. Potassium nitrate—Use a 0.2% solution of KNO_3 instead of water to set up the test. Water is used to moisten the substratum at later stages.

4. Low temperature germination—Test at a lower constant temperature or at a lower temperature alternating with the high temperature.

5. Prewashing—Soak and wash in water at 25°C before the germination test in order to wash away any water-soluble plant inhibitor.

6. Gibberellic acid (GA_3)—Use 200-1000 ppm solution of GA_3 instead of water.

7. Dry storage—Store in dry condition for weeks or months before testing.

8. Removal of some outer seed structures—Seed structures, such as involucre of bristles or lemma and palea of some Gramineae, will promote germination.

Hard Seed

For hard-coated seeds (hard seeds), such as okra, peas, bean, etc. which have been stored under very dry conditions, pretesting treatments can be carried out as follows:

1. Scarification:
   - manual — by filing, chipping, piercing, clipping, and sand papering the hard testa at the cotyledon end with any suitable tool
   - chemical — by dipping into concentrated acids, such as sulfuric acid (H_2SO_4) for a few minutes to more than an hour, depending on the species, and then thoroughly washing in running water
2. Soaking for 24-48 hours in water before testing.
3. Plunging seed in water of 55°C for up to 20 minutes.

Evaluation of the Test

The ISTA rules (ISTA 1985) fix the time (in days) for the first and second counts. Subsequent counts are done normally for a prolonged period of seven days if some of the seeds are still germinating. The stratification (prechilling period) for breaking dormancy is not included as part of the germination period. At the end of the second count, the remaining fresh, ungerminated seeds are reset with potassium nitrate or gibberelic acid solution (the concentration is given in ISTA rules) added in order to break dormancy, if it was not done at the beginning of the test.

In ISTA rules, ***germination*** is defined as the "emergence and development from the seed embryo of those essential structures which, for the kind of seed being tested, indicate the ability to develop into a normal plant under favorable conditions in the soil".

The assessment of germination test calls for experience and skill to evaluate the status of the seeds and seedlings under test.

Seedlings can be categorized into normal or abnormal, and seeds into hard, fresh ungerminated (dormant), or dead seed. A normal seedling is one that develops into an adult plant if left to grow in a favorable environment. It includes seedlings that are intact (totally healthy) and those with slight defects or secondary infections. Examples are given in the ISTA rules (p. 421-423, ISTA 1985). An abnormal seedling will not develop into a normal plant, even if it is allowed to develop further in favorable growing conditions. The three major classes of abnormal seedlings according to different causes are as follows:

- Damaged seedlings — seedlings with an essential structure missing or badly damaged so that balanced development is impaired. Examples are cotyledons or shoots cracked or completely separated from other parts of the seedling; cracked and split hypocotyls, epicotyls, or cotyledons; damaged or brcken coleoptile tips; split, stunted, or missing primary roots; etc.
- Deformed or unbalanced seedlings — seedlings with weak or unbalanced development due to internal physiological-biochemical disturbances. Examples of abnormalities are retarded or spindly primary roots; short and thick, looping, twisted, or spiralled hypocotyls, epicotyls, or mesocotyls; curled, discolored, or necrotic cotyledons; short and deformed, split, looping, twisted, or spiralled coleoptiles; shoots bending downward, roots with negative geotropism, chlorophyll deficiency; spindly or glassy seedlings.
- Decayed seedlings — seedlings with primary disease infection, and with decayed essential structures that prevent normal seedling development.

Hard seeds do not absorb water and, therefore, remain hard and intact at the end of testing. The seed coat can be broken first before retesting to confirm viability or be subjected to tetrazolium test. Fresh ungerminated seeds are physiologically dormant seeds which imbibe water but remain firm. Dormancy-breaking treatment or tetrazolium test can be used to confirm the viability. Dead seeds are usually soft and decayed. They should be removed and counted at each counting.

Calculation of Test Results and its Reliability

The total number of normal seedlings in each 100-seed replicate is calculated and expressed in percentage. Subreplicates of 50 or 25 seeds are combined together to form 100-seed replicate. The germination rate is the average of the four 100-seed replicates rounded to the nearest whole number (0.5 is taken to the higher figure) in a test. The percentage of abnormal seedlings and hard, fresh, and dead seeds is expressed similarly. The sum total of all the different components should add up to 100%.

The ISTA Rules (ISTA 1985) produced a tolerance table based on the range (difference between the highest and lowest replicates) at each germination rate (Table 5b). A test is considered reliable if the range is within the tolerance limit as indicated in that table.

The compatibility of two different germination tests can be compared using Table 5c in ISTA Rules (ISTA 1985). They are compatible if the difference in their germination rate is within the tolerance indicated for the average germination rate of the two tests.

Retesting is carried out when any one of the above two tolerance limits failed; when reliability of the germination test is suspected because of seed dormancy, phytotoxicity, fungal or bacterial infection; when a number of the seedlings are difficult to evaluate; or when there is evidence of mistakes in test conditions.

A copy of the Genetic Resources and Seed Unit's (GRSU's) recording form is shown in Fig. 6.6.

Biochemical (Tetrazolium) Test for Viability

The advantage of this method is the speed in estimating the viability of a seed sample which normally germinates slowly or has a dormancy problem in a standard germination test. The supposed viable dormant and hard seeds at the end of a germination test can be confirmed quickly with this method.

The principle involved is the reduction process which takes place in living cells of the indicators 2, 3, 5-triphenyl-tetrazolium chloride or bromide from colorless to a red, stable, and nondiffusible substance, triphenyl-formazan. The red-colored living part of a seed is, therefore, possible to be distinguished from a dead colorless one.

Procedure

1. Seeds should be soaked in water for 12-24 hours with the normal standard germination or direct-soaking technique to soften the seeds for later incision. This will enhance the staining process and make it more uniform.
2. The tissue of the seed for staining should be exposed by piercing the seed, longitudinal cutting, transverse cutting, transverse incision, excising of the embryo, or removing the seed coat depending on the species under testing. This process is done in replicates of 100 seeds each. Seeds should, therefore, be kept moist all the time during dissecting.
3. Batches of 100-seed replicates are soaked in a 0.5% or 1.0% solution of 2, 3, 5-triphenyl tetrazolium chloride or bromide in water or monopotassium dihydrogen phosphate/disodium monohydrogen phosphate (KH_2PO_4/Na_2HPO_4) buffer (to maintain a pH of 6.5-7.5) from 2 to 48 hours at a constant temperature of 30°C. Variation in both temperature and pH affects the staining result.
4. The stained seeds are drained and washed in water for evaluation. The interpretation of the results requires skill in relating the staining patterns of the embryo and other essential seed structures to seed germination. The embryo plane and other essential structures of seed should, therefore, be correctly dissected, exposed, and observed under magnification. With experience, the staining patterns may be used to predict the capacity of the seed to produce normal seedling in a standard germination test.

Minimum Germination Percentages

Table 6.2 shows minimum official germination percentages for vegetables by Republic of China (ROC) standards.

Crop: Date Set Up:

Treat.	Row no.	Acc. no.	1______ days					2______ days					3______ days					4______ days					Germination %	Average %	Remark
			N	Ab	D	H	L	N	Ab	D	H	L	N	Ab	D	H	L	N	Ab	D	H	L			

Fig. 6.6. Sample form of the GRSU, AVRDC germination test results.

Table 6.2. Minimum official germinating percentages for vegetables according to ROC national standard.

Vegetable	Germination Percentage	Vegetable	Germination Percentage
1. *Alliums*		4. Leguminous vegetables	
Chinese chive	70	broad bean	70
leek	70	lima bean	75
onion	75	pea	75
Welsh onion	75	snap (French) bean	75
		yam bean	80
2. Crucifers		yard-long bean	75
broccoli	75		
cauliflower	75	5. Solanaceous vegetables	
Chinese cabbage (heading)	75	eggplant	65
Chinese cabbage (non-heading)	75	pepper (sweet, hot)	65
common cabbage	75	tomato	75
kale	75		
mustard	75	6. Other tropical vegetables	
radish	75	amaranth	70
turnip	80	kangkong	70
		okra	80
3. Cucurbits		sweet corn	75
bitter gourd	65		
bottle gourd (calabash)	80	7. Other cool-season vegetables	
cucumber	80	asparagus	75
melon	80	beet (leaf)	75
luffa gourd	75	burdock	75
pumpkin	80	carrot	70
squash	80	celery	65
watermelon	80	coriander	75
watermelon (seedless)	60	endive	70
wax gourd	70	garland chrysanthemum	55
		lettuce	70
		spinach	60

Purity Analysis

A vegetable grower when buying seeds expects to get pure seeds. Pure seeds means that the seed stock must have little admixture of weed seeds, chaff, straw, and other foreign matter. It is impossible actually to remove all these mixtures, especially in commercial seed production; but purity analysis is the test to determine exactly how much, no matter how low is the amount.

Objectives of the Purity Test

There are two main objectives of the test:

1. To determine the composition of the sample being tested. This is expressed by weight, thus it indicates the composition of the seed lot.

2. To identify the various seeds, inert materials, and particles composing the sample. Therefore, aside from separating and weighing each component the various seeds have to be identified with a scientific name. For a common identification, the ISTA has a List of Stabilized Plant Names (ISTA 1983) for reference.

Purity Test Components

The working sample is then taken to a purity table for analysis. The ISTA Rules define three components to be distinguished:

Pure seed. This refers to the species indicated by the sender, or found to be dominant in the test. It shall also include all botanical varieties and cultivars of that species. Structures which can be identified as that of the species are regarded as pure seed.

1. Intact seeds (seeds in the botanical sense)
2. Achenes and similar fruits, schizocarps, and mericarps with or without perianth and regardless of whether they contain a true seed, unless it is readily apparent that no true seed is present (Compositae, Umbelliferae, etc.)
3. Pieces of seeds, achenes, mericarps, and caryopses, resulting from breakage, that are more than one-half their original size. Fabaceae and Brassicacea seeds with the seed coats entirely removed are regarded as inert matter.
4. Florets and caryopses of Graminae

Other seeds. These include seeds and seed-like structures of any plant species other than that of pure seed.

Inert matter. These are seeds, seed-like structures, and other matter, such as pieces of broken or damaged seeds; achenes, mericarps one-half the original size or less; seeds of Fabaceae and Brassicaceae with the seed coats entirely removed; and structures in which it is quite apparent that no true seed is present.

Other matters are soil, sand, stones, leaves, stems, pieces of flowers, bark, fungus bodies, nematode, and all other matter that is not seed.

Procedure for Purity Test

Separation. The working sample is spread on the working table and the following steps are observed:

Each particle is assessed individually on external appearance (shape, size, color, gloss, and surface texture) and/or appearance in transmitted light.

All other seeds and inert matter particles are removed, leaving the pure seed. These separations give the three components described. Seeds enclosed in fruits other than those mentioned under "Pure Seed" will be separated and the detached empty fruit will be considered as inert matter.

The component parts are separated and then weighed. The weighing is done in grams to the minimum number of decimal places required to calculate the percentage to one decimal place.

Tolerance. When doing duplicate analysis, the differences between the two must not exceed the tolerance limit as indicated in ISTA rules, otherwise, more pairs will be analyzed. In reporting results, the report must be done to one decimal place. Components of less than 0.05% is reported as "trace"; components of 0.05%-0.1% is 0.1%. The report shall also include the scientific names of the pure seed and each species of other seed, and the kind of inert matter

Test equipment. The following are very useful:

1. Optical aides — These include the magnifying glass, and binocular microscope.
2. Balances — These must meet certain requirements with respect to precision.
3. Weighing tables — A stable one probably made of concrete is preferable.
4. Sieves — A set of these will facilitate separation of the components.
5. Other equipment — These include spoon, spatulas, forceps, scalpel shallow trays, funnels, and metal containers.

When the purity test results are submitted, the station's leading analyst confirms the results by designating two analysts to carry out another analysis. The final result will then be done on a purity form (Fig. 6.7).

Seed Health Testing

There are plant diseases caused by bacteria, fungi, viruses, mycoplasma, and nematodes which can be carried on or in the seed. In this case, the disease is referred to as seed-borne, which means that the seed infection comes from the plant which produces the seed. These pathogens can infect the germinating seed in which case the seedling cannot emerge.

If germination is not affected but the pathogens multiply, the seedling is abnormal and grows or develops poorly. Since the seed is a planting material, the seed-borne pathogen will spread the disease to many farms where the particular disease is not yet present.

The part of the microorganism which causes the disease is called ***inoculum***. These are the spores, conidia, mycelia, and sclerotia of fungi, virus particles, and bacterial cells. The inoculum of a pathogen can also be airborne or soilborne. The transmission of the inoculum can also be done by other agents, such as rain, insects, and other animals. Even the farmer himself carries these inocula.

The routine methods of health testing, therefore, does not guarantee that the resulting plants will be free of the disease; however, it points out the presence of pathogens from another source, the seed itself. This will also prevent the introduction of new pathogens in an area which has always been free of them.

Objectives and Nature of Health Test

The main principle and objective of health tests, therefore, is to detect and identify the seed-borne organisms to determine the extent to which a seed lot has been contaminated. This will give a strong indication of the high risk of the disease developing in the crop under average weather conditions.

To fulfill the purpose of the tests, the methods to be used must meet the following requirements:

1. The method should be simple, cheap, and quick.

pure seed	inert 1) matter	other 2) seeds

space for additional specifications concerning the seed lot	*1) kind of inert matter*	
species as stated by sender	*2) kind of other seeds*	*analysis number* 5)
species as analyzed (Latin) *by leading analyst*		

analysis approved *by leading analyst*	Latin name of species *established by analyst*		1ST/2ND REPLICATE			
	grams	%	weighing working sample	blowing	analysis	weighing components
working sample			Average % of replicates	*1) kind of inert matter of this replicate*		
pure seed						
inert matter 1)						
other seeds 2)						
total		*2) kind of other seeds of this replicate*				

Fig. 6.7. Purity form. Each replicate requires a separate sheet.

2. The results can be reproduced for any one sample and comparable for different samples.
3. The pathogen is easily identified.
4. The method can be standardized to fit international use.

Health Tests Methods

Direct method (visual examination). This is the simplest test to detect evidence of disease symptoms and signs. The following are examples of inocula which can be directly observed:

1. Sclerotia of *Sclerotinia* spp. often present in cabbage and other crop seeds.
2. Spots on seeds of white-seeded beans caused by pathogenic infections of *Collectotricum lindemuthianum,* and by *Ascochyta pinodes* on pale-seeded peas. An ultraviolet lamp may also facilitate detection of infected seeds. For instance, a bright yellow-green flourescence is caused on *Ascochyta* infection on peas.
3. Fruiting bodies and conidial masses of pathogenic fungi when placed in droplets of water or in lactophenol containing a dye, such as Cotton Blue, which stains the fungal cells and can be detected under a stereo microscope. Examples on vegetables are *Septoria* infections of celery and parsley seeds.

To detect fungal spores and smaller pathogenic organisms, the sample seeds may be subjected to washings which will then be centrifuged to concentrate the infection into a small volume of water. This will facilitate identification under a magnifier.

There are many more examples of inocula which can be visually examined on vegetables and other crops.

Indirect methods. There are four methods of health testing:

- Blotter method—The seeds are placed on moistened blotter paper which is treated with an antibiotic (streptomycin sulfate) to suppress growth of bacteria. Incubation will result in the growth of the pathogens. Normally seven to eight days at 20°C are needed for incubation. At any rate, this condition will vary according to the infections present. The material is then evaluated after the incubation period on the basis of the vegetative growth, fruiting bodies and the typical symptoms on the seedlings.

- Agar test—This is one of the earliest and most popular tests. At present the potato dextrose agar (PDA) is commonly used. The agar test is a strictly sterile method. The glassware and other materials used are sterilized. The agar which is also sterilized will have to be handled carefully to prevent contamination. To help reduce contamination, the preparation of the test should be done in a room with an air-filtering system.

  If seeds are to be tested for fungal pathogens, the agar medium may be treated with a trace of streptomycin sulfate (100 mg/liter agar). This will restrict bacterial development on the seeds. The seeds may also be surface-treated with a chlorine solution (sodium hypochlorite): 1% solution for ten minutes, followed by rinsing. This treatment will limit the development of seed-borne nonpathogenic microflora which can make identification of the pathogens difficult.

The incubation can be done in a regular seed germinator at 20°-30°C. A flourescent light or a near ultraviolet (NUV) light is provided.

Each test should include four replicates for more reliability and confidence. Evaluations may be made easier if done frequently (every two days) to keep up with the rapid growth of the microorganisms. Identification should be based on both vegetative growth and the development of fruiting structure.

- Serological techniques —This method is based on the interaction of antigens and antibodies. These tests are fitted for the identification of both bacterial and virus pathogens.

  An antigen (virus or bacteria) is injected into the blood stream of a live animal (usually rabbit). The animal's blood fights off the effect of the antigen by building up antibodies in the bloodstream which can be recovered by bleeding the animal. This is the antiserum which is used to test for the presence of the same virus or bacteria in the homogenized seed.

  The next step is the test in agar where a precipitate occurs when the causal agent is present. This test is very specific, requiring a different antiserum for each disease pathogen. One modification of this test involves the use of a flourescent dye to mark the antibodies and make them readily detected under a microscope with an ultra violet light.

- Growing-on test —The suspected seeds are actually grown in soil or in sand, preferably inside the greenhouse, and characteristic symptoms observed on the seedlings.

  The above are examples of methods commonly used for health tests on seeds. Many countries now realize the importance of inspecting for seed-transmitted bacteria and viruses to reduce global spread of quarantine diseases, and to prevent the spread of seed-transmitted pathogens on an epidemic scale in the farms. A quarantine list of these diseases may be available from some countries of the European Economic Community (E.E.C.) and from the European Plant Protection Organization (E.P.P.O).

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CHAPTER 7
Crop Management

Variety and growing conditions are the major factors that determine the performance of a crop. Growing conditions include the natural physical and biological environment in the farm, as well as the cultural practices used by the farmer to grow the crop. Through appropriate management practices, the farmer can alter natural conditions to make them more favorable for crop productivity. Some varieties are more responsive than others to cultural management practices, such as fertilizer application. The farmer must, therefore, use the set of management practices that best suit his chosen variety, to achieve the highest profit.

Growing practices have changed considerably in recent years. This is partly due to changes in varietal characteristics as a result of plant breeding. More accurately, however, varieties and growing practices tend to adjust to each other. For example, the practice of staking became less common with the introduction of determinate tomato varieties. On the other hand, the introduction of hybrid bitter gourd led to the practice of transplanting for this traditionally direct-seeded crop.

The process of growing vegetables is never a mechanical job, like following the steps in a cookbook. Prescribed procedures need to be changed, depending on specific environmental conditions and available resources in the farm. The ultimate challenge to the grower is to be able to use the cheapest .

In the past, management practices were developed by the trial-and-error method. With increased understanding of the plant and its environment, however, management practices became more purposeful. Thus, modern farmers are now aware of soil pH and its possible effects on the crop. They also know how to adjust it by applying measured amounts of lime. Awareness of the value of supplementary macroelements and microelements in restoring soil fertility has enabled them to do intensive cultivation without drastic yield reduction.

The development of new materials has also influenced crop management. Mulches are now available as plastic films instead of the traditional grain straws. Transplants are now grown in scientifically designed synthetic trays instead of wooden seed flats or seedbeds.

Growing vegetables today is indeed very much different from the practice many years ago. Many improved practices are still being developed, through research and experimentation. A good understanding of principles and the theoretical bases of current growing practices should help the farmer in deciding which set of management practices are most appropriate for his conditions.

Preparing Seeds for Sowing

Before they are sown, the seeds are tested for germination following simple procedures described in Chapter 6. The test helps determine seeding rate, and shows if the seed is sufficiently vigorous for sowing. For instance, if the required number of plants is 1,000 and the germination percentage is 85%, then 1,000/.85 or 1,176 seeds must be planted. If the seeding rate is too high, excess seedlings may have to be thinned out, a practice which is wasteful in seeds and labor. On the other hand, if the seeding rate is too low, replanting, an equally expensive process, may have to be done.

Inside the seed, the delicate embryos are relatively well protected by the seed coat. However, when the seed coat breaks during germination, the young seedlings are exposed to the hazards of the soil environment, such as fluctuating soil moisture, insect damage, and soil-borne diseases. These young seedlings should, therefore, be protected against injury.

Soaking or Pregermination

This is a common practice for large-seeded crops with hard seed coats, such as bitter gourd and *Luffa* gourd. Before they are sown, the seeds are soaked in water and wrapped in damp cloth until they start to germinate (Fig. 7.1). The advantage is that it takes less time for the seedling to emerge after sowing. This minimizes the need for constant watering during the dry season, and the use of labor and irrigation water.

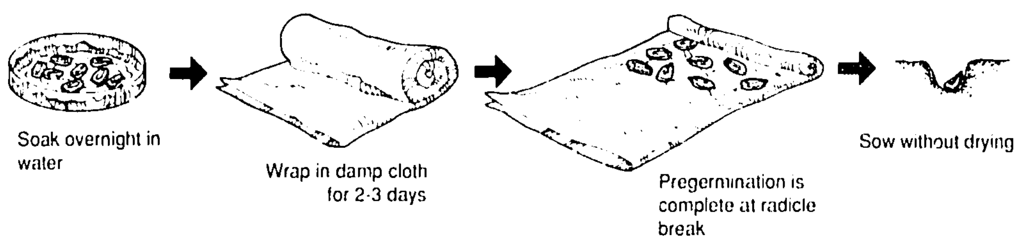

Fig. 7.1. Steps in pregermination and sowing of bitter gourd seeds.

The practice can also be done with small-seeded crops that are direct-seeded. However, this involves a more sophisticated sowing procedure. Small germinated seeds are much more difficult to handle because they are prone to mechanical damage. To minimize damage and to facilitate handling, seeds are suspended in a fluid medium and the mixture is sown. The process is called ***fluid-drilling.*** In advanced countries, special machines mounted on tractors are used to perform fluid-drilling efficiently. The fluid medium can be mixed with pesticides, growth hormones, and fertilizers to stimulate early growth of the seedlings. Fluid-drilling is not yet popular in developing countries.

Seed Treatment

Seed treatment refers to procedures that aim to disinfect the seeds or protect them against pests that may pose hazards during germination and subsequent stages of plant growth. The treatment may be physical or chemical.

Physical treatment may consist of soaking in warm water or applying dry heat. For example, cabbage seeds are soaked in water at 45°C for 20 minutes to control black rot. In pepper, heating seed in an oven at 76°C for three days following a waiting period of three months after harvest always eliminated all seed-borne viruses. In a few cases, these treatments are done by the seed producer before delivery of seeds.

Heat treatment (Fig. 7.2) is not normally a good practice because it tends to reduce germination. The viability of heat-treated seeds also decreases with continued storage after treatment. Therefore, alternative methods must be explored before using heat treatment. If this is to be used at all, it should be applied just before sowing.

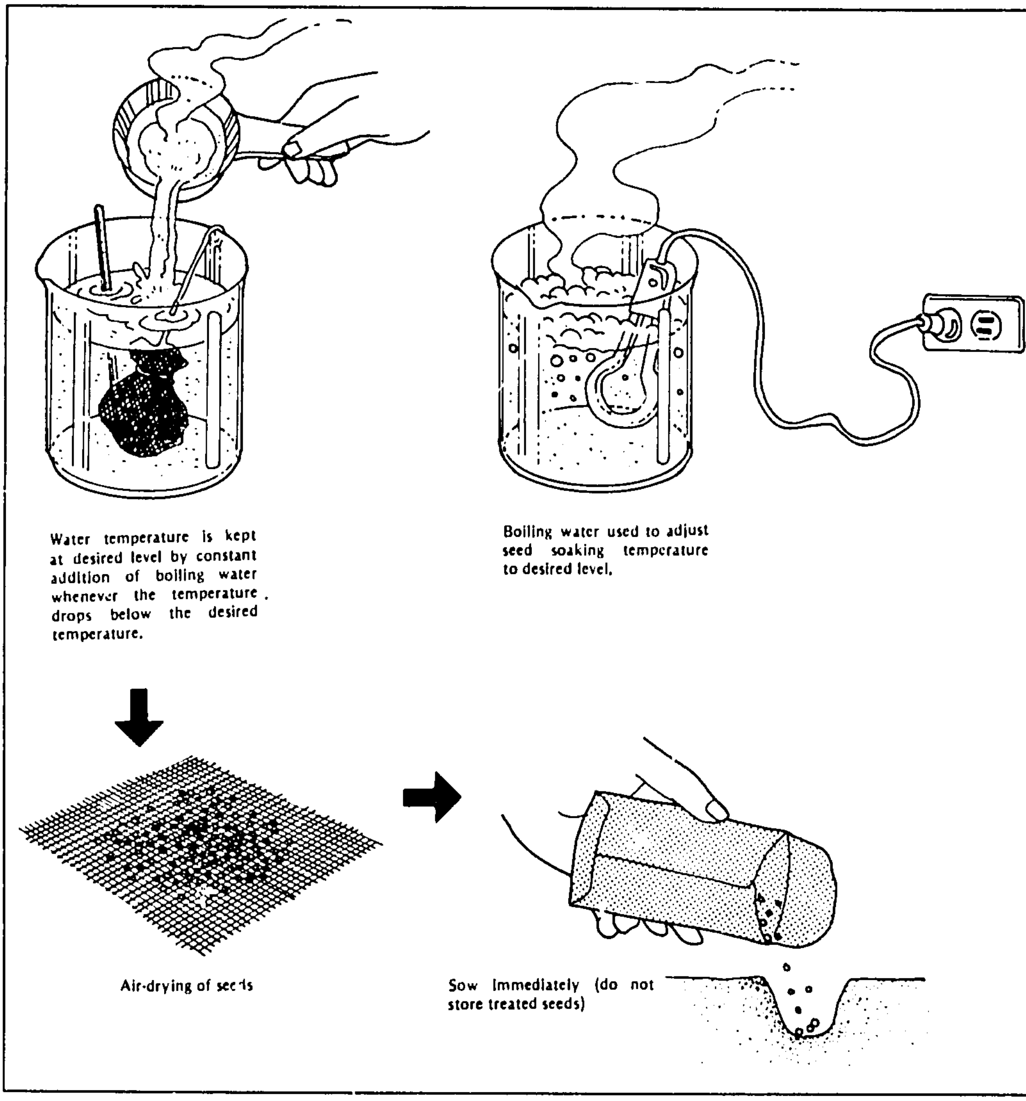

Fig. 7.2. A simple procedure for heat treatment and sowing of seeds.

Chemical treatment usually consists of a fungicide, insecticide, or a mixture of both. The chemical can be applied as powder, spray solution, or slurry (thick paste of powdered pesticide and water) at very low rates of approximately 1-5 g a.i./kg of seed. Many commercial seeds are pretreated before these are sold. The most common fungicides used for seed treatment are Thiram (Tetramethylthiuram-disulfide) and Captan (N-trichlo-romethyl-thio-4-cyclohexene-1, 2-dicarboximide). Both are broad spectrum in action and have low mammalian toxicity.

Some systemic fungicides, such as Ridomil (metalaxyl), provide protection against fungal diseases up to maturity of the plant. Detergents, such as the sodium or calcium form of hypochlorite and trisodium phosphate, are effective in eliminating seed-borne viruses, particularly those that are carried in the seed coat.

For example, immersion of pepper seed in 100 g/liter trisodium phosphate results in near-complete inactivation of the capsicum mosaic virus without affecting germination.

Diluted concentrations of acids, such as sulfuric acid, are also used for treating seeds against bacteria, fungi, and viruses. Among the insecticides, the common materials are Gardona and Malathion, which are very effective against weevil. Chemical treatment, like heat treatment, may reduce germination. The risk, however, is much less than in heat treatment.

Scarification

This procedure is done on hard-seeded crops, such as okra and some legumes. The principle is to soften or make a wound on the seed coat so that water can be easily absorbed by the seeds, thus hastening germination.

Scarification can be done by chemical means, such as treating winged bean seed with concentrated sulfuric acid (Fig. 7.3); or by physical means, such as passing okra seed through a metal brush in a rotating metal drum. In the former, thorough rinsing after treatment needs careful timing to prevent damage to the inner structures of the seed. Some seed companies scarify the seed by physical means before packing. Chemical scarification should be done immediately before sowing; otherwise, germination percentage may decrease.

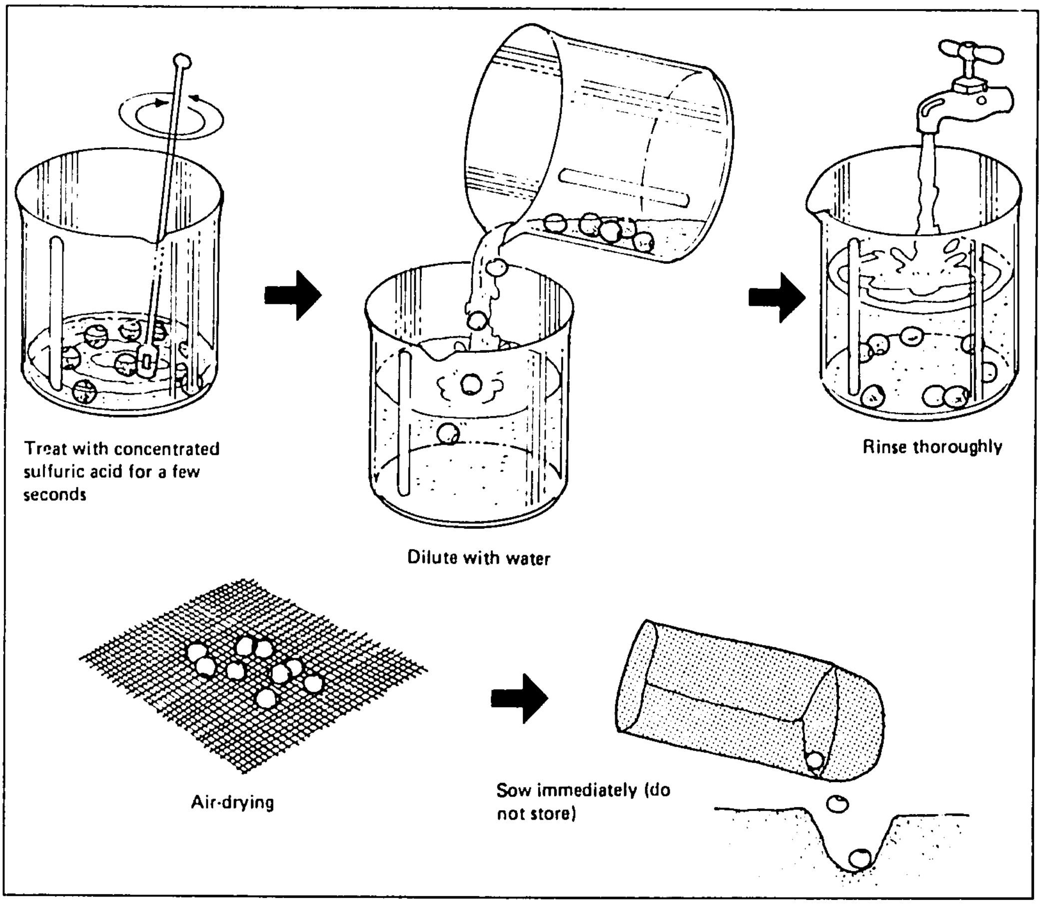

Fig. 7.3. Steps in sulfuric acid treatment and sowing of winged bean seeds.

With large seeds that are flat in shape, such as *Luffa* and watermelon, the seed coat is clipped at the side with a nail cutter, taking care that the cotyledon and embryo are not damaged (Fig. 7.4). This procedure facilitates the absorption of water. The seed should also be sown immediately.

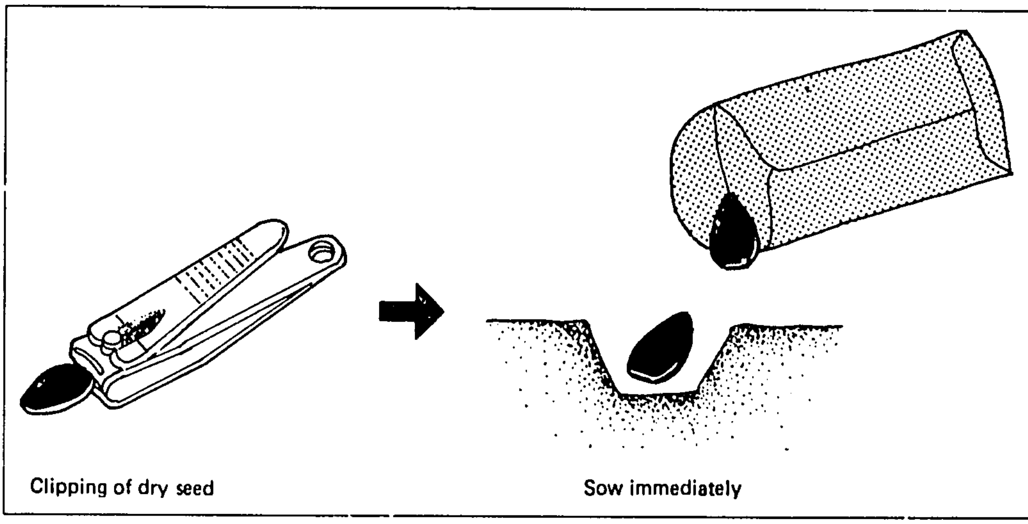

Fig. 7.4. Clipping of seeds of hybrid watermelon.

Vernalization

Vernalization can be done at the germinating seed or plant stages. Vernalization is the process of exposing the germinating seed or plant to low temperature (0°-5°C) for a certain period of time to induce early flowering and higher seed yield. Seed vernalization (Fig. 7.5) is used for seed production of *Brassicas* that are known to respond to this treatment. Radish seeds, for example, are vernalized at 5°C for eight days. Seeds should be immediately sown after vernalization. Vernalized seeds cannot be dried and stored as these will lose viability. When the objective is to produce fresh vegetables, seed vernalization should not be done.

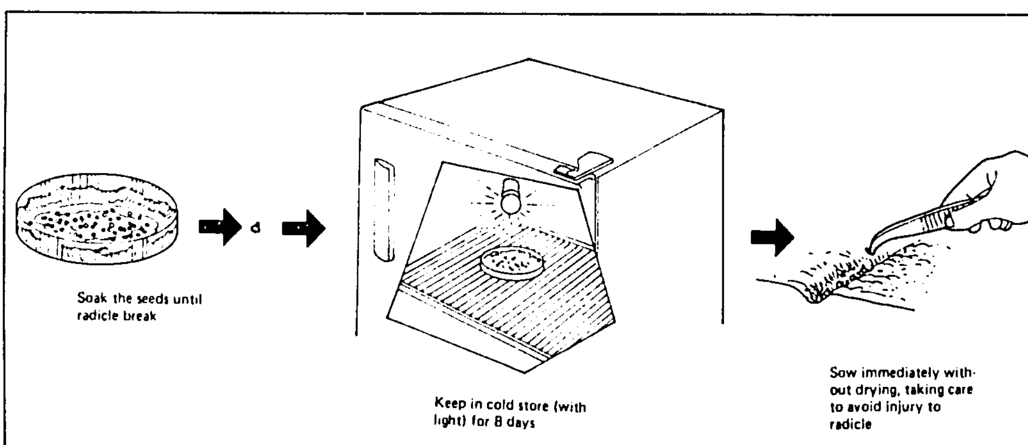

Fig. 7.5. Procedure for seed vernalization and sowing of pak-choi seeds.

In temperate countries, plant vernalization occurs under natural field conditions during the winter season. Among the vegetables, radish, Chinese cabbage, and mustard are known to respond to seed vernalization; they also respond to plant vernalization. However, cabbage, cauliflower, and broccoli do not respond to seed vernalization.

When vernalized plants are grown under favorable conditions, these tend to flower earlier than unvernalized plants. Flowering is more uniform among plants and seed yields are higher. The effect of vernalization may be partially or fully reversed by high temperatures in the production field. The phenomenon is sometimes called ***devernalization***. It explains the seeming lack of response to vernalization treatment of plants that are grown under relatively high temperatures. The exact mechanism of vernalization and devernalization is not known.

Varieties differ in their response to low temperature. For example, some Chinese cabbage varieties need only ten days at 5°-10°C to complete vernalization. Others need more than 30 days at 0°-5°C. Therefore, it is important to know the required conditions for different varieties. Once vernalization is completed, there is very little chance for devernalization to occur.

Seed Hardening

Like vernalization, seed hardening is a treatment that is applied to the germinating seed, and its effect is seen on the developing plant. The process consists of air-drying seeds that have started to germinate but have not produced any radicle (Fig 7.6). The hardened seeds are then sown immediately. Hardening makes seed emergence faster and more uniform. It also promotes faster seedling growth, better root-shoot ratio, and better transplant survival. The treatment is best done on slow-germinating seeds, such as tomato, eggplant, and pepper.

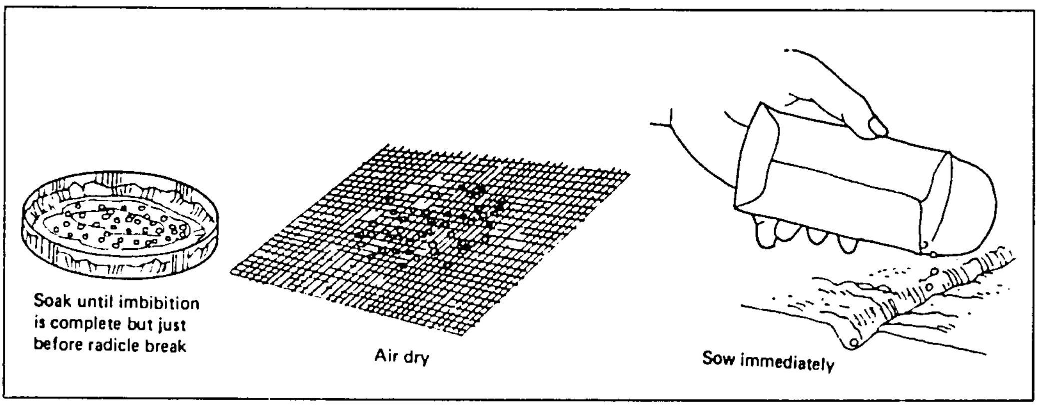

Fig. 7.6. Steps in hardening of tomato seeds.

Hardening can also be done at the seedling stage for all transplanted crops. In this case, the seedlings are allowed to wilt in the seedbed by reducing the frequency of watering and exposing the seedlings to full sun if these were previously grown under partial shade. The hardening process is started ten days before transplanting. The results are better root-shoot ratio and better transplant survival.

Seed Conditioning

In rare cases, seeds may have been overdried and stored at low moisture content (such as canned seed stored at low temperature); so that, they do not easily absorb water and they exhibit poor germination. This can be corrected by exposing the seed to high humidity for one to two days before sowing. A practical way is to put the seeds on a wire screen tray suspended in a sealed jar with water, without wetting the seeds (Fig. 7.7). The procedure improves the germination of seeds, such as pepper.

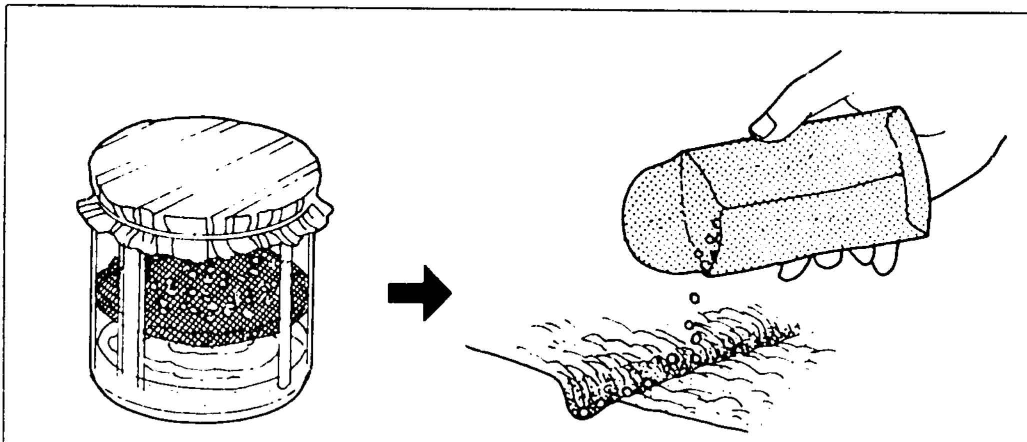

Fig. 7.7. Preconditioning of pepper seeds.

Methods of Planting Vegetable Crops

Vegetables can be classified into three categories, depending on the planting practice: a) crops that are usually transplanted, b) crops that are usually direct-seeded, and c) crops that should be direct-seeded. Examples for each category are listed below:

- Crops Usually Transplanted

Cabbage	Pepper
Chinese cabbage	Hybrid bitter gourd
Broccoli	Open-pollinated onion
Cauliflower	Celery
Tomato	Lettuce
Eggplant	

- Crops Usually Direct-Seeded

Watermelon	Snap bean
Cantaloupe	Cowpea
Squash	Soybean
Cucumber	Garden pea

Open-pollinated
Bitter gourd
Hybrid onion

Pak-choi
Water convolvulus
Yard-long bean

- Crops That Should Be Direct-Seeded

Radish
Carrot

Turnips
Beets

Radish and other crops in the above list are never transplanted because the tip of their tap roots may be damaged in the process, resulting in forked roots (Fig. 7.8). All other crops may be direct-seeded or transplanted, depending on the following factors:

- **Cost and availability of seed.** Direct-seeding always requires three to four times more seed than transplanting. When the cost of seed is high, as in hybrid seed, transplanting may be recommended instead of direct-seeding. For example, hybrid bitter gourds recommended for transplanting; but open-pollinated (OP) varieties of the same crop is always direct-seeded.

  A clear exception to this rule is the case of hybrid Granex of onion which is direct-seeded because it is able to produce bulbs of good size even in a relatively dense plant population. On the contrary, open-pollinated Red Creole is transplanted because this variety tends to produce small bulbs when grown at high densities. Transplanting of onion gives better control of plant population and avoids densely populated spots.

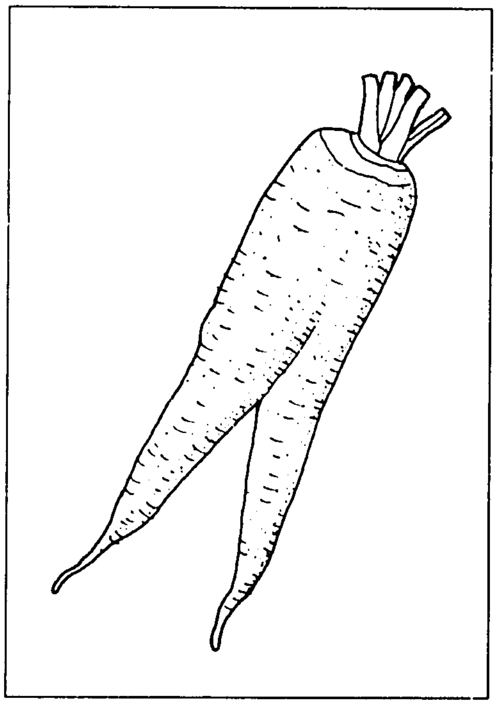

Fig. 7.8. Forked root of carrot results from root damage at seeding stage due to transplanting.

- **Quality of land preparation.** Direct-seeding of small-seeded crops is impractical when the field is not thoroughly pulverized during land preparation. Large soil clumps make it difficult to control depth of seeding, resulting in poor emergence. As a rule, small-seeded crops, such as lettuce and celery, should not be direct-seeded.

  Also, when land preparation is inadequate, weeds can be a serious problem in direct-seeded, slow-growing crops, such as onion and celery.

- **Root-regenerating ability of the crop.** Some crops, such as legumes, do not easily regenerate roots, hence, do not easily recover from transplanting shock. The opposite can be said of solanaceous crops and crucifers. Cucurbits are intermediate in rooting behavior and can be successfully transplanted if the procedure is done early enough at the cotyledonary leaf stage.

- **Multiple cropping.** When vegetables are grown after another crop, it is often advisable to start the seedlings even before the previous crop is harvested. This allows planting of the seedlings immediately after harvesting the previous crop, reducing the period when the field is unproductive.
- **Rapid growth rate.** Some vegetables such as sweet corn, cucumber, and yard-long beans germinate quickly and grow fast. They are easily established in the field even when conditions are not ideal. Hence, they are usually direct-seeded, unlike pepper and celery which grow very slowly in the initial growth stage.

When conditions are favorable judging from the above factors, it is more practical to transplant. This practice allows more intensive management of the seedlings in a small area of the seedbed than in the open field. The result is a good start for the crop, which is often translated into higher yields and better product quality.

Growing Transplants

The Vegetable Nursery

The facility for growing transplants, otherwise called the nursery, can be as simple as a raised bed in a selected corner of the field (usually near the water source), or as sophisticated as a glasshouse with microsprinklers and an automatic temperature control system. The common nursery facilities, from the simplest to the most advanced, are shown in Fig. 7.9. All of these nurseries seek to provide the following conditions for growing seedlings:

- **Protection from pests, including higher animals, such as chicken.** In a simple nursery, improvised fences, such as bamboo or nets, are provided. In screenhouses, the protection is better since the seedlings are totally enclosed. Fine mesh enclosures provide protection against many insect pests.
- **Protection from rain and sun.** Excessive rain can cause waterlogging in the seedbed, which may result in physiological damage to the seedlings. Excess moisture is also favorable for development of diseases. The only way to control rain damage fully is to provide a transparent roofing, which is costly. In resource-deficient farms, rain damage is controlled simply by providing nets, mulches, or equivalent devices to reduce the size of raindrops that fall on the seedbed. Adequate drainage is provided by raising the seedbeds.

  Excessive sunlight may also cause damage to newly germinated seedlings. To protect them, partial shade such as coconut leaves or nets are used. However, the shade should be removed as soon as the seedlings are established. Prolonged shading may result in spindly and weak seedlings, many of which may eventually die.

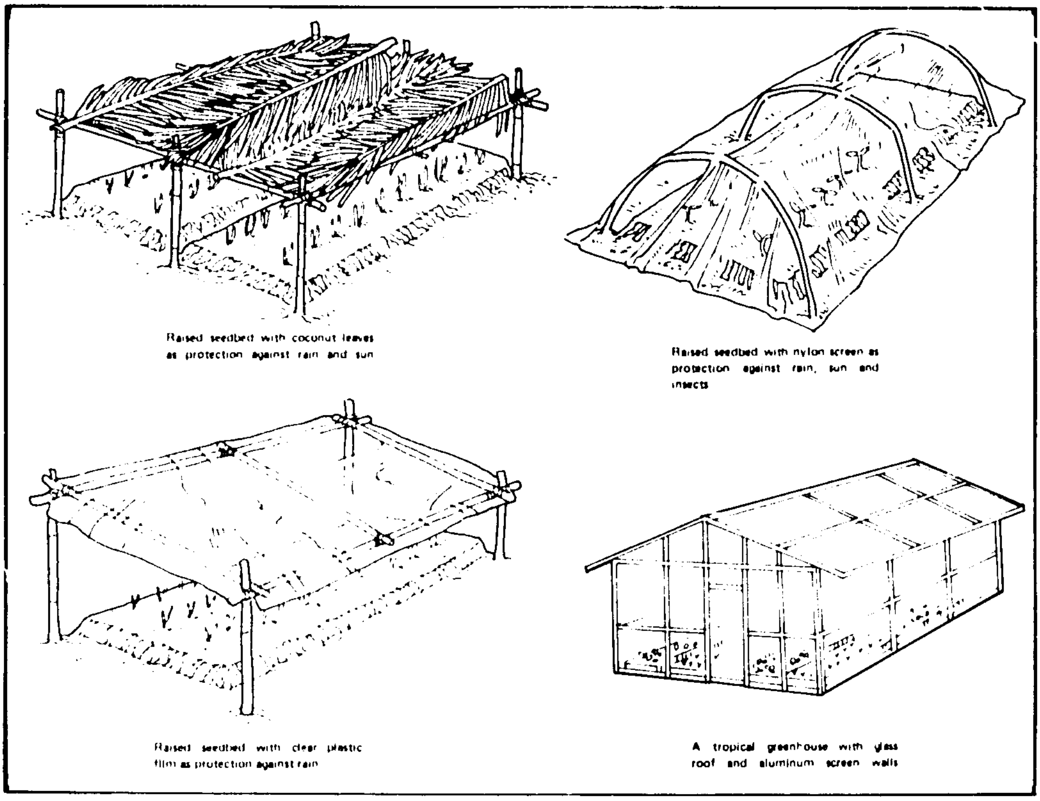

Fig. 7.9. Types of vegetable nurseries.

- **Protection against temperature extremes.** In the tropics (except in elevations exceeding 2,000 m where frost may occur during some parts of the year), the ambient temperature is normally suitable for seedling production. However, when seedlings are grown in glass- or plastic-roofed greenhouses to protect them from rain damage, they may suffer from excessively high temperatures during sunny days. The damage can be direct (physiological damage) or indirect (by favoring the development of diseases and multiplication of insect pests).

  Thus, a good tropical glasshouse must provide means of controlling temperature build-up (Fig. 7.10). This is achieved by the following methods: 1) raising the roof to promote better air circulation, 2) using dark-colored flooring that can absorb light and heat, 3) modifying the roof to provide outlets for hot air, and 4) installing cooling fans to blow cool air from outside. In the dry tropics evaporative cooling devices are also installed. These are not suitable for humid areas.

Germination and Seedling Growth Medium

Soil is the universally available medium for germinating seeds and growing seedlings. However, it is not necessarily the best medium. Some soils are unsuitable for growing seedlings. In developed countries, special mixtures of perlite, vermiculite, and peat are commercially available in ready-to-use mixes for specific purposes and are used as a substitute for soil. Capital-intensive farms in developing countries tend to import these soilless mixtures, without exploring possibilities of using locally available materials. The tropical environment is, in fact rich with material that can be utilized in formulating nursery mixes.

To help the vegetable farmer choose his materials for raising seedlings, the following characteristics of an ideal nursery medium should be considered:

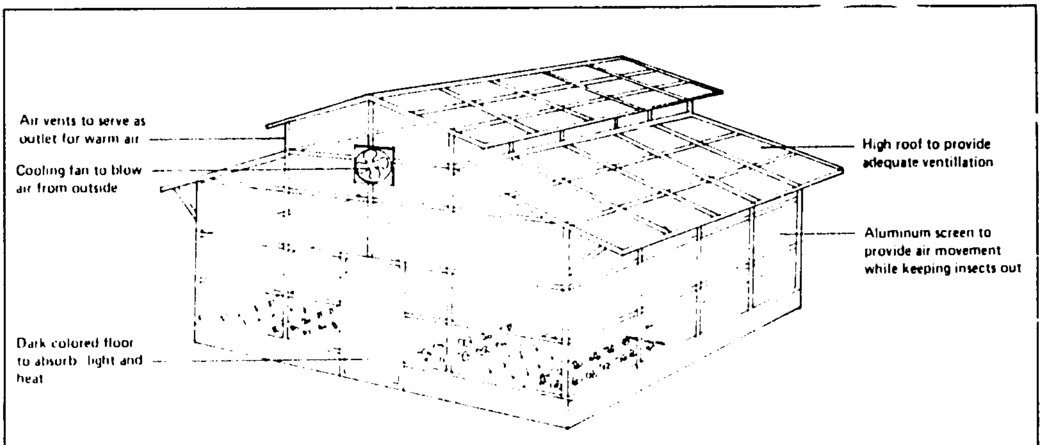

Fig. 7.10. Tropical greenhouse with various temperature control features.

Water-holding capacity and aeration. Organic materials, such as peat, are able to retain moisture without causing waterlogged conditions. This characteristic is crucial because the germinating seeds and the roots of seedlings need both water and air.

In contrast, sandy soil tends to lose moisture very quickly and clay soil tends to retain too much moisture so long that air supply in the root zone becomes restricted. In the tropics, coconut coir dust, rice husk, mosses, and dried (fully decomposed) manure are used in a nursery mix to improve the soil's water-holding capacity and aeration.

Capacity to supply plant nutrients. Vermiculite, perlite, and their tropical counterparts such as coconut coir dust and rice husk, are essentially inert and they contribute very little, if at all, to plant nutrition. So, mixes that are predominantly made up of these materials need elaborate fertilizer supplementation. Thus, nutrient-rich materials, such as compost, manure, and fertile soil, should be added to this nursery mix.

The pH of the soil mix should be adjusted to a range of 6.0-7.0 to ensure the availability of nutrients. A test of the medium using commercially available quick soil test kits should give the pH reading, as well as the available nutrients. Supplementary fertilizer should be mixed with the medium when needed.

Freedom from soil-borne plant pathogens. The soil contains millions of different kinds of microorganisms; many of these are helpful to the plant, but some are disease-causing. The nursery mix should retain only the beneficial types. To achieve this the nursery mix is often sterilized, either with the use of heat or chemicals. To most farmers in the developing countries, the only practical method is heat sterilization, which can be done in several ways:

- Raw heat method, such as burning straw on top of the seedbed (Fig. 7.11). — This method thoroughly sterilizes the thin top layer of the seedbed, often to not more than 5 cm deep. The deeper layers are not sterilized; thus, the soil should not be disturbed after sterilization. Raw heat may cause the loss of nitrogen, or convert this into toxic ammonia. To avoid toxic effects, the seedbed should not be used immediately after sterilization.

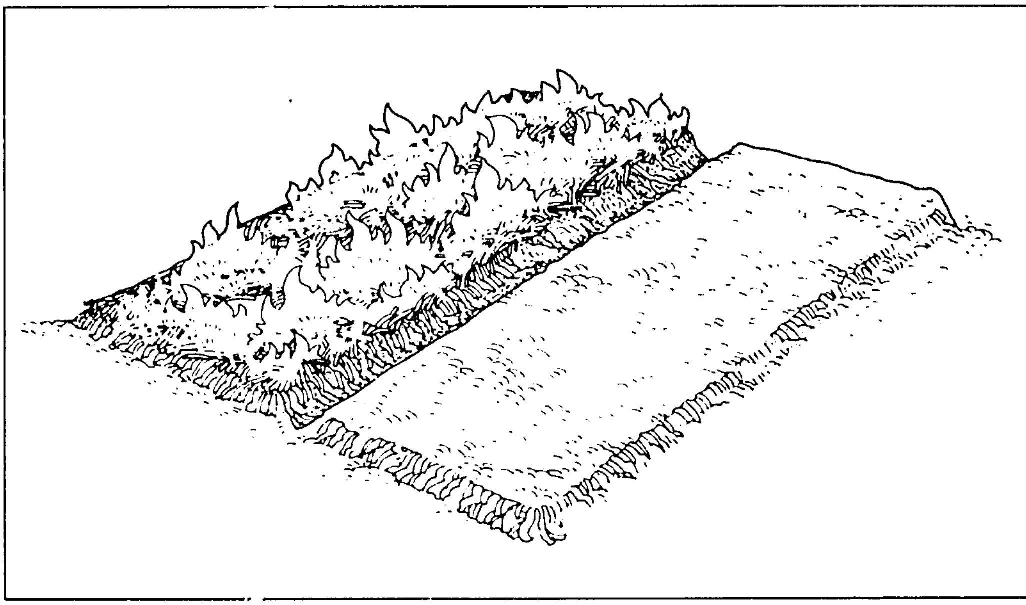

Fig. 7.11. Burning straw on top of the seedbed sterilizes the top soil to a depth of approximately 5 cm depending on thickness of the straw and time of burning.

- Hot plate sterilization (Fig. 7.12). — Unlike in the first method, the soil does not come in direct contact with the fire and is thus exposed to lower temperature. The soil mix is moistened; so that the steam generated by the heated soil serves as the sterilant in addition to the effect of the hot plate itself. During sterilization, the soil is constantly stirred to ensure even heating. Sterilization is completed when the soil has dried up.

Fig. 7.12. Hot plate sterilization using metal vat.

- Steam sterilization (Fig. 7.13). — In this method, the steam is conveyed to the soil mix until the temperature of the soil mix stabilizes at a desired level. With conventional steam generators, the soil temperature can reach the level of the steam itself.

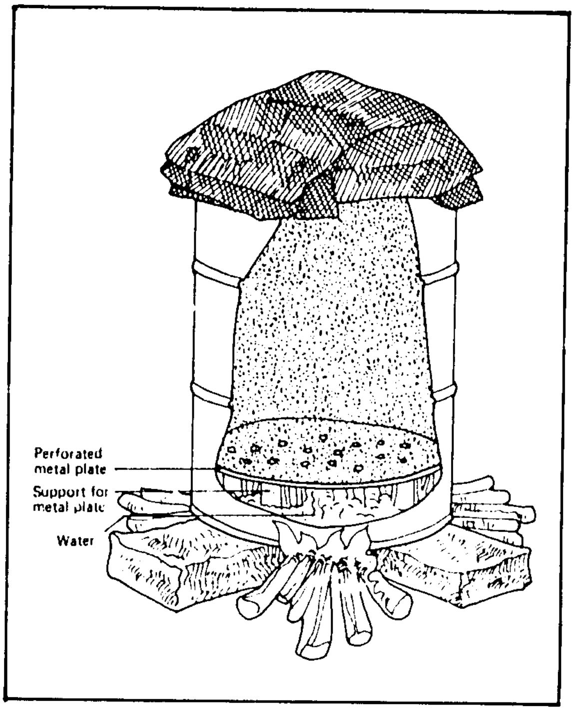

Fig. 7.13. A simple steam sterilization facility using recycled metal drums. To conserve heat and save fuel, a brick enclosure may be provided as shown in Fig. 7.13a.

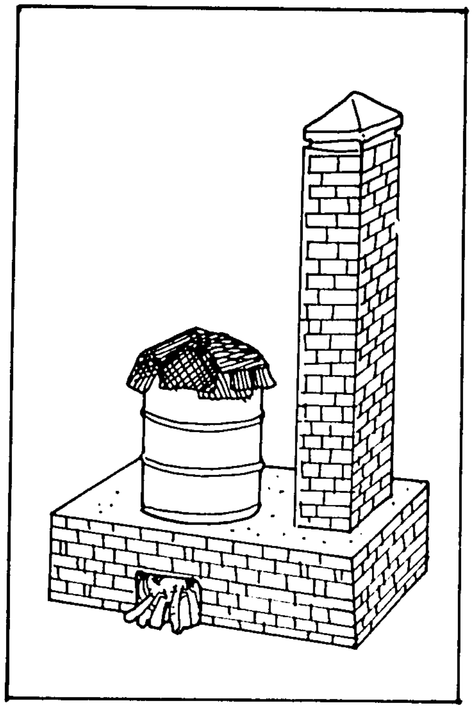

Fig. 7.13a. A brick enclosure for the fire to conserve heat.

However, with aerated-steam generators (Fig. 7.14), the soil temperature stabilizes at 70°C, a level which is lethal or can kill all harmful microorganisms but not all beneficial organisms. Thus, aerated-steam sterilizers give the best results among all sterilization methods, but this system is fairly expensive to purchase and operate.

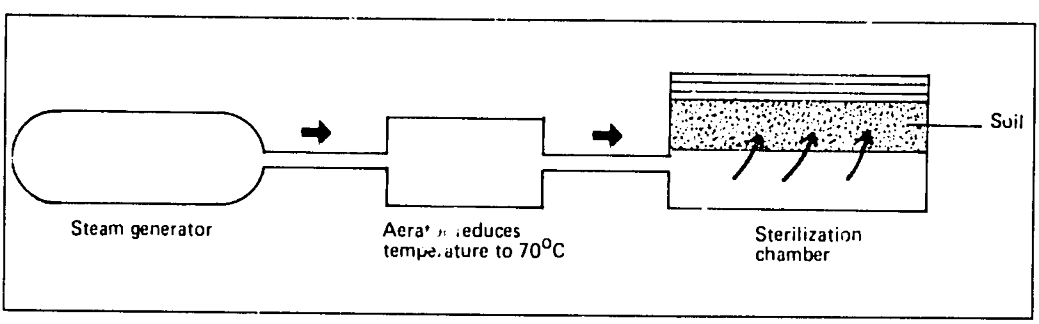

Fig. 7.14. A schematic diagram of an aerated steam sterilization system.

- Solarization (Fig. 7.15). — This is done by covering the seedbed with a transparent plastic sheet for three weeks. The heat of the sun increases the temperature of the soil, killing pathogenic microorganisms and weed seeds.

To avoid the harmful effects of toxic chemicals which may be released during heat sterilization, the sterilized soil should not be used immediately after sterilization. The gaseous chemicals should be allowed to dissipate naturally and soluble chemicals to leach by watering the sterilized soil thoroughly before seeding.

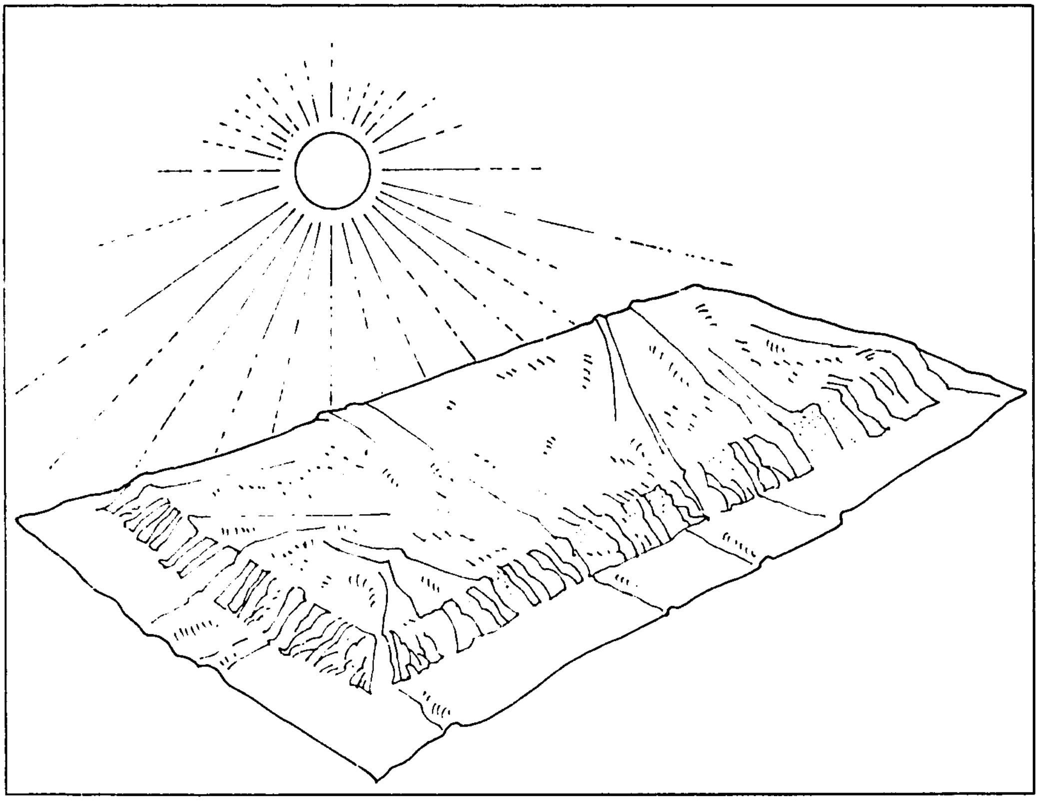

Fig. 7.15. Solarization by covering moist seedbed with transparent plastic film and exposing to direct sun for three weeks.

Soil can also be sterilized with the use of chemicals, either in the form of gas or liquid. Gas sterilization (fumigation) is normally preferred because most of the chemicals escape into the atmosphere after sterilization and may not cause serious problems with residues in the soil mix. The most common gas sterilant is methyl bromide which can be used in the farm on a system illustrated in Fig. 7.16.

Methyl bromide should not be used, however, if the soil mix is intended for bromine-sensitive plants, such as onions. Many countries require a special license to use methyl bromide which is an extremely toxic gas. Chemical sterilization can also be done with fungicides used as soil drench. PCNB (pentachloro-nitrobenzene) is commonly used for this purpose. Chemical soil sterilants are unable to kill all pests, however, and must therefore be used for specific purposes.

Where soil sterilization cannot be done, it is practical to use subsoil, which is relatively sterile, in the soil mix. The soil can be obtained from a depth of 1 m.

Tools, carts, seed flats, and all other materials that come in contact with the sterilized soil must also be sterilized. It is useless to spend on soil sterilization if the shovel used is infected.

Examples of nursery soil mixes are:

1:1:1 sieved sand: garden soil: compost
1:1:1 garden soil: coconut coir dust: compost
1:1:1 garden soil: animal manure: coconut coir dust

There are many possible combinations, depending on the availability of materials. Different combinations may be needed for different crops.

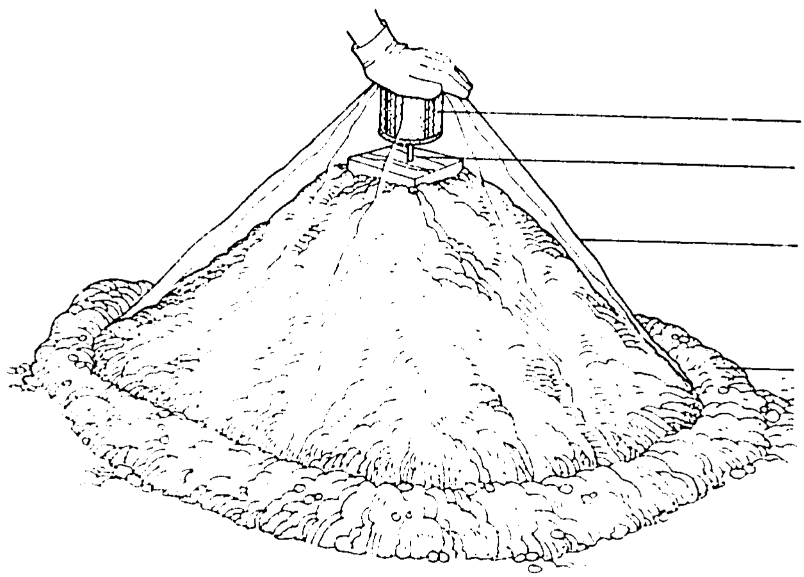

Fig. 7.16. A simple system for soil sterilization using methyl bromide. The plastic should not have holes and should be thick enough to avoid draining during handling.

Seed Flats

The seedbed method has been used for a long time as the most practical and cheapest method of producing seedlings (Fig. 7.17). However, it has the following disadvantages:

1. Pulling the seedlings during transplanting causes a lot of damage to the roots.
2. Pulling the seedlings with a ball of soil can be laborious and cause transport problems.
3. Spread of diseases within the seedbed is difficult to control.

These disadvantages led to the use of seed flats, of which a variety of models are now available. The seed flat is essentially a portable seedbed. The latest models are designed for machine transplanting. Seed flats are designed to be carried to the field where they are emptied of seedlings. Well-designed seed flats are light and sturdy; they also allow extraction of seedlings with minimal root damage. Almost all modern seed flats have cellular designs (Fig. 7.18).

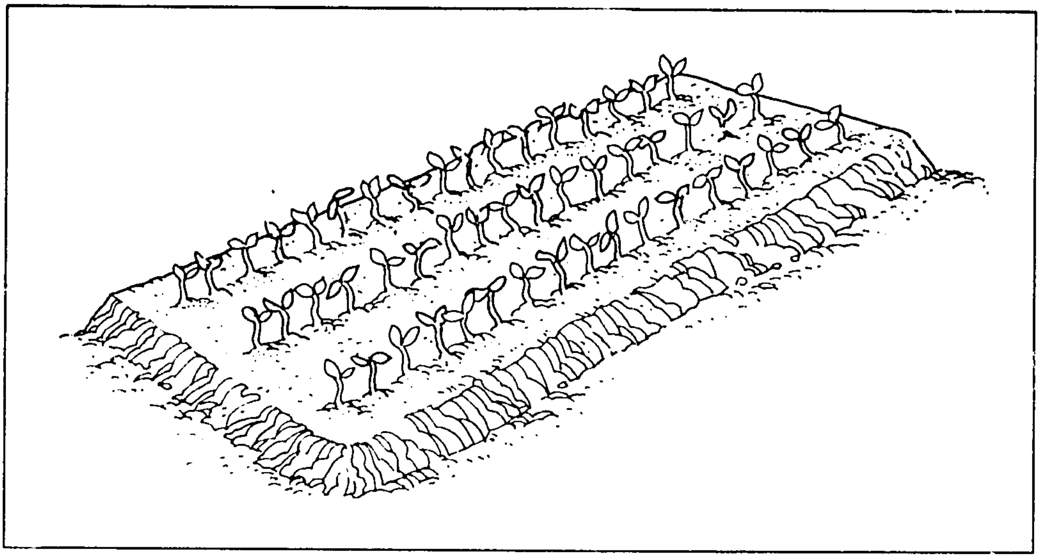

Fig. 7.17. Seedbed method of growing seedlings.

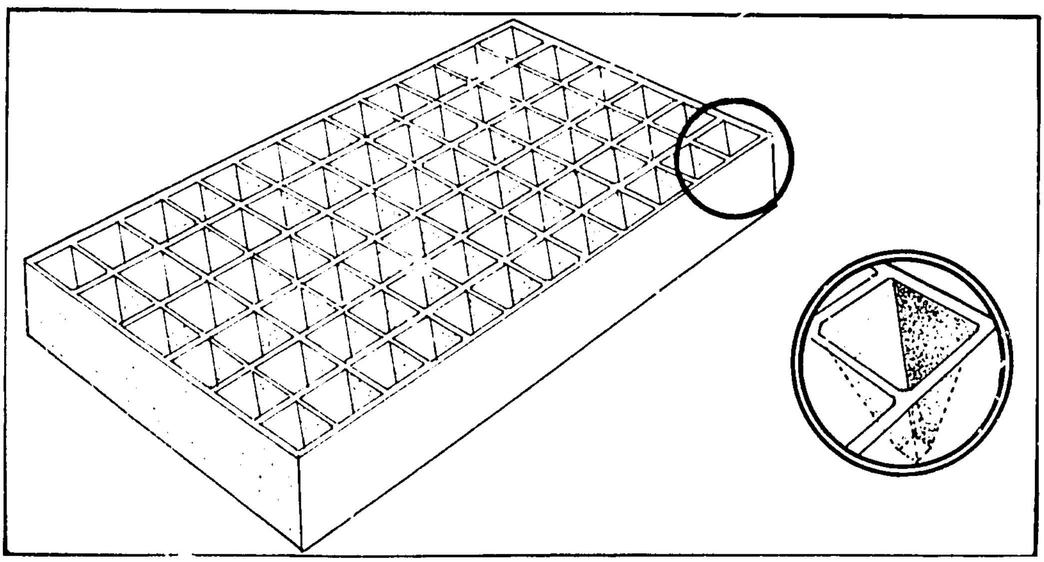

Fig. 7.18. Cellular design for modern seed flats.

One major advantage of seed flats over the seedbed is that they can be set on tables with slatted tops (wire mesh or bamboo). This exposes the seed flat to light and air and prevents outgrowth of roots from the drainage hole. This phenomenon is sometimes referred to as ***air pruning***. Air pruning restricts root growth to the soil in the seed flat and promotes root branching in the process. Well-branched roots that are not damaged during transplanting, recover easily from "transplanting shock".

Sowing and Pricking

Sowing on the seedbed can be done using three methods (Fig. 7.19): 1) broadcast seeding, 2) drill sowing with uniform spacing, 3) sowing at high density in the nursery bed, then transplanting (pricking) newly emerged seedlings into another seedbed, with uniform spacing. ***Method 1*** is the least labor-intensive among the three methods, but the seedlings are not evenly distributed — some of them are too crowded. ***Method 3*** is the most labor-intensive as far as the planting/transplanting operations are concerned; however, it may save labor in watering a bigger nursery bed area during the germination phase. Chapter 11, shows that ***Method 2*** can be mechanized.

Water Management

Watering of the seedbed should be done very carefully until the seedlings have emerged, especially when the seeds are small. Large water drops tend to erode the thin soil covering of the small seeds and may cause it to dry up. Watering with a mist sprayer is recommended for highly delicate seeds, such as lettuce and celery. As a rule, the seedbed should be kept moist but not wet until germination is achieved.

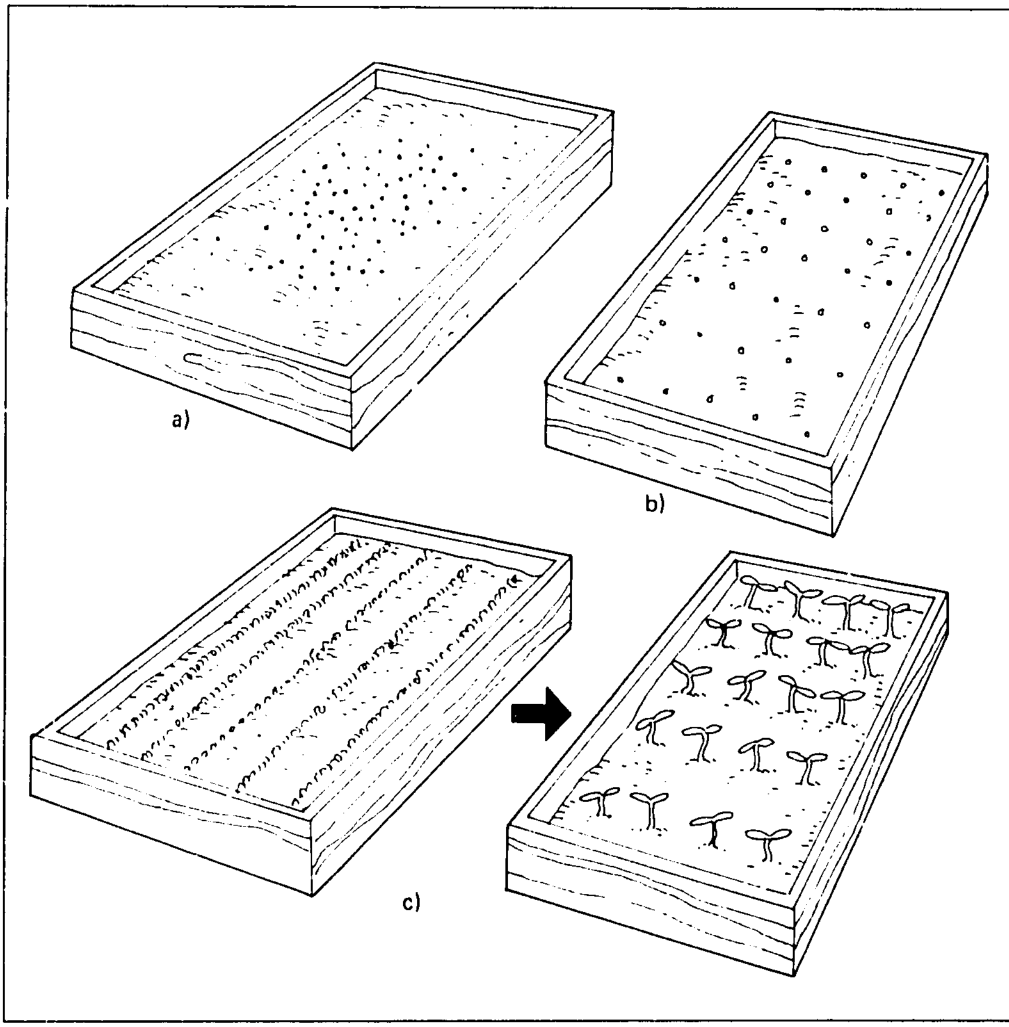

Fig. 7.19. Methods of sowing in the nursery bed: a) broadcast seeding, b) drill sowing, c) sowing at high density and transplanting (pricking).

Mulching of the seedbed immediately after sowing helps prevent erosion of the soil cover and conserves moisture. The mulch also keeps the soil temperature favorable for germination. The mulch can be very thick (5 cm) until seedling emergence; but it should be thinned at seedling emergence to prevent etiolation of the seedlings.

Watering during seedling production should be done preferably in the morning. If watering needs to be repeated, this should be done in the early afternoon. Watering in late afternoon causes the surface of the seedbed to remain moist at night, a condition favorable to the development of damping-off disease.

Ten days before transplanting, watering should be decreased to allow the shoots to grow slower and the roots to grow faster. The seedlings should also be exposed fully to the sun if they have been kept under partial shade. This process is called seedling hardening and it assures high transplant survival and quick recovery after transplanting.

A common mistake of farmers is that they take all precautions to sterilize their seedbed, tools, and other materials used in establishing the nursery, but forget to use clean water for watering the seedlings. Water for the seedbed must come preferably from the tap or from a deep well. Surface water may carry weed seeds, as well as plant pathogenic microorganisms.

Fertilizer Management

Fertilizers applied to the seedbed must be mixed with the soil before, not after sowing. This is necessary because the seedlings must be able to use the fertilizer immediately after it has developed the root system that absorbs the nutrients. Seedlings stay in the seedbed for only 20-30 days, on the average. Also, mixing of the fertilizer with the soil before sowing promotes even distribution of fertilizer and prevents fertilizer injury. Fertilizers in granular form that are applied late may not be available to the seedling immediately and may cause temporary nutrient deficiency.

Modern farmers prefer to use synthetic slow-release fertilizers to minimize loss of nutrients through leaching. In the case of seed flats constant watering causes rapid loss of soluble nutrients. However, this type of fertilizer is generally not available in developing countries.

The most logical substitute is organic matter (compost or manure) which, by itself, is a slow-release fertilizer. Only fully decomposed organic matter should be used because decomposing organic matter contains a lot of microorganisms which may compete with the seedling for nutrients. The decomposition process also helps release toxic chemicals, such as ammonia, which may damage the seedlings.

In some instances, it is also necessary to apply fertilizers as drench (starter solution) or as foliar sprays. They should only be used as corrective measures and should not substitute for sound planning and preparation of the nursery soil mix. In tomato seedling production, watering with 1% urea solution every five days can be done to correct N deficiency in the medium.

The following are the common problems in the nursery:

- **Damping-off**. This is a seedling disease commonly caused by fungi of the *Rhizoctonia* and *Pythium* genera. The disease organisms are favored by warm and wet nursery beds. The symptom consists of water-soaked lesions on the stem of seedlings at the point of contact with the soil. These lesions soften the stem, causing the seedling to lodge and eventually dry up and die.

The disease organisms multiply rapidly at night when dark and damp conditions are favorable; so, the disease can be controlled by making night time conditions unfavorable for the pathogens. One way is to keep the nursery bed relatively dry at night by avoiding watering in the late afternoon.

Other control measures are: 1) soil sterilization, 2) drenching with Brassicol (PCNB), 3) growing in seed flats to make it easy to isolate diseased spots, 4) exposure of the seedbed fully to the sun to dry the soil surface quickly, and 5) proper plant nutrition to enable the seedlings to reach maturity more quickly. Seedlings gradually develop resistance to damping-off as their tissues become more mature.

- **Oversized seedlings.** This situation is often caused by delayed field preparation and unfavorable weather conditions. Oversized seedlings are not only more difficult to handle during transplanting but have smaller chances of surviving field conditions. Oversized seedlings tend to suffer more injury, but they have less ability to regenerate roots than younger seedlings.

  Oversized seedlings can be avoided by prolonged hardening. Some seedlings, such as onions, can be pruned at the top to reduce the transpiring surface and make the root- shoot ratio more favorable for water balance.

- **Chemical toxicity.** Ammonia toxicity may occur when the soil is sterilized with heat. The symptom, yellowing of the leaves similar to iron deficiency, is more acute when fresh manure is used as a component of the nursery mix. Toxicity may also result from residues of chemicals used in soil sterilization. Chemical sterilants should be carefully selected and prolonged heat sterilization avoided to help control chemical toxicity.

Transplanting

Preparing Seedlings for Transplanting

When dry and sunny weather is expected immediately after transplanting, the seedlings must undergo the hardening process. In noncellular seed flats, such as wooden flats and seedbeds, it is a good practice to prune the roots one week before transplanting by passing a sharp knife around each seedling (Fig. 7.20). This procedure stimulates root branching close to the main root and assures a good root-shoot ratio. The dense root system immediately around the main root serves to hold the nursery soil and prevents bare-root transplanting. Transplanting from seedbeds or noncellular seed flats usually causes damage to roots that are too far from the tap root.

A starter fertilizer solution of 0.1% urea or ammonium sulfate is applied to the seedlings just before transplanting. This assures a ready supply of nutrients for root recovery.

Preparing the Field for Transplanting

If the field is dry, it must be irrigated thoroughly a few hours before transplanting. The irrigation is preferably localized along the plant rows, leaving the areas between the rows dry for the transplanting operation (Fig. 7.21). This is possible with furrow and drip irrigation but not with sprinkler irrigation. Watering immediately before transplanting works with light sandy soil but not with clay soils. The latter tends to be sticky and difficult to manage during transplanting. Manure and fertilizer should be applied before transplanting.

If mulch is to be applied, this must be spread before transplanting to prevent damage to the seedlings during mulch application.

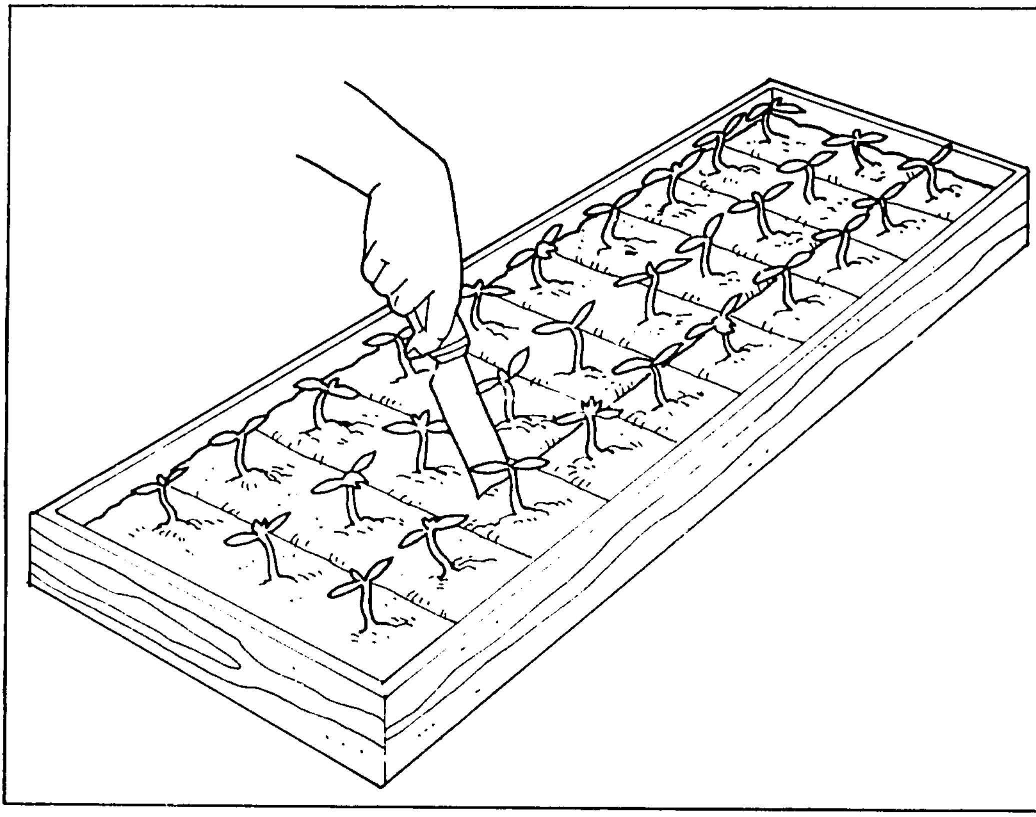

Fig. 7.20. Passing a knife in blocks around the seedlings to prune the roots and stimulate root branching.

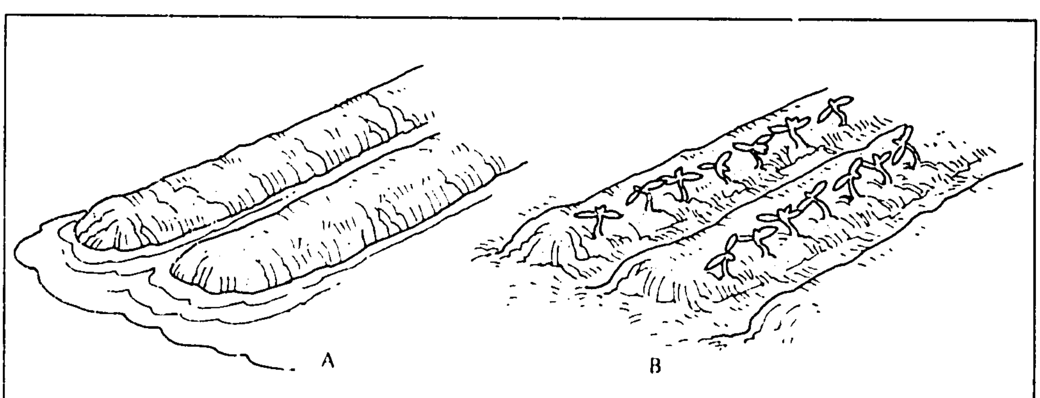

Fig. 7.21. The field is irrigated using the furrow method (a) before transplanting (b).

Ideal Conditions for Transplanting

A cloudy, cool weather and moist but not wet soil are ideal for transplanting. During sunny days, transplanting is best done in the late afternoon to give time for the seedlings to recover at night. However, seedlings that are adequately hardened with slightly damaged roots recover well when transplanted in a well-irrigated field, even on a hot day.

Transplanting Shock

"Transplanting shock" refers to the temporary growth retardation or mortality of seedlings after transplanting. This can be prevented by adequately preparing the seedlings, as well as the field, for transplanting as earlier described. Seedlings can recover easily if watered frequently for one week after transplanting. Protection during extremely hot days can be provided by banana bracts (Fig. 7.22). This procedure is generally labor-intensive and is not normally required if seedling preparation and transplanting procedures are carefully followed. It is practical in small-scale farming when labor is cheap and banana bracts are easily available.

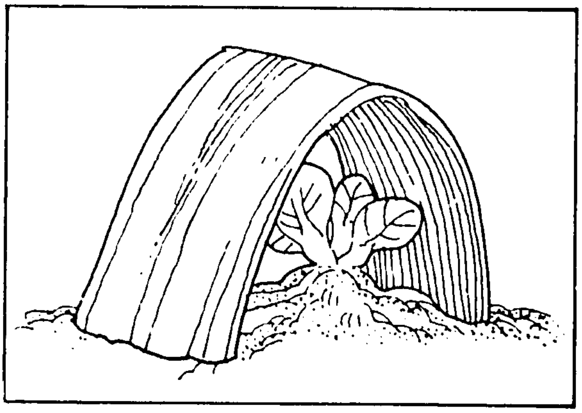

Fig. 7.22. Protection of newly transplanted seedlings with banana bracts is practical in small farm where labor is cheap and banana bracts are easily available.

Direct Seeding

Direct seeding can be done by drilling or broadcasting (Fig. 7.23). The ***drill method*** is normally recommended under the following conditions: 1) when crops are widely-spaced, such as with cucurbits; 2) for long-season crops, such as yard-long bean; 3) when weed problem is anticipated and mechanical weed control will be used; 4) when furrow irrigation will be used; and 5) when the seeds are expensive.

Farmers rarely use the broadcast method for planting vegetable crops, except the following: 1) kale, 2) nonheading Chinese cabbage (pak-choi), 3) water convolvulus (kangkong), 4) nonheading leaf mustard, and 5) radish. These crops require close spacing, mature early (less than 50 days), have cheap seeds, and grow relatively fast. The ***broadcast method*** is feasible when the field is adequately prepared, i.e., well-pulverized, weedless, and irrigated by sprinklers. Beds that are approximately 1.0-1.5 m wide are used in the broadcast method.

The most important factor in direct seeding is the planting depth. A consistent planting depth is possible only in a well-prepared field. Soil particles should be fine when small seeds, such as those of carrots and nonheading Chinese cabbage are planted. For large-seeded crops, such as watermelon, the need for thorough land preparation is less.

Fig. 7.23. Direct seeding can be done by drilling in rows (a) or broadcasting (b).

Seeds should be placed deeper in light (sandy) soils to prevent them from drying up. Shallow planting is required in heavy soils. As a rule of thumb, the soil cover after settling should be about five times the diameter of the seed. The soil should be irrigated immediately after sowing to create a favorable condition for germination. It should be kept moist until the seedlings are established, by which time water can be applied less frequently.

Land Preparation

Land preparation is done to create favorable conditions for seed germination, seedling establishment, and subsequent management of the crop. Properly done, it eliminates most of the weeds and soil-borne pathogenic microorganisms. It also improves the water-holding capacity, drainage, and aeration of the soil. Likewise, it facilitates field operations, such as furrow irrigation and mechanized weed control.

Systems of Land Preparation

Paddy field. In the tropics, a large number of commercial vegetables are grown during the cool, dry season immediately following the wet-season flooded rice crop. Under this condition, weeds and soil-borne diseases are minimal because of the prolonged anaerobic condition of the rice paddy which is unfavorable to the survival of weed seeds and pathogenic microorganisms. Consequently, the need for land preparation is diminished. Under rainfed conditions, land preparation may actually cause more harm than good because the soil tends to dry faster.

Moreover, puddled condition of the soil may cause difficulty in land preparation, particularly in heavy clays. In difficult soils, land preparation is sometimes not practiced as in garlic production (Fig. 7.24) or done partially, as in watermelon production (Fig. 7.25).

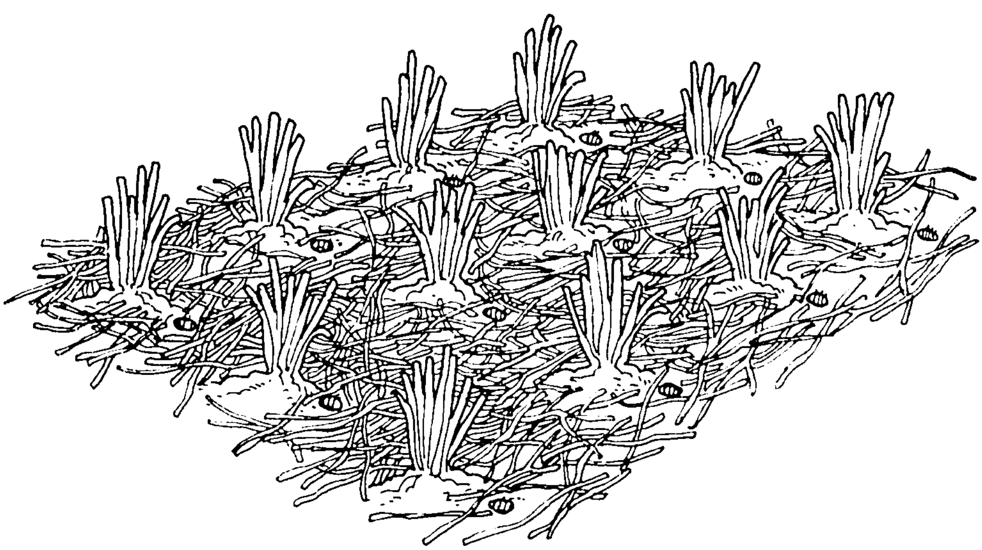

Fig. 7.24. Traditional way of planting garlic in Northern Luzon (Philippines) in paddy field after the rice crop, without land preparation. The field is flooded after rice harvest, mulched with rice straw before planting.

Upland field. The upland field is entirely different from that of the paddy field. Except on steep hillsides where thorough land preparation may cause problems of erosion, complete land preparation is normally required in the former.

Mechanized Land Preparation

Land preparation requires much labor. Traditionally in the tropics, this is provided by man and animals. However, this procedure is very time-consuming, expensive,

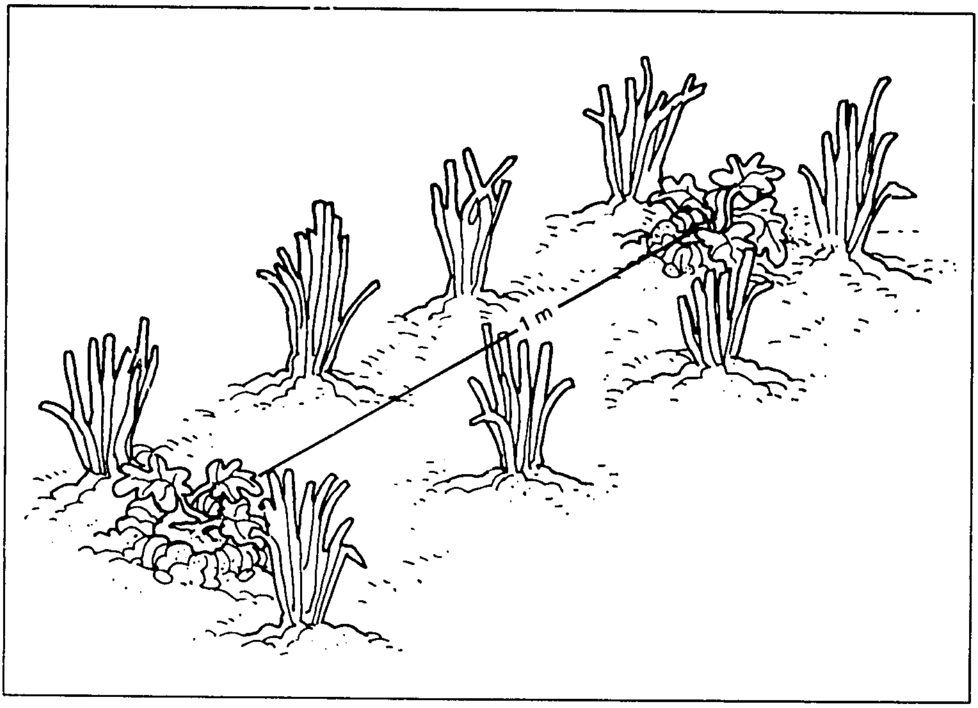

Fig. 7.25. Traditional way of planting watermelon after paddy rice, with limited land preparation.

and not completely effective. The traditional hand tools and animal-drawn implements are as follows:

1. **Clearing/mowing.** This is an optional step necessary only in opening new areas for vegetable growing and in preparing the field after a prolonged mismanaged fallow (rest) period. Under these conditions, the farm may be too weedy to be plowed. Before plowing, then, it may be necessary to clear the field of obstructions and tall weeds.

2. **Tillage.** After the field is free of obstructions, it is subsequently cultivated, with the objective of turning it, pulverizing, levelling, and forming ridges in preparation for planting. Depending on soil conditions and equipment, it can be a single or multistep process.

   a. Plowing — This procedure is required for heavy soils with problems of internal drainage, but may not be necessary for light soils. Plowing should be as deep as the equipment will allow — the deeper, the better. Deep plowing effectively turns the soil, putting the surface soil at the bottom of the furrow slice, together with the weed seeds and pathogenic microorganisms which are abundant. At the same time, it exposes the deeper layers of the soil which are relatively more sterile.

   Loosening of a thick layer of soil improves internal drainage. The soil may be too hard to achieve maximum plowing depth at first passing. A second passing should get the right depth. By this time, plowing would be easier and deeper because the bulk of the [illegible] soil has been loosened.

Success in plowing is determined to a large extent by the soil moisture, which should ideally be at field capacity. Plowing wet soil may result in the formation of hard soil clods that may not easily be broken by the harrow and succeeding equipment. Extremely dry clay soils, on the other hand, may be too hard for compact machines, the common type available to the tropical farmer.

b. Harrowing — Plowing light soils in properly managed farms may be skipped; as a disc harrow or even a rototiller can accomplish what a plow does for heavy soils. However, the turning effect of the harrow on the soil is very small and cultivation is relatively shallow. In heavy soils, the harrow breaks up large soil clods that are caused by plowing.

In many cases, it is advisable to plow again after the first harrowing to kill the weeds that have started to germinate. The second plowing also makes it possible to cut deeper into the soil as the loosened topsoil offers less resistance to the plow. Harrowing is done again; then, the cycle of plowing may be repeated a third time, depending on the need for weed control or deeper plowing.

c. Rototilling — Cultivation using the rotary tiller breaks the soil into small particles. For heavy soils, rototilling is done after plowing and harrowing. For light soils, both plowing and harrowing may be skipped if the rotary tiller is powerful enough to perform the tillage operation. Adjustments in the turning speed of the rototiller results in different degrees of pulverization of the soil. It is not necessary to pulverize the soil thoroughly for transplanting crops or for direct-seeding large-seeded crops.

d. Levelling — This is necessary only if furrow irrigation is used. It is also important to remove low areas which may be waterlogged during the wet season. A level field with a slight grade allows even distribution of water applied through the furrow method. Levelling can be an expensive procedure; the need for it can be minimized through proper plowing. It should be done before broadcast fertilizer application, liming, and manuring but after rototilling.

e. Ridging — The final step in land preparation is making the furrows or beds in preparation for planting. The size of beds or distance between furrows depends on the season, soil type, irrigation method, degree and kind of mechanization, and the crop. In heavy soils, wider beds can be used, even if irrigation is by furrow method because the lateral movement of water under this condition is easier done. In lighter soils, narrower beds are recommended.

The standard bed width for fields that are watered by overhead irrigation and operated manually is 1.5 m from center to center. Wide beds minimize compaction of the soil, as movement of workers is limited to the canals between beds. For mechanized interrow cultivation, single-row planting is better suited than multiple rows.

During the wet season, single-row planting is recommended to minimize competition for space between rows of luxuriantly growing plants; consequently, narrower beds are prepared. The reverse is true during the dry season when plants tend to be less vegetative. Multiple-row beds tend to reduce irrigation water loss by evaporation; hence it is preferred over single-row beds for the dry season crop (Fig. 7.26).

Fig. 7.26. Multiple-row bed (a) is preferred for dry season crop in nonmechanized farm with sprinkler irrigation. Single row bed (b) is preferred for wet season crop and for mechanized farms.

Viny crops and those with big canopies need more space between rows. For example, squash is planted in single rows with an interrow distance of 1.5-3.0 m, depending on variety. On the other hand, onions are planted in multiple-row beds with a spacing of 20 cm between rows.

3. **Manuring, liming, and fertilizer application.** If manure, lime, and fertilizers are needed, these can be applied through appropriate tractor-mounted machines. Lime is applied approximately one month before planting (after primary tillage) to allow enough time for it to react with the soil. Manure can be applied immediately before planting if the material is sufficiently dry and decomposed. Fresh manure tends to generate heat and ammonia during decomposition, and may directly harm the crop. Furthermore, decay microorganisms which are active in the decomposing manure may compete with the plant for nutrients, causing mineral deficiency.

   Chemical fertilizer may be broadcast like manure and lime or applied along the crop row during planting. The latter is preferred because it allows a more efficient utilization of fertilizer. However, it is not easy to mechanize application of fertilizer in this manner. Some seeding machines, however, are equipped with fertilizer applicators that put the fertilizer in precise location relative to the seed.

Traditional Land Preparation

In developing countries with small farms and low capital, land preparation is often done manually or with the help of draft animals. The result is substandard land preparation, particularly in heavy soils which are more bower-intensive. The usual problem with manual land preparation is inadequate depth.

Case 1: Market gardens. Under the highly intensive production system in the market gardens, there is little time for land preparation. Usually the same patch of land is planted with another crop of vegetables within a few days after harvesting the previous crop. Land is prepared as soon as the previous crop is harvested and completed very quickly (Fig. 7.27). The hoe is used for digging and the rake, for levelling. It is theoretically possible to get as much as eight crops from the same patch of land, with a turn-around time of 40 days or less for fast-growing crops, such as leafy vegetables (kale, amaranth, and nonheading Chinese cabbage).

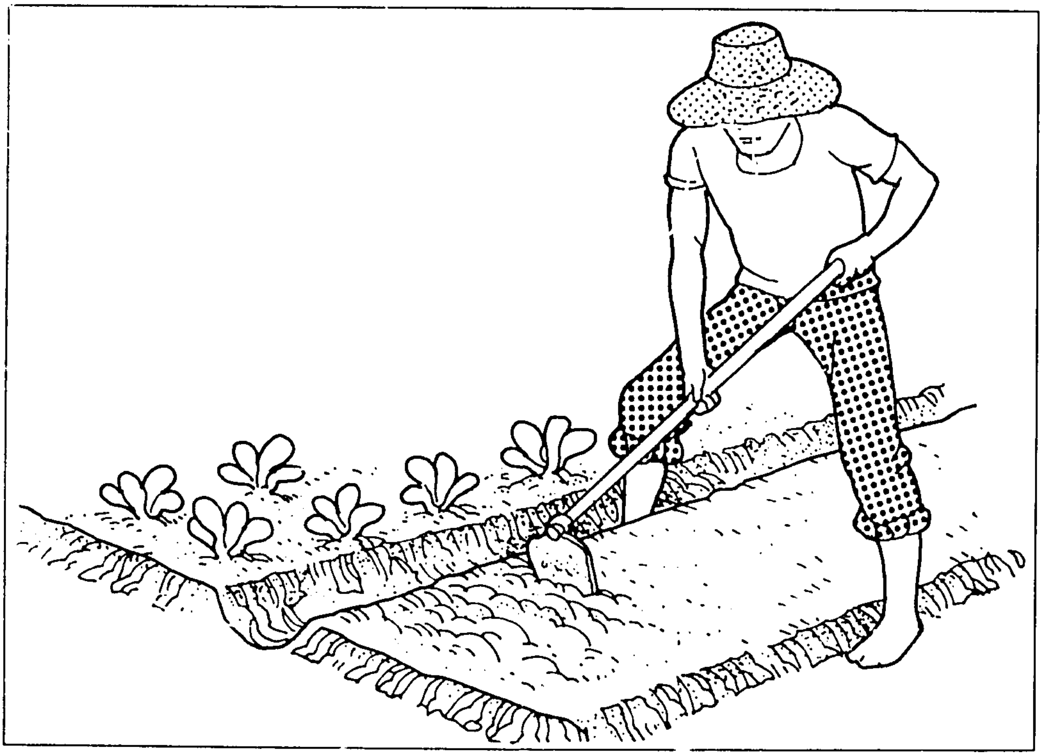

Fig. 7.27. Land preparation is done immediately after harvesting in intensive vegetable farms.

In this system, weeds cannot get established; however, soil nutrient depletion and accumulation of diseases are potential problems. To control them, farmers apply heavy dosages of manure or other forms of organic and inorganic fertilizers. Diseases are controlled by crop rotation, strict sanitation practices, and proper selection of crop mixes.

Case 2: Truck gardens. Like the market gardens, the truck gardens are specialized vegetable production farms. Vegetables are grown throughout the year in an intensive production system. However, it is much less intensive than the market gardens because the crops have relatively long maturity periods (cabbage, carrot, garden peas, snap beans) and there is a longer fallow period between crops. The land is prepared by using the technique illustrated in Fig. 7.28.

Case 3: Land preparation with animal-drawn implements. Clearing the field of weeds and organic debris is done with a spike-tooth harrow. The field is subsequently plowed with a mouldboard plow. After plowing, the soil clods are broken into smaller particles, again with the use of the spike-tooth harrow; levelling is also achieved in the process. Normally, several passes of the harrow is required before satisfactory tilth is achieved. Ridging is finally done with the mouldboard plow.

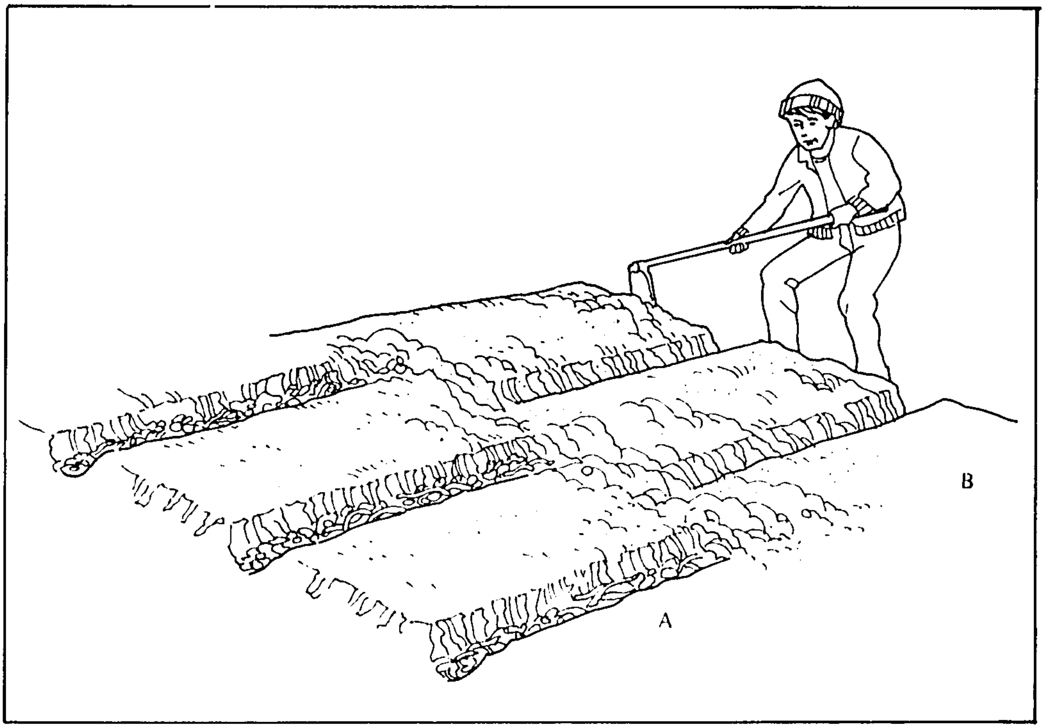

Fig. 7.28. Land preparation involves putting crop residues in the drainage canal (a) and digging the new beds by covering the residues (b).

Field Management Practices

Some field management practices are directly related to the use of fertilizers and water and pest management which are discussed in detail in Chapters 8,9 and 10. This section shall focus on management practices that are not covered in these chapters.

Spacing and Plant Population

The ideal spacing and plant population are those that maximize yield and quality without unduly increasing costs. As a rule, all crops tend to increase yield per unit area as plant population is increased, but only up to a certain limit. Beyond this limit, the yield may not increase further and may even drop (Fig. 7.29). The appropriate spacing differs from one situation to the other. For example, the population range for okra is 30,000 to 120,000/ha, depending primarily on the variety. Cabbages are planted at a higher density if smaller heads are preferred.

In mechanized farming, the flexibility for interrow spacing is determined by the type of machinery used. However, there is still a lot of flexibility for spacing within rows and, consequently, for plant population.

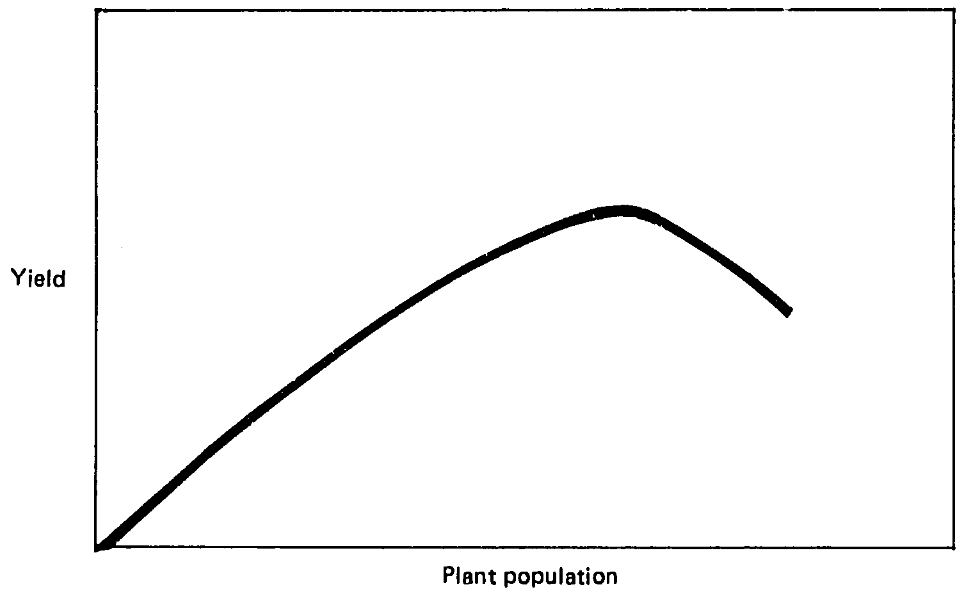

Fig. 7.29. Reproductive yield generally increases with increasing plant population up to a certain point, then the yield drops.

Mulching

Mulching serves several purposes: 1) to control soil temperature, either by keeping it cool (such as using straw mulch in a tropical environment) or keeping it warm (such as using clear plastic during spring planting in temperate and semitemperate areas); 2) to prevent loss of soil moisture; 3) to control weeds by shading them and diseases by preventing soil contact with the plant foliage. Some reflective mulches (such as silver-colored plastic that reflects light) are said to be effective in repelling insects.

The most practical mulching material is rice straw in the lowland tropics where many vegetables are grown in a cropping system with rice. Plastic mulches are generally unsuitable for tropical conditions, except in the highlands where the temperature is lower. However, both can be used effectively in warm conditions if dark-colored plastic is used in combination with rice straw (Fig. 7.30). Rice straw serves to insulate the plastic from direct sunlight and prevents the build up of soil temperature during the day. Dark plastic prevents sunlight from reaching the soil surface and heating it.

Staking and Training

With few exceptions, all viny vegetables are staked. The general methods of staking are shown in Fig. 7.31. There are three types of plants for purposes of staking: 1) plants (such as cucurbits) with special structures such as tendrils which allow them to climb; 2) plants that twine (such as yard-long beans); and 3) plants (such as tomatoes) that do not have the natural ability to climb and must, therefore, be tied to the stakes.

Staking facilitates management operations, such as irrigation, intertillage, pest control, and harvesting. It also helps produce better products. For wet-season tomatoes,

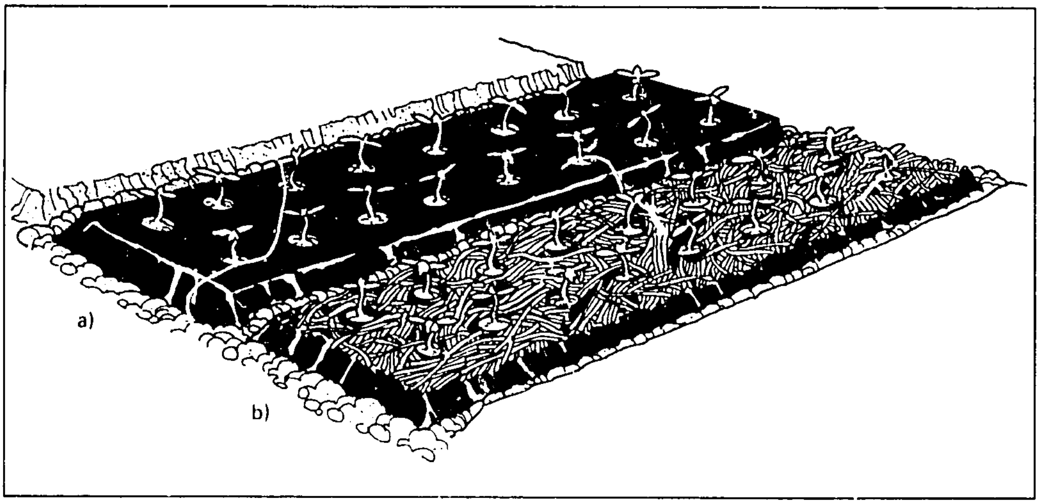

Fig. 7.30. Black plastic mulch is applied before transplanting of tomato. At transplanting, holes are made on the plastic where tomatoes are planted a). Subsequently, the plastic mulch is covered with straw mulch b).

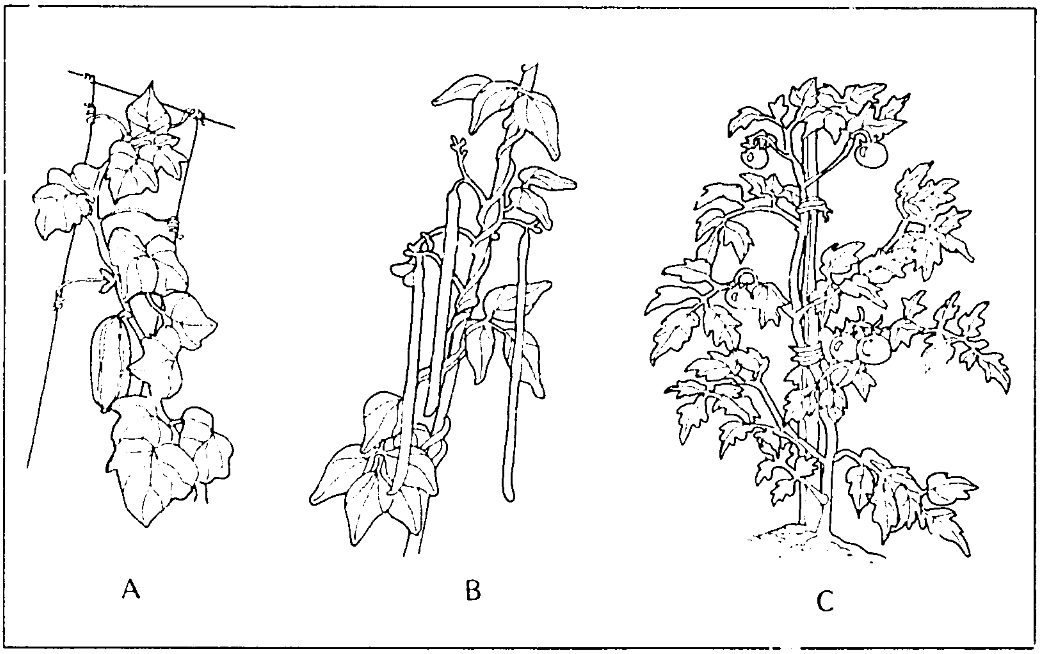

Fig. 7.31. Methods of staking: (a) for climbing plants, (b) for twining plants, and (c) for plants that do not have the ability to climb or twine.

staking is necessary. However, it can be very costly, accounting for as much as 50% of production cost. Where labor and materials for staking are cheap, it is always desirable to stake.

Training or repositioning of the vines is done with viny crops that are grown under prostrate culture (without stakes) to prevent overcrowding in some spots in the field. In insect-pollinated crops, such as watermelon and squash, dense vines and foliage may interfere with insect activity and reduce fruit set. In staked crops, training is necessary in the initial stages to keep the vines off the ground.

Pruning

Pruning has many uses in vegetable production. In indeterminate tomatoes, pruning results in single-stem plants which can easily be tied to the stake (Fig. 7.31c). The fruits are consequently larger because the plant's nutrients are not diverted to the branches. More plants can also be grown in an area.

In the case of cucurbits, such as *Luffa*, pruning of the tip of the seedling stimulates early branching and fruiting on lower nodes (Fig. 7.32). A distinct method of pruning is done on mature plants that have declined in productivity. In this case, the main stem is cut 20 cm from the ground and stimulated to produce new branches by applying fertilizer and irrigation. The result is a ratoon crop, which starts to produce fruits sooner than if seed planting is done instead. However, the yields are usually lower. The practice of ratooning works very well with some varieties of okra and eggplant during the wet season.

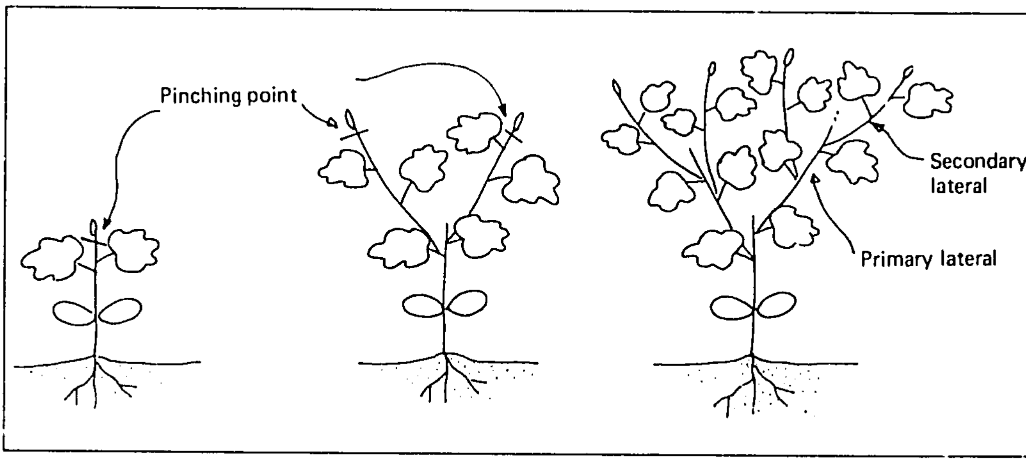

Fig. 7.32. Procedure for pruning of *Luffa:* a) pinching of main stem, b) pinching of primary lateral, c) secondary laterals are formed.

Pruning should be done with a sharp blade to minimize damage to the plant tissues and to facilitate recovery. To prevent spread of diseases, the blade should be dipped regularly in detergent solution.

Fruit Thinning

To control fruit size, some fruits are removed before they enlarge. Some plants, particularly cucurbits, produce female flowers and set fruit so early that vegetative growth is still insufficient to support the normal growth of the fruit. When this happens, further vegetative growth is restricted, while additional fruit setting and development is equally affected.

To promote the formation of bigger and better fruits, the first one or two fruits on the vine is removed. The number of fruits per vine is subsequently limited to one. The practice of fruit thinning is widely used in melons and watermelons

Synthetic Plant Growth Regulators

Several commercial, synthetic, plant-growth regulators are now in the market. Very few, however, have found popular acceptance in vegetable production because their effectiveness is very specific to target crops, cultivars, environmental conditions, timing and method of application, and concentration.

A mistake in application can damage the crop or, at least, render the treatment ineffective. Plant growth regulators also have undesirable side effects, such as puffiness in tomato fruits. At present, the main uses of commercial growth regulators are the following:

Promoting fruit set. When tomatoes are grown under unfavorable conditions, such as during summer in tropical countries, the usual problem is low fruit set. The problem is due to high night temperatures (above 22°C) and high humidity which result in poor pollination and flower fertilization. Although the problem is solved with the use of heat-tolerant varieties, these are inadequate under extreme conditions. Application of plant growth regulators has been shown to improve fruit setting, particularly in varieties that have low level of heat tolerance.

Synthetic plant growth regulators (PGRs), such as 4-chlorosphescoxyacetic acid (CPA) now used commercially in Korea, Japan, and China are known to influence fruit setting in tomatoes. These are applied at 50 mg/liter as a spray on flower clusters when they are in bloom. Spraying is usually done on each cluster at 7- to 14-day intervals, starting with the first cluster. It is claimed that the treatment increases fruit set and fruit size and induces early yields. However, it may cause puffy fruits at high concentrations or under high temperatures.

CPA is known to be equally effective in promoting fruit set in fruit vegetables with many ovules, such as squash and eggplant. Other PGRs that enhance fruit set are 2,4-dichlorophenoxyacetic acid (2,4-D) at 5-10 mg/liter spray on tomato flower clusters at full bloom, Benzyladenine (BA) applied to the peduncle of watermelon, melon, squash, and bottle gourd on the day of flower opening, and gibberellic acid (GA_3) applied as foliar spray to eggplants on the day of flower opening. All of these including CPA are registered in Japan.

Altering sex expression. Although predominantly monoecious, vegetables in the cucurbit family have a wide diversity of sex expression, ranging from highly male to purely female (gynoecious). Sex expression is genetically controlled but subject to environmental influences, including temperature, photoperiod, and growth regulators.

In viny squash, ethephon (chloroethyl-phosphonic acid, the most widely used PGR in agriculture) applied twice as foliar spray at 200 ppm at the seedling stage, promotes earlier appearance of the female flower and increases yield. Ethephon applied as a foliar spray at the three- to five-leaf stage has similar effects on cucumber, but is best used in combination with another PGR, methyl chlorflurenol.

Ethephon increases femaleness in cucumbers, but GA_3 promotes maleness. In Japan, this effect of GA_3 is used to increase the fruit size by reducing competition from other fruits that result from many female flowers. Plant breeders use GA_3 to induce gynoecious lines to produce male flowers and facilitate gynoecious inbred line maintenance. In bitter gourd, however, GA_3 at 40 mg/liter applied three times at five-day intervals during the eight- to ten-trueleaf stage increases femaleness.

Promoting uniform ripening. Ethrel has also been used commercially to induce uniform ripening of tomato. It is usually applied as a foliar spray two weeks before the breaker stage of the first cluster. Effects reported include accelerating the maturity of fruits by about five days and increasing the early but not the total yield. On the negative side, Ethrel tends to reduce fruit size and burn leaves when used improperly. It has, however, helped improve the yield of mechanically harvested processing tomatoes.

Altering dormancy. To prolong storage life, it is desirable to prolong the dormancy period of bulb and tuber crops by preventing sprouting. This is achieved in garlic and potato by a foliar spray of 2000 ppm solution of maleic hydrazide two weeks before harvest. Onion also responds to this treatment. It is not recommended, however, to use maleic-hydrazide-treated bulbs and tubers for planting.

Early reports indicate that maleic hydrazide may be carcinogenic. For this reason, its use has substantially declined. More recent evidence, however, tends to contradict these reports.

The dormancy period can be shortened, too, with other kinds of growth regulators like calcium carbide at 1 kg/t of tubers (two weeks treatment) or GA_3 at 5 ppm (sprayed) for white potato. The latter is less preferred because it causes rapid elongation of the shoot, making it more prone to mechanical damage and disease injury.

Protected Cultivation

The need for a year-round supply of fresh vegetables cannot be met adequately in many parts of the world, considering that there are cycles in seasons and unpredictable weather conditions. Even during the most favorable season, there are environmental constraints in production that limit yield and quality of vegetable products. These are compounded by the detrimental effects of pesticide residues on vegetables. This awareness led to the development of production systems that provide physical barriers to unfavorable climatic and biological influences. These systems are called protected cultivation.

Protected cultivation started in the temperate zone, primarily to produce vegetables during the cold winter months or prolong the growing season by starting early in spring and by extending up to late fall. Under these conditions, the main constraint is low temperature. Thus, glasshouse production has become a distinct system in the cold countries.

In the tropics, the most favorable season for growing many vegetables is the winter season. Outside of this season, temperatures become too high for some vegetables and precipitation too heavy for many vegetables. Some growers have found it profitable to adopt protected cultivation techniques even at great expense. There are differences in the degree of protection, however, from the simplest net enclosure to the sophisticated plastic houses with movable roofs (Fig. 7.33).

The use of net enclosures is primarily aimed at controlling insect pests that are difficult to manage by intensive use of pesticides. The most common crops that are protected by nets are the *Brassicas*, specifically cauliflower and broccoli, the high value crops, which are highly susceptible to diamondback moth. With the use of nets, the insect is controlled effectively without using pesticides. The nets also tend to reduce the temperature in the field and break raindrops into sprays.

The use of plastics in the tropics, on the other hand, is primarily aimed at protecting the crop against excessive rain. If the plastic is coated with a thin layer of whitewash, partial shading can also be achieved easily during hot summer days.

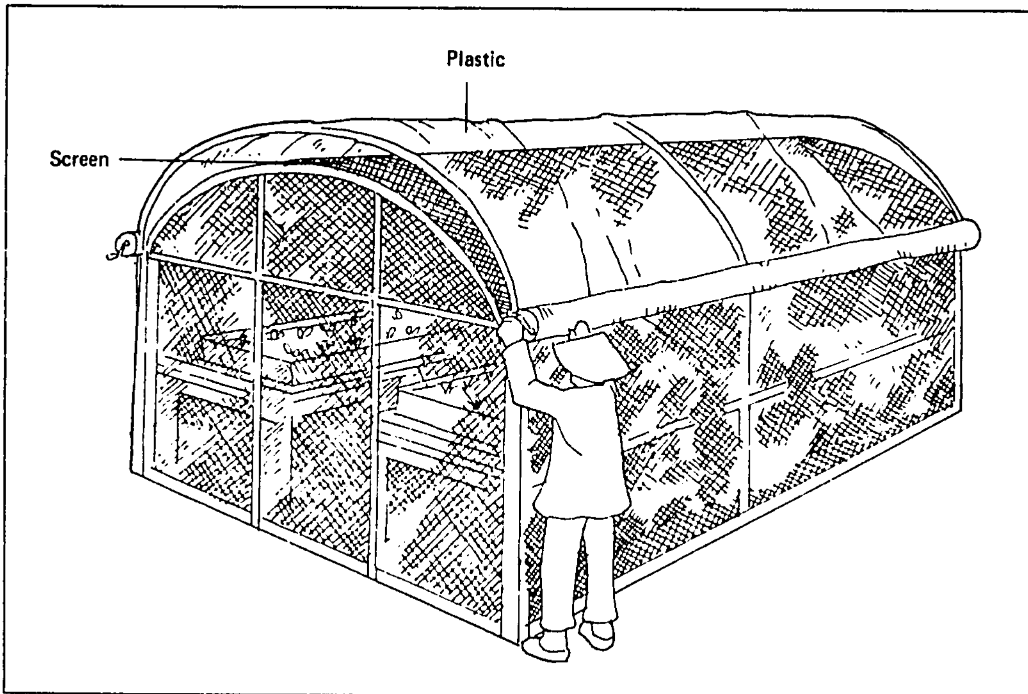

Fig. 7.33. A tropical greenhouse with movable roof. Plastic roofing is rolled downwards during hot weather.

The use of plastics, starting with the world's first plastic greenhouse in the University of Kentucky in 1948, has contributed largely to the popularization of protected cultivation. In 1985-1986, it was estimated that as much as 2.9 million ha of agricultural crops were mulched with plastic. Plastic mulches have gained commercial acceptance for tomato, melon, cucumber, squash, pepper, eggplant, and watermelon.

The same estimate made by the International Committee for Plastics in Agriculture (CIPA) shows that 200,000 ha used plastic row covers for field-grown crops and up to 163,000 ha used plastic greenhouses.

The main problem of using plastics in the tropics is the build-up of heat; so that, their use was initially limited to the highlands where temperature is low throughout the year. However, with improvements in plastic house designs, it has become possible to use plastics even in the warm climate of low elevations.

Cropping Systems

Role of Vegetables in Cropping Systems

Long growing seasons, small landholdings, and high labor-land ratios make multicrop production systems advantageous in many parts of the tropics. Multiple-cropping maximizes land productivity per unit of time.

Although multiple-cropping is an old established practice in some parts of the tropics, the concept has received only limited attention from the scientific world and only in relatively recent times. Research on multiple-cropping systems applies new technology to exploit natural resources, such as space, moisture, and radiation for food output and to sustain production.

Due to their diversity and relatively short maturity, vegetables can be easily incorporated into many cropping systems. Therefore, multiple-cropping predominates in intensive vegetable production areas.

Common Cropping Systems with Vegetables

Sequential cropping. It is the planting of two or more crops, one after another, in the same field to maximize land productivity. In the low elevations of tropical Asia where rice is the dominant crop, one or two vegetable crops grown between two wet-season rice crops is a common sequential cropping pattern. Since the main rice crop is grown during the warm summer months, the postrice vegetable season in the low elevations is sufficiently cool to favor the production of semitemperate crops, such as cabbage, white potato, carrot, salad tomato, and bulb onion.

In addition, it is the main season for tropical vegetables, such as eggplant, mungbean, melon, and watermelon. In the specialized vegetable production areas of the tropical highlands, different species of vegetables, such as cabbage, carrot, snap bean, potato, and garden peas are grown in rotation. The advantages of sequential cropping are the following:

1. Pest control — Weeds are controlled effectively when the farm land is used continuously for growing crops. A prolonged fallow or rest period between crops increases weed population, particularly in areas with an even rainfall distribution, because this condition favors the growth and multiplication of weeds. This problem is less severe in areas that are extremely dry during the fallow period.

   Proper sequencing of crops, so that two successive crops do not share the same disease or insect problem, can effectively break the life cycle of pests. This eventually reduces pest population and makes control easier.

   In a rotation system with rice, the flooded condition in the rice crop effectively reduces soil-borne diseases which may affect vegetables. It is also an important factor in the control of dryland weeds.

2. Full use of residual soil moisture and nutrients — After the wet-season paddy rice crop, residual soil moisture is usually adequate to support the establishment of another crop. In rainfed conditions, the residual moisture is not sufficient to support a second rice crop but may be enough for a short-season vegetable crop, such as mungbean. Fertilizers applied on the previous rice crop can also be utilized by a succeeding vegetable crop. Futhermore, fertilizers applied on the vegetable crop can also be used by the succeeding rice crop. With irrigation, two short-season vegetable crops may be grown between two rice crops with the use of early-maturing rice varieties.

3. Sustained soil fertility — The balance of nutrients in the soil can be maintained by rotating crops of different nutrient utilization patterns. Leguminous vegetables can fix atmospheric nitrogen and return some of these to the soil at the end of the season.

When planning a sequential cropping system, crops which can be transplanted should be grown in the seedbed before the current crop is harvested. This shortens the growing period of the succeeding crop.

Crops should be carefully selected, taking into account their most favorable planting date. For example, in the North Hemisphere tropics, onion should not be planted later than December because the crop may be exposed to unfavorable temperature and photoperiod conditions. Early-maturing crops are generally preferred to allow the growing of more crops per year.

Crops belonging to the same family should not be planted in succession to prevent accumulation of pests. For example, eggplant should not follow tomato or pepper because this may build up bacterial wilt, a soil-borne disease that affects all of these crops. Radish should not follow cabbage because both are hosts to diamondback moth, an insect pest that is very difficult to control.

Some crops produce root exudates which may remain in the soil and harm the next crop. Decomposed residues may also cause damage to the next crop.

To make full use of soil nutrients from different strata, deep-rooted crops should be grown in rotation with shallow-rooted crops. A list of crops according to rooting depth is shown in Chapter 9.

Based on the above principles, vegetables may be classified according to their suitability to monocropping or rotation as follows:

- Crops which improve quality through continuous cropping: onion, and pumpkin.
- Crops which are less susceptible to the adverse effects of continuous cropping: Chinese cabbage, cauliflower, cabbage.
- Crops that require a one-year interval: Welsh onion, spinach.
- Crops that require a two-year interval: potato, cucumber.
- Crops that require a three-year interval: tomato, hot pepper, peas.
- Crops that require a five-year interval: watermelon, eggplant.

The high cropping intensity of a sequential cropping system requires sustained application of compost or manure to replenish the organic matter in the soil and improve its biological and physical conditions.

Relay-cropping. This is the planting of a second crop before the first crop is harvested. Relay-cropping is done to 1) reduce the time that is necessary to grow several crops in the same piece of land, 2) utilize the residual soil moisture and fertilizer, 3) protect the seedlings of the second crop from intense sunlight, and 4) utilize solar radiation more fully by increasing the ground cover between consecutive crops. Although relay-cropping may reduce the yield of the first crop, the benefit from this practice usually outweighs the loss in yield.

To succeed in relay-cropping, certain conditions must be met. The land should be prepared thoroughly for the first crop; so that, it will serve the needs of the two crops. In a relay-cropping scheme, it is difficult to prepare the land for the second crop without causing damage to the first crop, especially if the latter is closely spaced. The first crop must also be planted and evenly spaced in straight rows to facilitate field operations during planting and initial growth of the second crop. Weeds should be controlled more thoroughly during the first crop to avoid harm to the second crop.

The relay crop must be shade-tolerant; otherwise, the population of the first crop must be reduced to minimize shading effects on the relay crop. If the relay crop will not be irrigated, it must be drought-tolerant, too. There are varieties that are known to possess shade and drought tolerances. Examples of these are the following:

- Drought-tolerant varieties:
  Yard-long bean - Sandigan, CSL 14, CSD 5
  Mungbean - IPB M79-6-11, IPB M79-13-98

- Shade-tolerant varieties:
  Yard-long bean - CSL 24, CSD 8
  Mungbean - Pag-asa 3, VC 1163
  Okra - 86-4025, 86-46002, 86-46005
  Tomato - F1 4497
  Bell pepper - Sinagtala
  Hot pepper - Red Santaka

- Drought- and shade-tolerant varieties:
  Mungbean - Pag-asa 7

Crops that are used for relay-cropping with rice in Taiwan are shown below:

- With overlapping period of two weeks: watermelon, oriental pickling melon, muskmelon, cabbage, cauliflower, tomato, peas, asparagus, lettuce, potato, carrot, eggplant, cowpea
- With overlapping period of four weeks: sweet potato, sesbania, okra
- With overlapping period of six weeks: sweet potato

Crops that are used for relay planting with corn in Taiwan are shown below:

- With overlapping period of two weeks: cabbage, cowpea, muskmelon, vegetable soybean, watermelon
- With overlapping period of four weeks: tomato, eggplant, okra
- With overlapping period of six weeks: sweet potato

The best time for sowing or transplanting the second crop between the rows of rice is immediately after training the irrigation water from the field for the last time. Usually this is about two weeks before harvest of the rice crop, but it can be done earlier to allow earlier planting of the relay crop.

If it is necessary to increase the overlapping duration, alternate rows of the first crop may be harvested. This is possible in the case of some vegetable legumes, such as cowpea, the alternate rows of which can be harvested for green pods, and the maize planted in the harvested rows (Fig. 7.34). The remaining plants can be harvested for seed. Another method is to remove the lower leaves of the first crop to allow more sunlight to reach the relay crop. This is possible in the case of erect plants, such as okra (Fig. 7.35).

The main drawback to relay-cropping is the high labor requirement. Cultural management practices, such as planting, cultivation, fertilizer application, and weed control, cannot be done mechanically without damaging the first crop. It is, therefore, appropriate only for farms with an excess in labor.

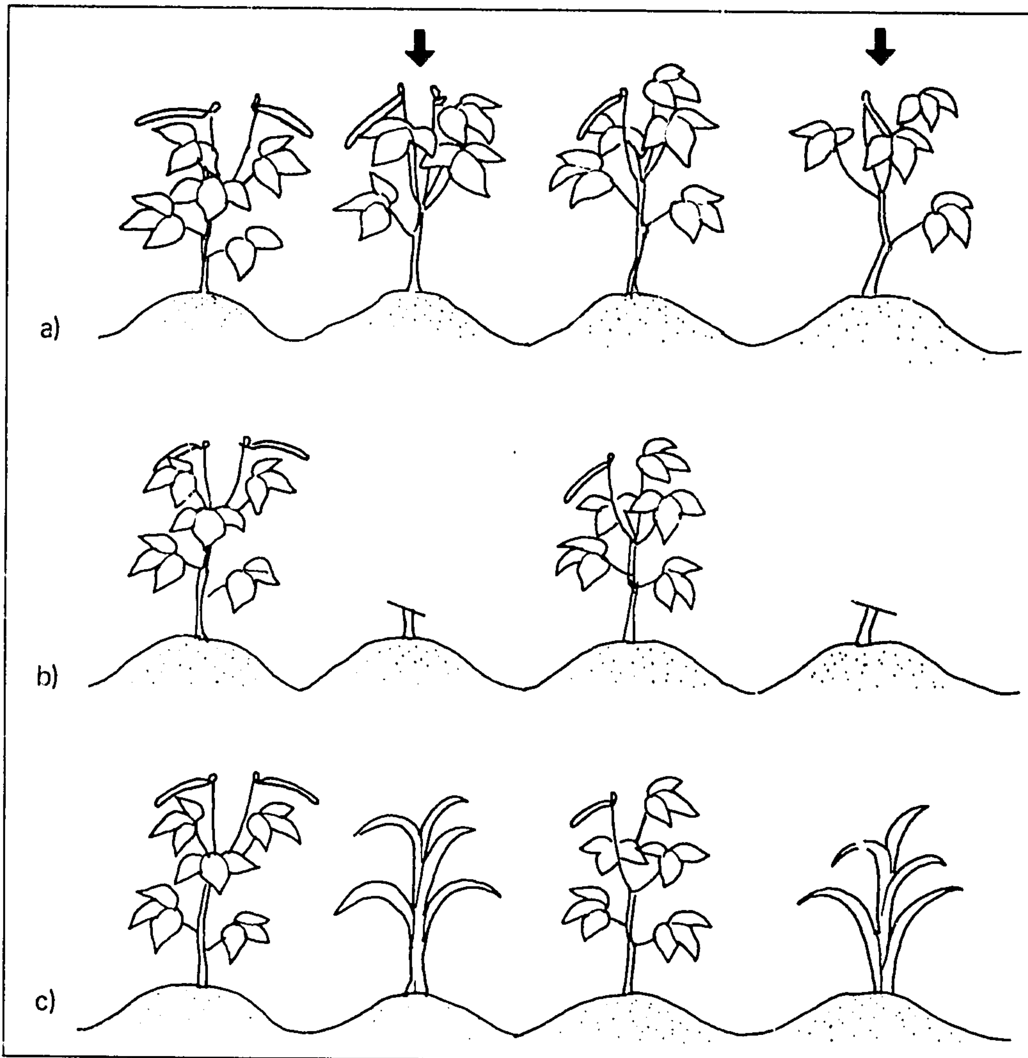

Fig. 7.34. Relay-intercropping of corn with cowpea: a) every other row (as shown by arrow) of cowpea is harvested for green pods; b) after-harvest, the harvested rows are cut and corn is planted along these harvested rows; c) the remaining rows of cowpea are allowed to mature for seed.

Intercropping. Intercropping is the practice of growing two or more crops in the same field at (or about) the same time. Intercropping has the following advantages:

- Yield advantage — The term "Land Equivalent Ratio" (LER) is commonly used to indicate the biological efficiency of an intercropping system, and is defined as the relative land area required by single crops to produce the same yield as in intercropping. LER is calculated as follows:

$$LER = LA + LB = AI/AS + BI/BS$$

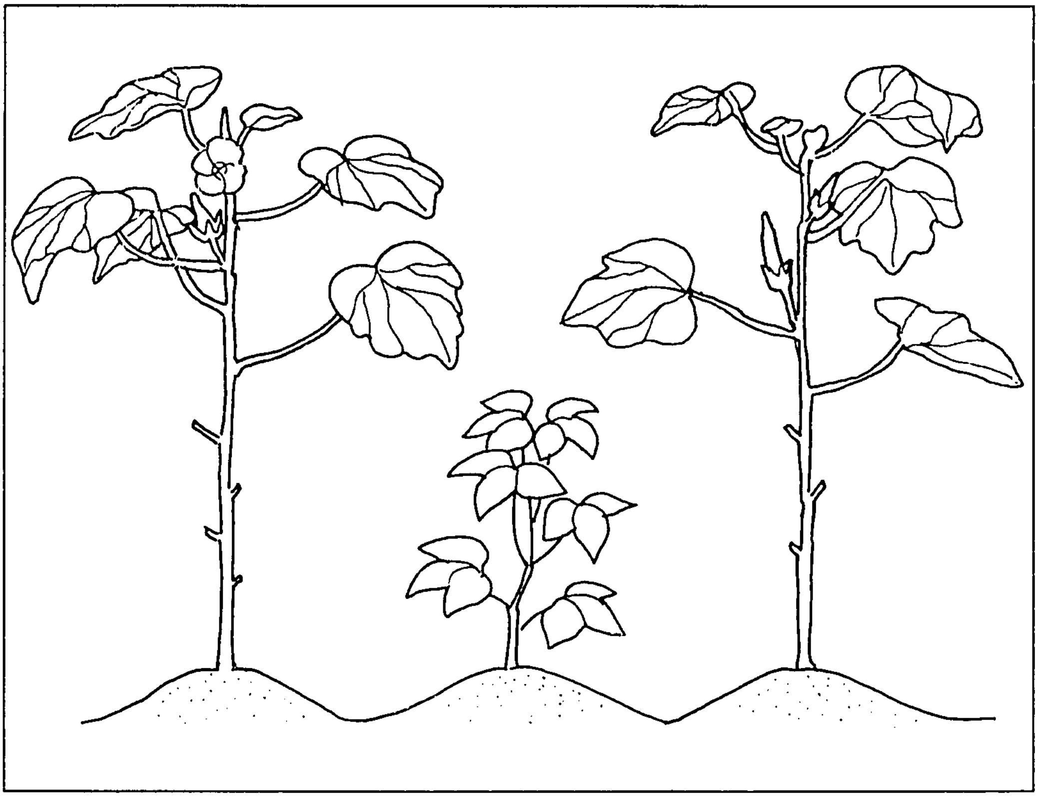

Fig. 7.35. Relay-intercropping with okra. Lower leaves of okra are cut to reduce shading on assorted crop.

Where LA and LB are the individual LERs of two crops A and B, LA is obtained by dividing the yield of crop A in intercropping AI) by the yield of the same crop in sole cropping (AS). LB is calculated in the same way.

An LER greater than one means that intercropping is more efficient than monocropping of the component crops. On the other hand, a LER less than one means that intercropping is less efficient than monocropping. Experimental evidence tends to show that LER greater than one is usually achieved in intercropping.

The yield advantage can be explained in several ways:

1. There is better use of light, nutrients, and water by allowing the intercrop to utilize these resources that may otherwise be wasted.
2. A crop which covers the soil rapidly without competing excessively with the associated crop, can reduce the growth of weeds and prevent these from competing with the crops.

- Yield stability — It is often claimed that a major reason for the predominance of intercropping in poorly developed agriculture is that it gives greater stability of yield over seasons. For example, if cabbage is intercropped with corn and cabbage is attacked by diamondback moth, the performance of corn will not be affected because corn is not a host of diamondback moth.

If cabbage is planted as a monocrop, then the entire field can be lost. On the other hand, if corn is attacked by corn borer, the performance of cabbage will not be affected because cabbage is not a host of corn borer. On the contrary, the loss of the corn crop may create a favorable condition for cabbage, because the shading effect and possible competition of corn with cabbage for nutrients and water will be reduced.

The component crop may also serve as a host for natural enemies of pests of the other crop. This is the reason why peanut is a good intercrop for corn: the spiders that thrive on peanuts serve to control the corn borer population in the corn crop. In the case of tomato and cabbage intercropping, the tomato is believed to serve as repellant against diamondback moth.

Companion planting is a form of intercropping in which the space-sharing plants are selected on the bases of their ability to enhance one another through pest control and other mechanisms. In selecting crops for intercropping, it is better to plant companion crops and avoid competition. A listing of such crops is presented in Table 7.1.

Finally, intercropping serves as an insurance against the uncertainties of the market in less developed countries. If the price of one crop happens to be too low at harvest time, then the profits can be obtained from the intercrop.

- Soil erosion control — Some forms of cover on the soil surface are needed to protect against run-off and soil loss. Intercropped fields usually have a higher combined population density and produce an earlier ground cover than monocropping.

- Enhanced employment opportunities — Intercropping is a labor-intensive type of farming. A stable employment is also provided by two or more crops that have different peaks of labor requirement. In a monocrop situation, a lot of labor is required during some stages of crop growth, but these may not be necessary during other stages.

Crops used in an intercropping scheme are potential competitors for farm resources. However, there is also the potential for complementation. It is important to develop suitable management practices that minimize intercrop competition and maximize complementary effects.

Selection of species for intercropping must take the following into consideration: 1) allelopathy and residue problems, 2) depth of rooting, and 3) combining crops with different nutrient demands. These factors were discussed in some detail under the topic "Sequential Cropping" in the earlier part of the Chapter. In addition, the following factors must be considered: 4) combining tall crops with short but shade-tolerant ones. Tall crops, such as corn and okra, and crops that are grown on stakes such as indeterminate tomato, pole beans, bitter gourd, and cucumber can be intercropped with shade-tolerant crops, such as celery, Chinese cabbage, green onion, and cabbage (Fig. 7.36); and 5) growing short-season crops between late-maturing crops.

This practice allows the utilization of space between rows of long-duration crops, while providing early income from vegetable farming. For example, the fast-growing leaf type of Chinese cabbage (pak-choi) is transplanted and harvested within 30 days between the rows of eggplant, even before the eggplant begins to flower (Fig.7.37).

Table 7.1. Vegetable companions and antagonists.[a]

Vegetable	Companion	Antagonist
asparagus	tomato, parsley, basil	
beans	potato, carrot, cucumber, cauliflower, cabbage, summer savory, most other vegetables and herbs	onion, garlic, gladiolus
bottle gourd	sponge gourd, cucumber, bitter gourd	
bush beans	potato, cucumber, corn, strawberry, celery, summer savory	onion
pole beans	corn, summer savory	onion, beet, kohlrabi, sunflower
beets	onion, kohlrabi	pole beans
Brassica crops	aromatic plants, potato, celery, tomato, dill, sage, peppermint, rosemary, beet, onion, camomile	strawberry, pole bean
carrot	peas, leaf lettuce, chives, onion, leek, rosemary, sage, tomato	dill
celery	leek, tomato, bush beans, cauliflower, cabbage	
chives	carrot	peas, beans
corn	okra, tomato, bush beans, pole beans, cabbage, peanut, vine squash, potato, peas, cucumber.	
cucumber	pole beans, radish, okra, eggplant, beans corn, peas, radish, sunflower	potato, aromatic herbs
eggplant	beans, kangkong, vine squash, Chinese cabbage, radish	
kangkong	tomato, okra, corn, eggplant, amaranth, any crop on trellis	
leek	onion, celery, carrot	
Moringa	kangkong, Chinese cabbage, nightshade, jute, lettuce, bush squash, amaranth	
lettuce	carrot, radish, strawberry, cucumber	
mungbean	corn	
okra	kangkong, vine squash, Chinese cabbage, radish	
onion, garlic	beet, strawberry, tomato, lettuce, summer savory, carrot. camomile	peas, beans
parsley	tomato, asparagus	
peas	carrot, turnip, radish, cucumber, corn, beans, most vegetables and herbs	onion, garlic
potato	beans, corn, cabbage, sunflower	squash, cucumber, tomato, raspberry
squash	corn	potato
radish	peas, nasturtium, lettuce, cucumber	
soybean	grows with anything, helps everything	
spinach	strawberry	
Luffa gourd	bottle gourd, cucumber, bitter gourd	
tomato	chives, onion, parsley, lettuce, asparagus, marigold, nasturtium, carrot, radish, Chinese cabbage, kangkong, vine squash	kohlrabi, potato, fennel, cabbage
turnip	peas	

[a] J. Jeavons 1982.

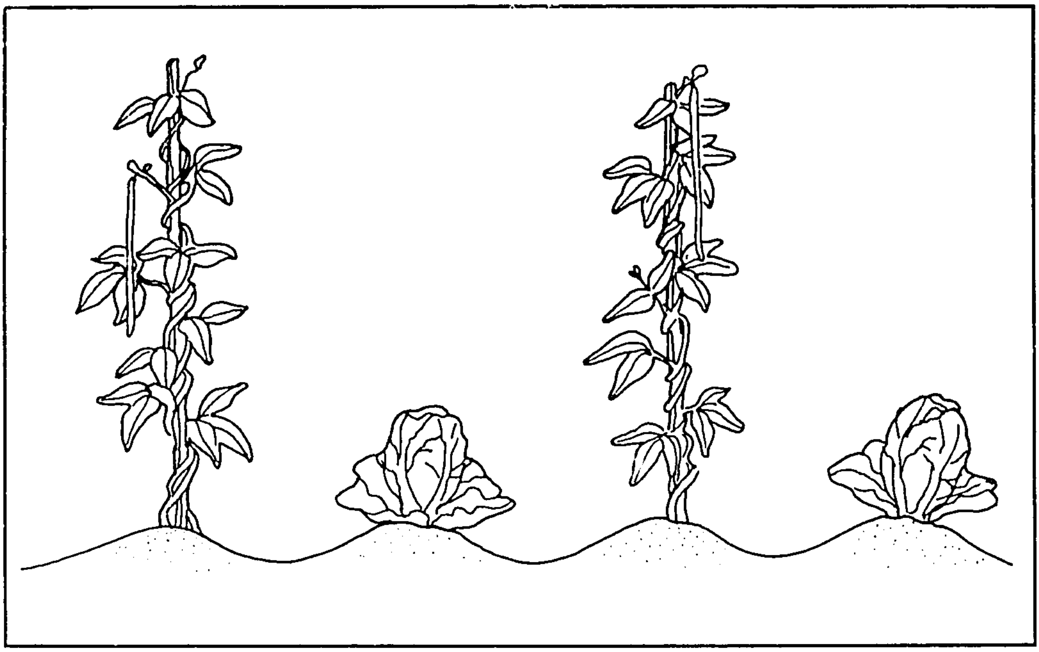

Fig. 7.36. Intercropping of pole bean with Chinese cabbage.

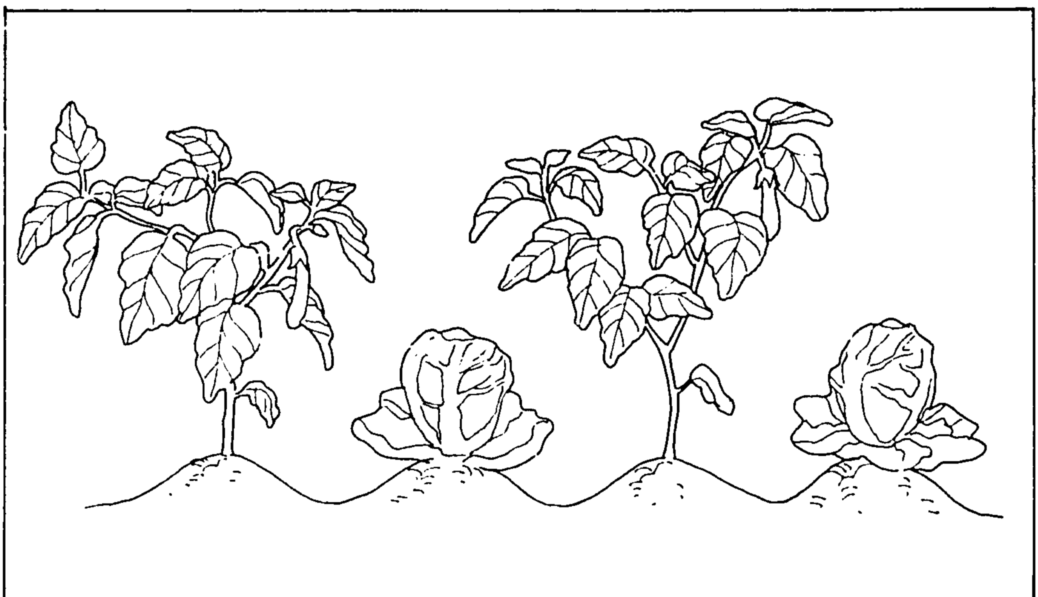

Fig. 7.37. Intercropping of slow-growing plant (eggplant) with fast-growing plant (Chinese cabbage). Chinese cabbage is ready for harvest at about the time that the first fruits of eggplant are setting.

Vegetables can also be intercropped with long-season field crops, such as sugar cane, or with perennials, such as coconut.

Plant populations and spatial arrangement in the field are of great importance in crop associations of two or more species, as these affect the efficiency with which solar radiation and space are utilized. Light is considered the most critical factor in intercropping with regard to temporal use of resources. The amount of light intercepted by a crop canopy depends mainly on its leaf area.

Intercropping usually results in a higher total leaf-area development and possibly a higher combined plant population. However, the plant population and spatial arrangement of associated crops should be planned to reduce interspecific competition and enhance light penetration. For example, row spacing should be increased but plant spacing decreased for tall crops to improve the availability of light to an associated crop grown between the rows. However, this should be done without increasing the intra-specific competition for nutrients and water, thereby, reducing the yield of the tall crop significantly.

In intercropping, competition for soil nutrients between component crops does not occur until there is an overlapping of depletion zones of their roots. A crop tends to "avoid" areas that have already been depleted of resources by associated crops; hence, the component species often occupy different niches.

Changing the relative planting time can easily manipulate the relative competitive ability and the yield of component crops, and should be taken into consideration when establishing a new intercropping system. Another rule is that the high nutrient-absorption period in associated crops should not overlap, e.g., their reproductive stages should not occur at about the same time.

Cropping Systems in Retrospect

All the cropping systems for vegetables discussed so far involve growing several crops in the same piece of land. In the case of sequential cropping, the crops are separated by time. In intercropping, two or more crops are grown together without temporal (or strictly, even spatial) separation. Relay-cropping is the intermediate case; that is, there is a temporal and spatial overlap between two succeeding crops.

A critical look at these systems tends to suggest that these are really attempts to approximate the ways of nature. In the wild, plant species grow in a mixed (intercropping), seemingly chaotic manner. Yet, there are successions of species with the changes in season (sequential cropping), some of them overlapping in space and time (relay-cropping).

All the cropping systems share something in common: they are labor-intensive because it is difficult, if not impossible, to mechanize these crop production systems. The emphasis is on productivity of land and other physical farm resources, rather than on labor productivity. Yield per unit area per unit time is high; thus, it is appropriate in situations where land is limited and labor is plentiful.

This situation fits perfectly into that of a small and overpopulated developing country, where most of the labor force have very little choice but to engage in agriculture, where farm wages are low because labor productivity is low. This is probably the defect of the system: it ties down most of the labor force to low-paying jobs and perpetuates large-scale poverty. The production system should, therefore, be considered a temporary measure to be phased out as soon as other better-paying jobs are generated.

Agricultural development, if it is to be measured in terms of benefits of agriculture to society, can only be achieved through a production system that maximizes labor productivity first and foremost. To put it differently, a society has achieved agricultural development when one farmer or farm worker can produce enough food to feed 100 or more people rather than five or less, which is the norm today in the underdeveloped world of subsistence "natural" farming.

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CHAPTER 8

Soil Management

Part I - Soil Productivity

Soil productivity is defined as the capability of soil to produce a specific crop (or sequence of crops) under a specific management system which includes planting date, fertilization, irrigation schedule, tillage, and pest control.

Soil productivity is an economic concept which considers inputs (a specified system of management), output (yields of particular crops), and soil type. Soils differ in their capacity to absorb management inputs on a given type of soil for maximum profit.

A soil must be fertile to be productive; however, some fertile soils are not necessarily productive. For instance, many fertile soils in the arid regions are not considered productive for vegetable crops because of lack of irrigation.

Soil scientists use several methods to assess soil productivity for various crops. These include yield measurement over a period of time using current management practices, climate, and nature of the soil. Thus, soil productivity reflects all the factors, soil and nonsoil, that influence crop yields.

Evaluation of Soil Productivity Potential

Evaluation Standards. The potential productivity of a specific soil may be evaluated based on the physical, chemical, and biological features of the soil. These include soil depth, texture and structure, nutrient and organic matter content, drainage, topography, and presence of injurious factors. These standard items are summarized in Table 8.1.

Table 8.1. Standard items used for evaluation of soil productivity potential.

Standard Item	Item to be Measured	Index or Criteria
1. Depth of topsoil (t)	Depth of topsoil	Depth of layer in cm
2. Effective depth of soil (d)	Effective depth of soil	Depth of layer in cm
3. Gravel content of topsoil (g)	Content and size of gravel and its degree of weathering	Distribution % in cross section of tonsoil
4. Difficulty in tillage (p)	Texture of topsoil	Course - fine
	Stickiness of topsoil	To tools when wet
	Hardness of topsoil	To tools when dry
5. Percolation on flooding (l)[a]	Texture of soil layer 50 cm deeper under topsoil	Fine - course
	Maximum compactness of the above-mentioned soil layer	Value of Yamanaka's cone-penetrometer
6. Oxidation-reduction status (r)[a]	Content of easily decomposable organic matter	Amount of NH_4-N formed/ 100 g of dry soil
	Content of free iron oxides	% to dry soil
	Gleyzation degree	Occurring position of Gley horizon

Table 8.1. Continued.

	Standard Item	Item to be Measured	Index or Criteria
7.	Dryness or wetness of land (w)	Percolation	Yamanaka's infiltration methods, etc.
		Retentivity	Difference between field capacity and wilting point
		Moisture	Moisture status of the soil profile
8.	Natural fertility (f)	Nutrient holding capacity	CEC in meq
		Nutrient fixation ability	P absorption coeficient
		Base status	Saturation degree of exchangeable Ca
9.	Abundance of nutrients (n)	Exchangeable Ca	CaO mg/100 g of D.S.
		Exchangeable Mg	MgO mg/100 g of D.S.
		Exchangeable K	K_2O mg/100 g of D.S.
		Available P	P_2O_5 mg/100 g of D.S.
		Available N	N mg/100 g of D.S.
		Available Si	SiO_2 mg/100 g of D.S.
		Micronutrients	Occurring status of deficient symptoms
		Acidity	pH, Y_1
10.	Presence of injurious factors (i)	Chemical	Heavy metal and irrigation water pan
		Physical	
11.	Risk of disaster (a)	Submergence	Degree of submergence due to heavy rain, etc.
		Landslide	Slope, parent materials
12.	Slope (s)	Natural slope	Gradient of slope
		Direction of slope	Major direction of slope
		Artificial slope	
13.	Erosion (e)	Erosion rate	Occurring status of rill & gully
		Water resistance of soil	Dispersion of topsoil
		Wind resistance of soil	Hardness of air-drysoil

[a]For paddy soils.

The 13 standard items used for evaluation and their letter symbols are as follows:

1. Depth of topsoil (t): Topsoil here means the topmost soil layer through which plant roots can easily extend.
2. Effective depth of soil (d): Depth of soil layer through which plant roots can penetrate fairly freely.
3. Gravel content of topsoil (g): Content and size of gravel and its degree of weathering.
4. Difficulty of tillage (p): Texture, stickiness, and hardness of topsoil when dry or wet are considered.
5. Percolation on flooding (l): For paddy soils only. Texture and maximum compactness of soil layer 50 cm deep under plow layer are considered.

6. Oxidation-reduction status (r): For paddy soils only. Easily decomposable organic matter and free iron oxide contents of plow layer and gleyzation degree are considered.
7. Dryness or wetness of land (w): Not used for paddy soils.
8. Natural fertility (f): Nutrient-holding and fixing capacities and base status are considered.
9. Abundance of nutrient (n): Content of various nutrients and acidity are considered.
10. Presence of injurious factors (i): Chemically and physically injurious factors such as heavy metals are considered.
11. Risk of disaster (a): Possibilities of flooding, landslide, etc. are considered.
12. Slope (s): Not used for paddy soils.
13. Erosion (e): Not used for paddy soils.

Limiting Factors. Limiting factors in upland soils and methods of improving them are as follows:

1. Physical factors

a. Depth of topsoil — Soil productivity is very closely related to the depth of topsoil. In many cases, the thinner the topsoil, the lower is its ability to supply water and nutrients. In addition, soil productivity depends largely upon the kind of soils and local environmental conditions.

Therefore, topsoils more than 25, 40, and 60 cm deep are normally recommended for common upland crops, vegetables and long-root crops, respectively.

If a topsoil is high in clay, soil dressing should be done to enhance the noncapillary porosity. Yearly application of fresh and easily decomposable organic matter, is also effective in improving soil physical properties.

If a gravelly layer is present in the subsoil layer, soil dressing is necessary. This may be combined with inorganic soil amendments, such as lime and phosphate, and if necessary, organic matter such as compost or stable manure. If a pan or other compact layers are present, deep tillage, soil layer mixing tillage, or subsoil tillage should be done together with the application of the soil amendments mentioned above.

b. Effective depth of soil — Almost the same measures as in No. 1 should be made.

c. Soil compactness and macroporosity in a major zone of the root system (Table 8.2) — Root branching and quality of the root vegetables are impaired in soils with compactness higher than 24-25 mm (by Nakayama's cone penetrometer).

Soils within a major root system should have a compactness of less than 22 mm and a macroporosity of not less than 10% for good root distribution.

If a gravelly layer, such as a clay-gravel layer of nonvolcanic origin and a sand-gravel layer of volcanic origin are present soil dressing and elimination of the layer with deep tillage should be done. For a fine-textured compact layer, subsoiling is effective.

d. Available water-holding capacity in the major root system — The amount of available water (pF 1.8~pF 2.7) in the soil up to 40 cm deep is estimated to be 20 mm (5% in soil volume). In general, maintaining this value is easier in volcanic ash soil than in nonvolcanic, mineral soil or in sandy soil.

Table 8.2. Soil compactness and distribution of root system of some crops.

Soil		Hardness (mm)[a]								
		12, 13	14, 15	16, 17	18, 19	20, 21	22, 23	24, 25	26, 27	28, 29
		Root distribution (%)								
Sandy soil	Sweet potato	82	100	82	76	79	68	70	18	0
	Peanut	80	86	92	78	60	28	16	0	0
	Tomato	90	88	87	72	82	38	16	16	16
	Eggplant	100	100	100	100	92	66	8	0	0
	Pumpkin	100	100	100	100	86	86	30	8	2
	Pepper	100	82	93	74	85	19	12	0	0
	Cucumber	100	84	76	82	86	41	19	0	0
	Water melon	100	81	73	93	93	43	12	0	0
Loamy soil	Sweet potato	100	93	80	95	59	57	17	10	4
	Peanut	80	92	79	72	72	80	48	8	0
	Eggplant	100	92	80	73	73	80	38	18	0
	Lettuce	84	94	94	86	82	76	12	16	0
	Taro	100	100	100	100	67	7	18	8	4
Clayey soil	Strawberry	100	79	76	72	59	36	13	13	6
	Broad bean	100	100	92	—	—	—	—	—	—
	Cucumber	86	86	86	86	80	30	19	8	4
	Lettuce	100	82	86	62	62	6	0	0	0
Volcanic ash soil	Sweet potato	100	100	100	82	83	82	10	0	0
	Peanut	100	100	96	96	94	48	0	0	0

[a]Hardness is measured by Nakasone's cone penetrometer. Soil compactness affects not only air permeability and water percolation, but also root growth in the soils. Vegetables, especially root ones, may be grown in soils with a hardness of less than 18.

When the amount of water is lower than this value in a soil, subsoiling and mulching may be used to enhance water percolation effectively into the soil and to prevent evaporation of rain water from the soil surface.

Table 8.3 shows water consumption of vegetables at different depths of the surface soil.

2. Chemical factors

a. pH — The optimum pH range for maximum crop growth (pH 5.5~7.5 for major vegetables) vary because of the differences in crop cultivars and the influence of meteorological and soil conditions. (See Table 3.10 in Chapter 3 for the pH range of different vegetables.)

Crops growing on very acidic soils may develop deficiency in macronutrients, such as Ca and Mg. They may also have decreased available phosphate because of the reaction with aluminum (Al) and iron (Fe) in the soil. Moreover, the Al and Mn which are easily soluble injure the roots. On the other hand, alkaline soils and soils with high pH promote deficiency in micronutrients, such as Mn, B, and Zn. These nutrients are present in the soil but are in unavailable forms.

Table 8.3. Water consumption of vegetables (mm/day).[a]

Irrigation Water Depth (cm)	Without 0-10	10-20	20-30	30-40	Total	With 0-10	10-20	20-30	30-40	Total
Tomato	1.7	1.8	1.3	1.1	**5.9**	3.4	2.4	2.9	1.7	**10.4**
Cucumber	0.0	0.0	0.0	0.0	**0.0**	3.4	1.5	0.4	0.2	**5.5**
Cauliflower	0.0	0.1	1.4	0.5	**2.0**	0.3	1.1	1.7	0.5	**3.6**
Mitsuba[b]	1.2	0.6	1.0	0.4	**3.2**	0.8	1.5	1.0	1.3	**4.6**
Taro	0.5	1.7	1.0	0.5	**3.7**	3.4	0.6	0.4	0.1	**4.5**
Ginger	2.5	0.0	0.0	0.0	**2.5**	0.7	2.1	0.1	0.0	**2.9**

[a]N.B.: Easily available water. Such water remains in a soil after removal of gravitation water, and can easily move through capillary pores. If the easily available water is deficient in the topsoil, but present in the underlying soil layers, the plants are able to absorb it in their rhizosphere.

[b] *Cryptotaenia japonica* Hassk.

In case of strongly acidic soils, liming and application of organic matter, such as compost, stable manure or green manure are necessary. Application of phosphatic fertilizer may also be done.

b. Natural fertility — As soil fertility is formed under the combined influence of both natural soil genesis and man's agricultural activities, it is impossible to distinguish between natural and artificial fertilities. However, those properties considered to be formed largely by natural factors are called natural fertility. It is not impossible, of course, to alter natural fertility by human action. Soils with limiting factors due to low natural fertility are the following.

- those with poor nutrient-holding capacity.
- those with strong ability to fix phosphate and is easily changed into unavailable forms for the plant when phosphate is applied.
- those with a low degree of exchangeable base saturation (Table 8.4).

To improve soils of low nutrient-holding capacity, compost or stable manure and soil dressing should be applied. Mountain soil as a soil dressing have low organic matter and nutrient content; so compost or stable manure, bases, and phosphate have to be applied along with soil dressing.

To improve soils with high phosphate fixing ability, heavy dressing of phosphate is necessary. Likewise, compost or stable manure, lime, and calcium silicate may be effective.

To improve base status, deep tillage and application of compost, stable manure, or straw, besides heavy dressing of bases, are desirable.

c. Abundance of nutrients — Although nutrient content in the topsoil is also related to natural fertility, the amount is likely to fluctuate and be influenced by management including fertilizer application. Therefore, the abundance of nutrients is decided separately from natural fertility. In upland fields, the macronutrients, such as N, P, K, Ca, Mg, micronutrients, and soil acidity indicate nutrient abundance.

Soils poor in available nitrogen need yearly application of organic matter together with basal and split application of nitrogen fertilizers. For phosphate-deficient soils, phosphate

Table 8.4. Cation exchange capacity and base content.

Andosol (Volcanic Ash Soil)		Nonvolcanic Ash Soil	
CEC (meq/100 g)	CaO (mg/100 g)	CEC (meq/100 g)	CaO (mg/100 g)
10	130-210	5	65-95
20	220-380	15	190-280
30	330-570	25	320-470
40	510-760	35	450-660
CEC (meq/100 g)	MgO (mg/100 g)	CEC (meq/100 g)	MgO (mg/100 g)
10	30-50	5	5-25
20	50-90	15	40-70
30	90-140	25	70-110
40	95-180	35	100-160
CEC (meq/100 g)	K_2O (mg/100 g)	CEC (meq/100 g)	K_2O (mg/100 g)
10	15-45	5	15-21
20	15-85	15	15-65
30	20-130	25	16-105
40	26-170	35	23-150

Base Ratio

Ca		Mg		K
65-75	:	20-25	:	2-10

materials should be applied and, to enhance their effect, organic matter and bases are necessary. Soils poor in potassium need increased supply of this nutrient. However, careful consideration should always be balanced because excess potassium inhibits magnesium uptake. For soils poor in calcium and magnesium, lime-magnesium materials like dolomite should be applied, but always together with organic matter to preserve and increase soil humus. Application of materials like lime and magnesium can increase micronutrient content of poor soils.

d. Presence of injurious factors — Rocks, pans, and gravel layers which may be physically injurious, should be crushed or removed by machines. At the same time, soil dressing and soil amendment materials and organic matter should be applied.

Chemically injurious factors include noxious substances, such as heavy metals and waste water. To prevent pollution by heavy metals, any of the following methods may be used:

- Replacing polluted soil.
- Soil dressing by overlaying.
- Soil-turning tillage.
- Application of lime, phosphate, and organic amendment materials to change heavy metals temporarily to soluble forms.
- Proper water management should also be done to prevent the deterioration of irrigation water.

Part II - Soil Fertility

Soil fertility can be defined as the quality of the soil that enables it to supply the proper kind and amount of the elements needed for plant growth when other factors such as light, temperature, and other soil characters are favorable.

Soil as a Plant-Nutrient Medium

There are physical, chemical, and biological soil properties which are important to plant nutrition. The soil can be said to have three major components (Fig. 8.1). The solid phase is the main nutrient source. It holds the primary minerals which contain the essential macroelements and microelements and the large organic particles mostly made up of the C, H, O, and smaller amounts of other essential èlements. This solid phase also has the finer (colloidal) particles where the exchangeable cations are absorbed.

The second component is the liquid phase where the nutrient elements occur in ionic forms readily absorbed by the plant roots. The gaseous phase of the soil is where gas exchanges between the living organisms in the soil and the atmosphere take place.

The actual transfer involves the movement of ions. The positively charged ions, called ***cations*** include K^+, Mg^{2+}, Ca^{2+} Fe^{3+}, Zn^{2+}, and Cu^{2+}. The negatively charge ions (***anions***) are NO_3^-, $H_2PO_4^{2-}$ and Cl. The liquid phase is also called the ***soil solution***. Chemical and biological processes that occur in the soil solution and in the solid soil surfaces produce the ions necessary for plant nutrition. The soil, therefore, is not only a nutrient reservoir but also a medium through which the nutrient elements are made available to the plants. To promote soil fertility, an adequate supply of nutrients must be maintained in the soil. These nutrients must be available at a rate suitable to normal crop growth. This involves a complex transfer to the soil solution and to the plant. Moreover, an adequate nutrient ratio is necessary, the total concentration being equally vital. Such a balance tends to ensure the desirable physiological conditions necessary for successful plant production.

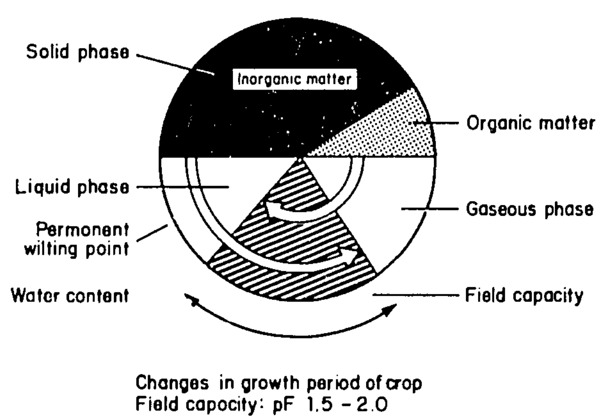

Fig. 8.1. The relationship between liquid and gaseous phase in the three phases distribution of soil.

Soil Nitrogen and Organic Matter

The forms of soil nitrogen are organic nitrogen, ammonium nitrogen, soluble inorganic nitrate compounds, and ammonium nitrogen fixed by certain clay minerals. Soil nitrogen is always in a state of change.

Soil nitrogen changes. Nitrogen may be transformed through immobilization, mineralization, nitrification, and denitrification.

Immobilization is the process by which microbes decompose plant and animal residues. Through this process, nitrogen becomes tied up in the tissue of the microbe.

Mineralization (ammonification) is the conversion of an element (inorganic combination) to the available form as a result of microbial decomposition (the breakdown of organic N to inorganic form).

Nitrification is a microbial reaction converting ammonium nitrogen to nitrate form (formation of nitrates from ammonia in soils by soil organisms). Aeration, temperature (approximately 30°C optimum), moisture, available calcium and magnesium, and fertilizer enhance microbial nitrification.

Denitrification is a process where soil organisms, particularly anaerobic organisms (living or active in the absence of air or free oxygen) convert nitrate nitrogen to gaseous forms, which are then lost from the soil (the reduction of nitrates to nitrites, ammonia, free nitrogen) Figs. 8.2 to 8.4 illustrate these changes.

When organic residues with a wide carbon-nitrogen (C/N) ratio are added to the soil which contains nitrate nitrogen, decay organisms prevail and the nitrifying bacteria become more or less inactive. During the nitrate depression period, plants obtain little

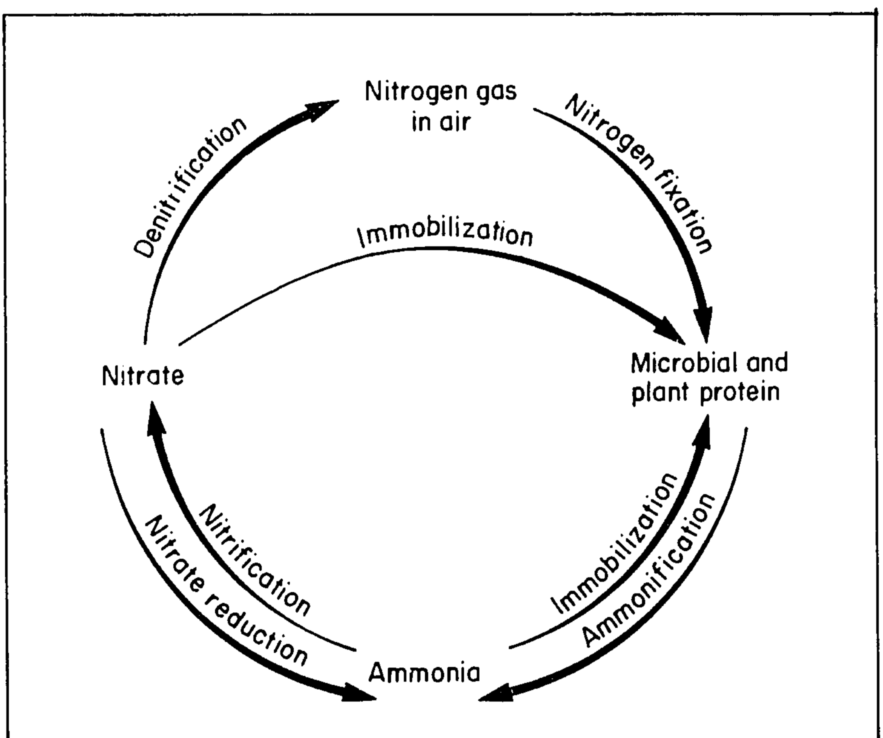

Fig. 8.2. The soil nitrogen cycle.

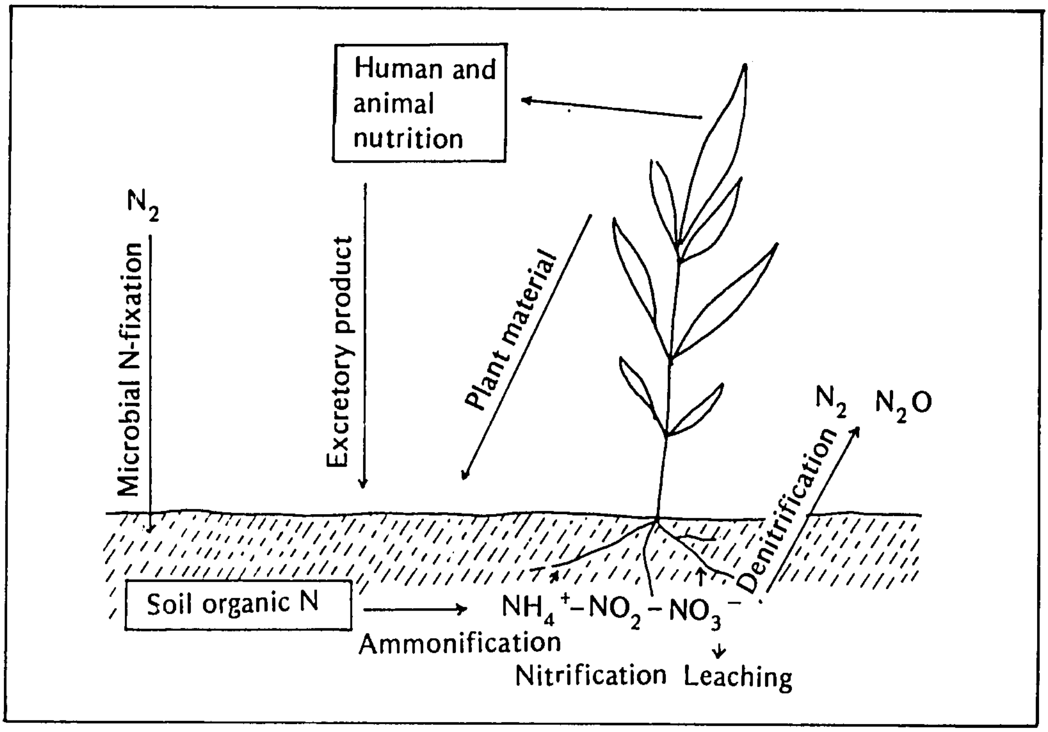

Fig. 8.3. Nitrogen cycle in nature.

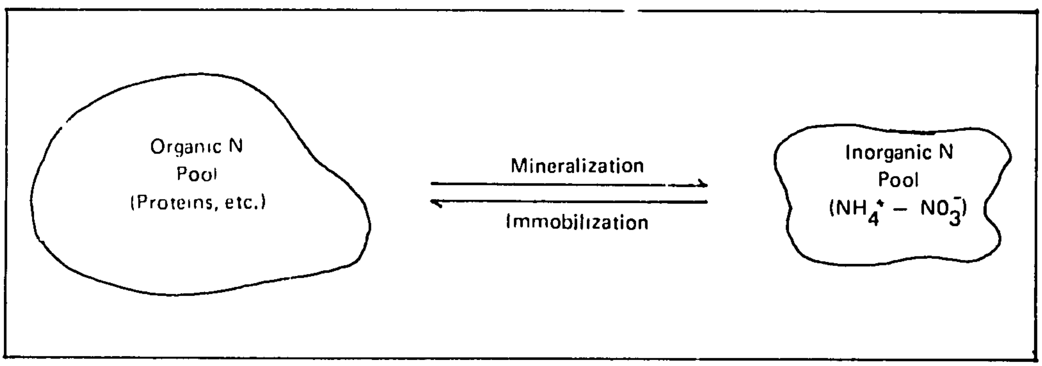

Fig. 8.4. Mineralization and immobilization of N.

nitrogen from the soil. The length of this period is determined by several factors, the most important of which is the C/N ratio of the applied organic residues (Fig. 8.5).

In general, nitrogen is in a dynamic state of equilibrium between input and output in agricultural ecosystems within the framework of the natural environment. Among soil inputs, fertilizers, manures, and the return of crop residues are more important, as major nitrogen sources, than others. However,under field conditions, the greatest part of soil nitrogen is present in organic form and is slowly released to plants after conversion to inorganic forms by mineralization and/or nitrification.

Meanwhile, nitrogen lost through harvest is of prime importance. Leaching loss, when in large amounts, is another major cause of nitrogen loss. Fertilizer should be applied properly to ensure farm productivity and to avoid unnecessary loss of elements in the soil (Fig. 8.6).

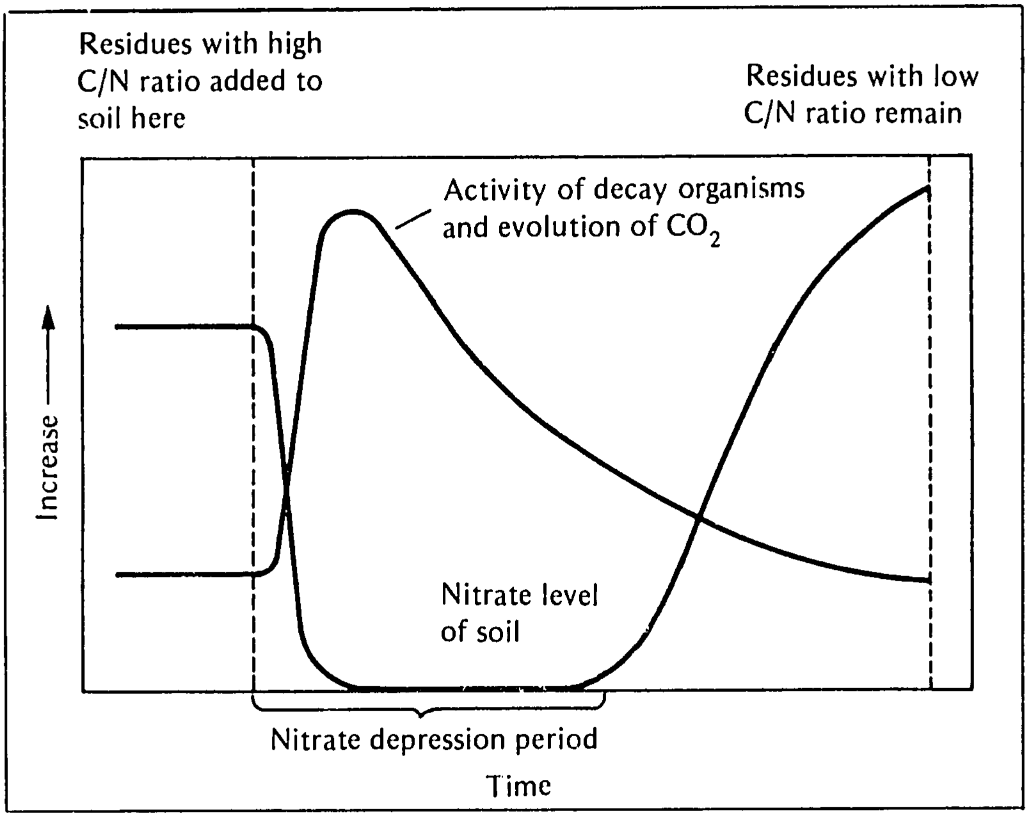

Fig. 8.5. Cyclical relationship between the stage of decay of organic residues and the presence of nitrate nitrogen in soil.

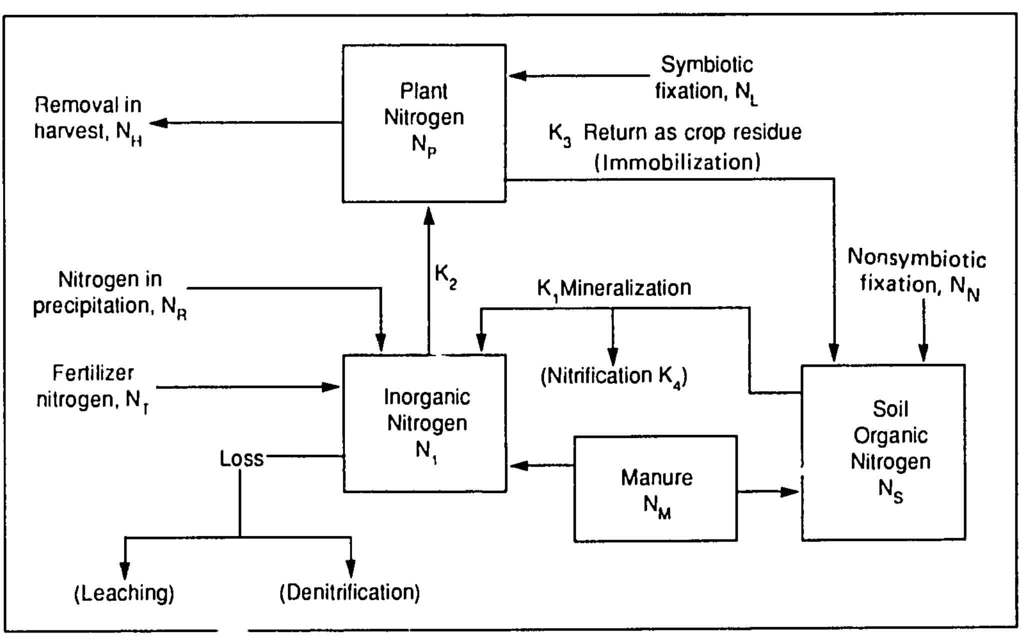

Fig. 8.6. Generalized balance sheet for nitrogen on a cropped soil.

Microbial nitrogen fixation. Legumes of the Rhizobium species fix nitrogen. The amount of nitrogen fixed by the bacteria depends on several important factors, such as drainage, moisture, pH, and available calcium. In vegetables grown after flooded rice culture, nitrogen fixation by blue-green algae and Azolla may be very significant (Table 8.5).

Table 8.5. Nitrogen gains from biological N_2 fixation.

Ecosystem	Range in Reported Values (kg N/ha/year)
Arable land	7-28
Pasture (nonlegume)	7-114
Pasture (grass-legume)	73-865
Forest	58-594
Paddy	13-99
Waters	70-250

Ammonium nitrogen (NH_4^+). Nitrogen in this form may be taken up by the plant, especially when young. It may also be incorporated into the tissue of microbes. Through microbial nitrification, NH_4^+ can be converted to NO_3^-. However, NH_4^+ may become fixed by clay minerals and become relatively unavailable for plant growth.

Nitrate nitrogen (NO_3^-). This form is water soluble and may be easily lost by leaching as a form of calcium nitrate [Ca $(NO_3)_2$]. It may be taken up more readily by plant easier than NH_4^+ except in paddy conditions. Under poor drainage and aeration conditions, NO_3^- may be converted into gaseous nitrogen which escapes from the soil even in upland conditions.

Management of soil nitrogen. The objective of nitrogen management is to maintain an adequate supply of nitrogen in the soil and, by knowing the processes of transformation, assure a ready supply to meet the peaks of crop demands. An adequate supply can be maintained by adding compost, including legumes in crop rotation, and applying fertilizer nitrogen.

To assure a ready supply of nitrogen to the crop, one should know when the crop needs the nitrogen most, so he can properly time his fertilizer application. Each soil has a normal or equilibrium level of nitrogen, although that of most intensively cropped soils are well below the maximum. However, the soil can only hold a certain amount of nitrogen, beyond which, raising the nitrogen content will only result in unnecessary nitrogen loss by leaching, volatilization, and erosion.

Soil Phosphorus

Small total amount of phosphorus is present in the soil, but this is relatively unavailable in the native form. In addition, phosphorus supplied by fertilizer can be fixed in several ways (Fig. 8.7).

Inorganic phosphorus (approximately 50% of the total), such as calcium-containing phosphorus compounds, are formed especially in high pH; while the iron and aluminum compounds are formed at low pH. The availability of these compounds is affected by pH, soluble iron, aluminum, manganese, presence of iron and manganese-containing minerals, available calcium and calcium- containing minerals, and soil temperature. depending to a greater degree upon the formation of their insoluble compounds by fixation and/or precipitation (Fig. 8.8).

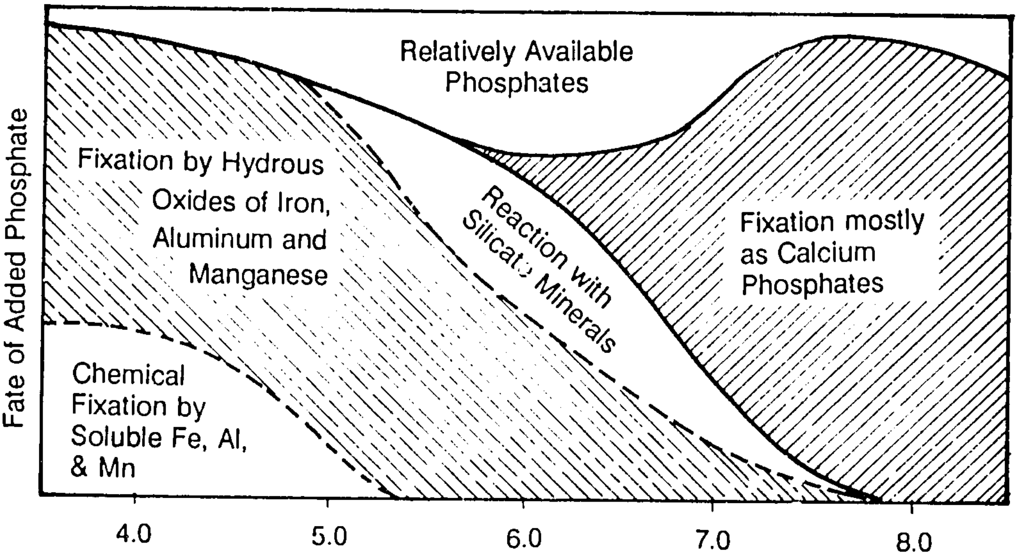

Fig. 8.7. The inorganic fixation of added phosphates at various soil pH value.

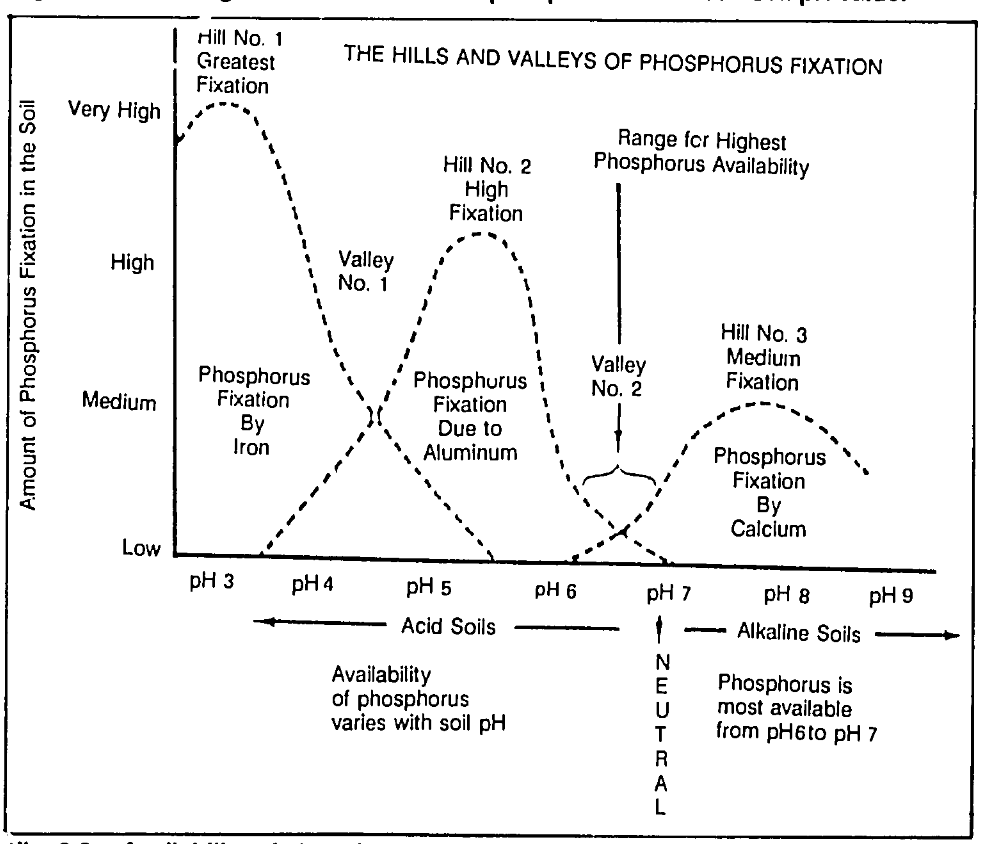

Fig. 8.8. Availability of phosphorus.

Phosphorus reactions in low pH soils. The precipitation equations of phosphorus with Fe, Al, and Mn ion are as follows:

$$\underset{}{Al^{3+}} + \underset{\text{(soluble)}}{H_2PO_4^- + 2H_2O} \rightleftharpoons 2H^+ + \underset{\text{(insoluble)}}{Al(OH)_2H_2PO_4}$$

The fixation of phosphorus by hydrous oxides is shown below:

$$Al\begin{cases}OH\\OH\\OH\end{cases} + H_2PO_4^- \;(\text{Soluble}) \rightleftharpoons Al\begin{cases}OH\\OH\\H_2PO_4\end{cases} + OH^- \quad (\text{Insoluble})$$

Phosphorus reactions in high pH soils. The precipitations of phosphorus occur in reaction with calcium compounds:

$$\underset{\text{(soluble)}}{Ca(H_2PO_4)_2} + 2Ca^{2+} \rightleftharpoons \underset{\text{(insoluble)}}{Ca_3(PO_4)_2} + 4H^+$$

$$\underset{\text{(soluble)}}{Ca(H_2PO_4)_2} + CaCO_3 \rightleftharpoons \underset{\text{(insoluble)}}{Ca_3(PO_4)_2} + 2CO_2 + 2H_2O$$

Organic phosphorus. Little is known about the availability of organic phosphorus compounds to plants. Forms in organic matter include phytins, nucleic acids, and phospholipids. Availability of organic phosphorus is determined by the amount of organic matter in the soil and its rate of decomposition, and the activity of microbes. More available phosphorus is obtained by applying fresh organic materials.

Control of phosphorus. It is best to maintain the soil pH (6-7) and the level of organic matter. It is also good to use fertilizers covered or coated by various materials. Despite careful management, a large portion of added phosphate will become unavailable to the plant. However, this phosphorus is not subject to leaching loss and remains in the soil. Throughout the years, it can become slowly available to the plant.

Soil Potassium

Most soils, except sandy soils, are high in total potassium. However, the quantity of potassium held in an exchangeable form in clay is very low. Unlike phosphorus and organic nitrogen, much potassium is lost by leaching. Potassium and nitrogen removed by the crop are very high, often three to four times more than phosphorus. Many vegetable crops have very high potassium requirements. Plants will take up more soluble potassium than what they need when large quantities are present in the soil. However, the excess potassium absorbed will not increase yield (Fig. 8.9).

About 90-98% of the soil potassium in the form of feldspars and micas are not available to plants. Only about 2% is readily available. Of this, potassium in solution makes up only 10% and is subject to leaching. The remaining exchangeable potassium is held in soil clays.

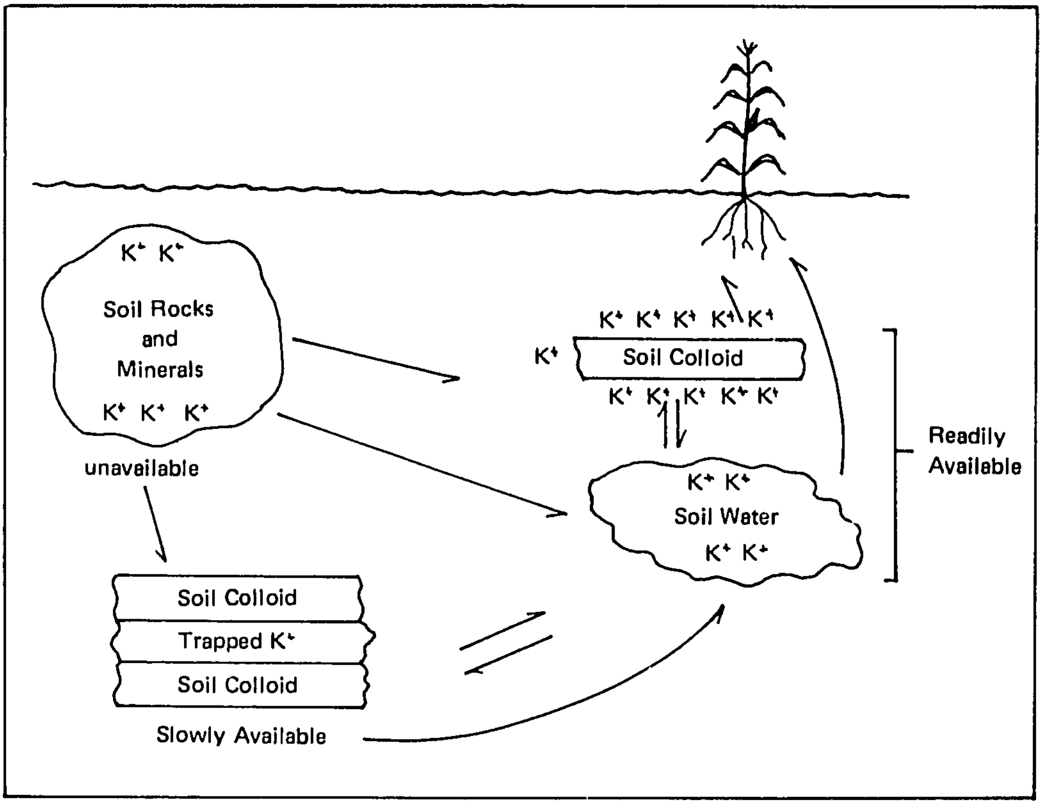

Fig. 8.9. How potassium moves in the soil.

Slowly available and nonexchangeable forms include potassium ions fixed by the soil clays and organic matter, which cannot be replaced by the ordinary exchange method. Fig. 8.10 shows the potassium cycle.

Factors which affect potassium fixation in the soils depend on the type of clay. Illite and vermiculite fix potassium in large amounts, whereas kaolinite fixes little clay. Wetting and drying affect fixation. Montmorillinite, for example, can fix more potassium when it is dry. Some of these can be released by freezing and thawing. Liming may sometimes increase the potassium fixation in the soil. This may be beneficial since it prevents leaching loss.

Frequent light applications of potassium fertilizers are usually better than large and less frequent ones because of leaching and luxury consumption by crops. As plants take up large quantities of potassium, returning crop residues to the soil become very important.

Soil Sulfur

The natural sources of sulfur are incorporated in soil minerals, such as sulfides of iron, nickel, and copper. Atmospheric sulfur from the combustion of coal is carried down to the soil by rain. Some organic forms also have cycles of immobilization and availability similar to nitrogen. Deficiencies increase with less sulfur being added and as fertilizer becomes more pure in nitrogen, phosphorus and potassium. The sulfur cycle in nature is shown in Fig. 8.11.

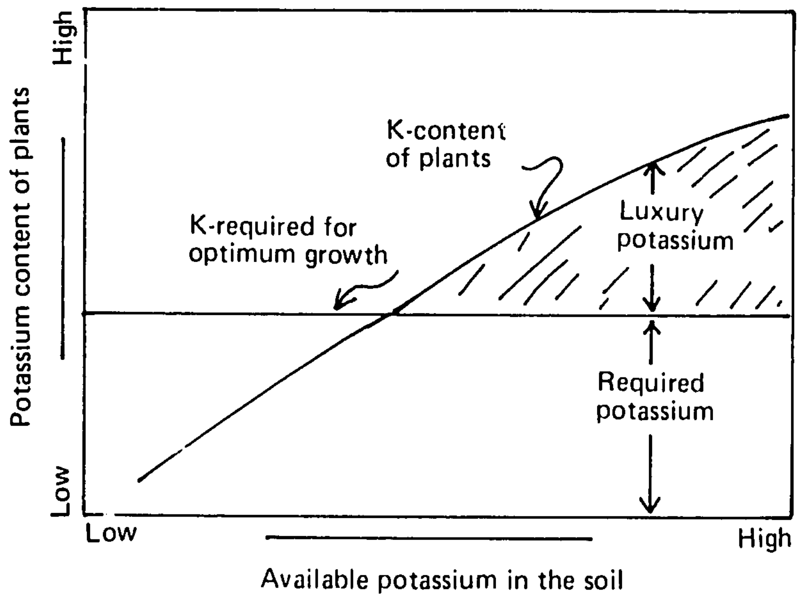

Fig. 8.10. A relationship between the potassium content of plants and the available potassium.

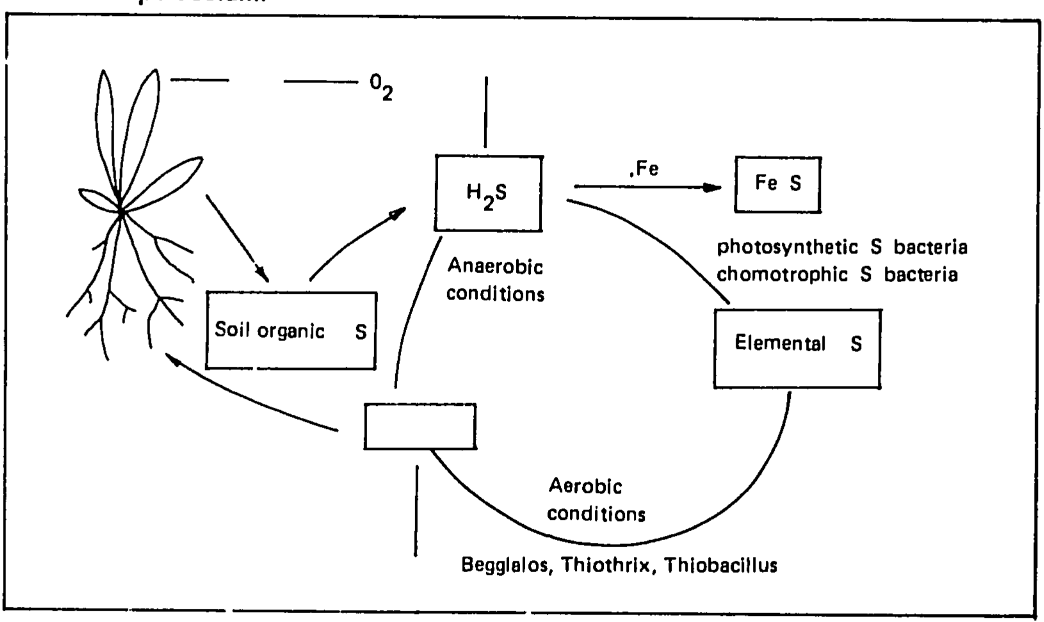

Fig. 8.11. Sulphur cycle in nature.

Soil Calcium

Calcium is more commonly present in the soil than other plant nutrients. The most common sources of calcium in the soil are the minerals anorthite ($Ca_2Si_2O_8$), calcite ($CaCO_3$), dolomite [$Ca_2Mg(CO_3)_2$] and gypsum ($CaSO_42H_2O$). Calcium is liberated when these minerals disintegrate and decompose. The calcium content of soils vary widely from as low as 0.1% in the humid tropics to as high as 25% in calcareous soils.

Available calcium exists in the soil as the calcium ion (Ca^{2+}) in the soil solution and as the exchangeable ion absorbed on the clay complex. These two forms are in equilibrium with each other. The calcium ion in the solution is easily leached when there is too much water and especially in light sandy soils.

Soil Magnesium

The magnesium content of the soil varies from 0.1% in the coarse, sandy soils in the humid regions to about 4% in the fine-textured and semi-arid soils. Primary sources are such minerals as biotite and dolomite.

The magnesium available to plants is in the exchangeable and the water-soluble forms of the magnesium ion (Mg^{2+}). Its behavior in the soil is similar to that of calcium. The absorption by plants depends on the amount of K present, soil pH, degree of magnesium saturation of the soil colloids, nature of the other exchangeable ions, and type of clay — the same factors affecting calcium absorption by plants. Moreover, the magnesium ion is also easily leached in a manner similar to the calcium ion.

Soil Micronutrients

The major soil micronutrients of iron, manganese, zinc, copper, boron, molybdenum, and chlorine are necessary for plant growth. There is a significant interest in this aspect of soil fertility. Crop removal reduces the amount of trace elements below the level required for normal plant growth. The use of improved crop varieties and macronutrient fertilizer has increased crop production level tremendously, resulting in greater micronutrient removal. The use of more pure fertilizers has also reduced the level of micronutrient-containing impurities. There is also concern over the level of trace elements in the soil and in the food supply, as most of these elements are also necessary for human nutrition.

Range in concentration. Differences in the micronutrient level resulting in deficiency and toxicity are often small. Generally, these elements are present in inorganic forms as primary soil minerals and clays, and in organic forms. Reactions affecting their availability are not well known. Conditions that promote micronutrient deficiency are leaching, acid and sandy soils, organic soils (histosols), soils with very high pH, and soils intensively cropped and heavily fertilized with only nitrogen, phosphorus, and potassium.

There are also frequent interactions between nutrients. For example, excessive amounts of zinc, manganese, or copper may cause iron deficiency. Heavy fertilization may cause copper deficiency. Excessive potassium may decrease manganese and calcium uptake, and vice versa. These interaction problems are complex and likely to increase.

Soil pH

The importance of soil pH to plant growth is illustrated in Figs. 8.12-8.14. The pH of the soil solution greatly influences many of the important soil and plant processes. This factor must, therefore, be considered in soil management.

Usually, the harmful effects do not come from the H^{+} ions themselves, but from toxicity of Al^{3+} and Mn^{2+} ions which are soluble at low pH. Nutrient availability and microbial growth are considerably affected by various degrees of pH.

At high pH values, the bicarbonate ion may become toxic. Alkaline soils often have a high salt concentration which is harmful to plant growth. Salt concentration is measured

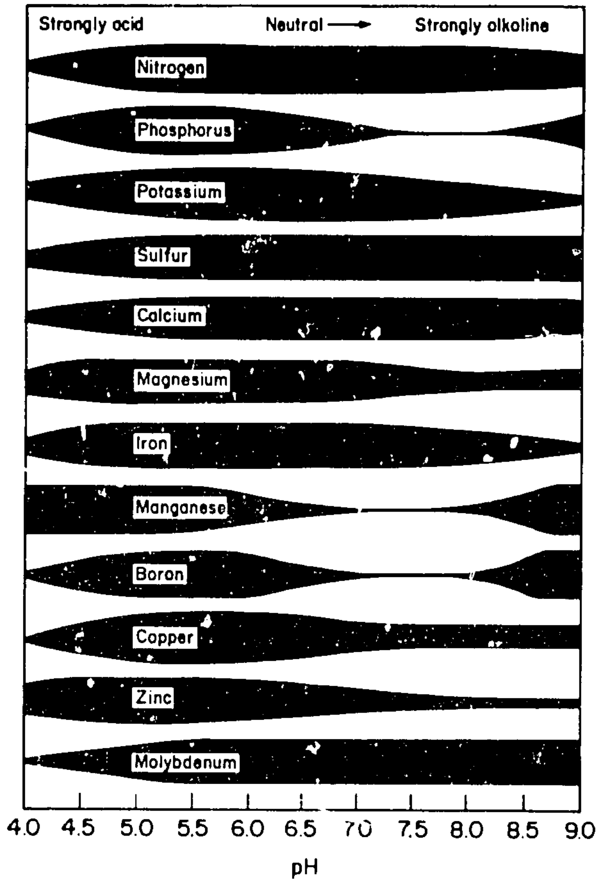

Fig. 8.12. Influence of pH on the availability of plant nutrients in organic soils.

by the electrical conductivity (EC) of the soil. EC values of more than 4 mS/cm are harmful to plants (Fig 8.15).

Limitations of soil pH value. The pH value limitations can vary greatly depending on the season, fertilizer application, and field location. However, pH is often a valuable measure, as many correlations of practical significance to plant growth and soil fertility can be made.

Measurement. In the laboratory, the pH can be determined by a pH meter, a glass electrode which measures the concentration of H^+ ions in solution. In the field, indicator dyes that have a color range of pH values are used.

Soil Fertility Evaluation

Soil fertility evaluation is based mainly on the tests and observations made on the plants and soils and are very important in maintaining or improving soil fertility. There are four evaluation techniques commonly used: nutrient-deficiency symptoms of plants, plant tissue analysis, chemical soil tests, and biological tests. The important aspects for each method are briefly presented.

Nutrient deficiency symptoms. A deficiency of one or more nutrient elements may cause an abnormal appearance or specific symptoms in the plant. These symptoms can be grouped into the following: early crop failure at seedling stage, abnormal growth (stunting), specific leaf symptoms, internal disorders, delayed or abnormal maturity, poor quality and yield. They may be used to supplement other techniques in determining nutrient deficiency; however, it requires skill and experience to distinguish among deficiency symptoms and to determine the factors affecting their appearance.

Plant analysis. The nutrient concentration in the plant is the combined effects of factors that have influenced up to sampling time. It is related to plant growth and its

Range of pH	Crops that are tolerant
below 5.4	Tea, tobacco, taro, pepper, upland rice
5.5-5.9 (strong tolerance)	Radish, turnip, cauliflower, sweet potato, soybean, timothy
5.5-5.9 (weak tolerance)	White clover, tomato, wheat, potato, broad bean
6.0-6.5	Adzuki bean, red clover
above 6.6	Lettuce, barley, eggplant, pea, spinach, welsh onion, naked barley

Fig. 8.13. The relation between plant growth and acidity.

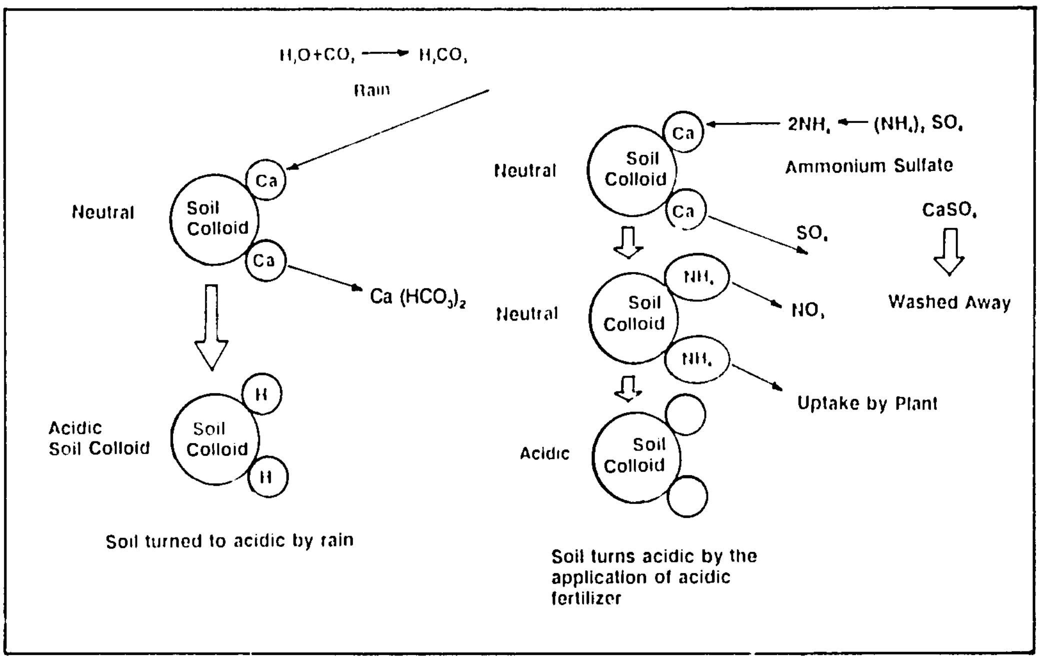

Fig. 8.14. Ways in which soils become acid.

accompanying changes over a period of time. When the nutrient is not enough for maximum growth under field conditions, increasing the supply enhances growth and yield as well as the nutrient's proportion in the plant. However, adding more nutrients after attaining maximum yield will further increase nutrient concentration without any corresponding yield increase (luxury consumption), but may lead to a toxic concentration causing yield decrease.

This relationship between plant composition and yield or growth is determined by plant analysis, which also gives a measure of the soil fertility under a set of growing conditions.

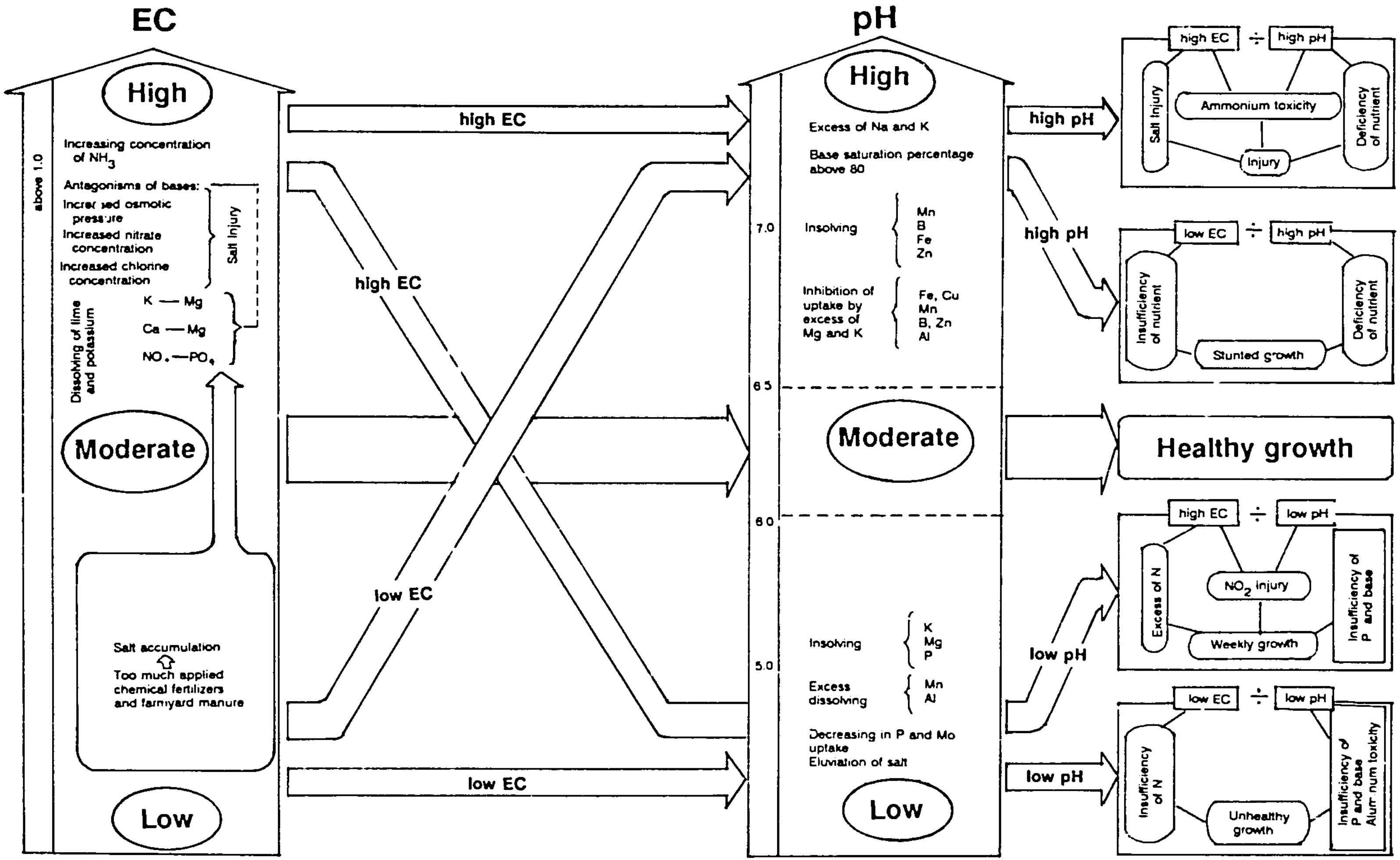

Fig. 8.15. EC and soil pH in relation to growth injuries on plants.

Fig. 8.16 shows this relationship. Some values have been established for some crops as regards the amount of N, P, and K on specific tissues when these are either deficient or sufficient (Table 8.6).

Table 8.6. Plant-tissue analysis guide for some western crops.[a]

Crop	Sampling Data	Nutrient[b]	Nutrient Deficient	Nutrient Sufficient
Cantaloupe	Early fruit, petiole of sixth leaf from vine tip	N	5000	9000
		P	1500	2500
		K	3	5
Lettuce	Heading, midrib of wrapper leaf	N	4000	8000
		P	2000	4000
		K	2	4
Potatoes	Midseason, petiole of fourth leaf from growing tip	N	6000	9000
		P	8000	16000
		K	7	9
Tomato (canning)	Early bloom, petiole of fourth leaf from growing tip	N	8000	12000
		P	2000	3000
		K	3	9
Watermelon	Early fruit, petiole of sixth leaf from growing tip	N	5000	9000
		P	1500	2500
		K	3	5

[a]Data from Western Fertilizer Handbook 1985.

[b]N as nitrate, P as phosphates soluble in acetic acid, in parts per million; and K as percentage of total K.

Soil tests. These tests estimate the nutrient-supplying power of the soil. They include determination of phosphorus, sulfur, micronutrient, organic matter, and soil acidity.

The chemical tests are much more rapid than the deficiency symptom and the plant-analysis methods. These are done before the crop is planted so that soil requirements may be determined at planting time.

The tests themselves cannot predict nutrient needs of the crop. The values have to be calibrated against field experiments for more reliable recommendations on designated areas. For instance, the results of soil tests will be calibrated against the responses obtained from experiments on a wide range of soils. It takes time and effort before recommendations from soil tests can closely approximate the actual needs of a particular area.

Soil testing has certain limitations. Many forms of the elements are present in the soil, with varying degrees of availability, depending on their chemical form and the environmental factors during the season of the crop's growth. Another limitation might be the difficulty in obtaining a truly representative sample of the solution used to extract the element (water, hydrochloric acid, acetic acid).

Biological tests. There are two main methods used in biological tests: field tests and microbiological tests.

In field tests, plants are grown in the field or in the greenhouse with the desired nutrient treatment to be evaluated and calibrated against soil chemical tests. The responses of

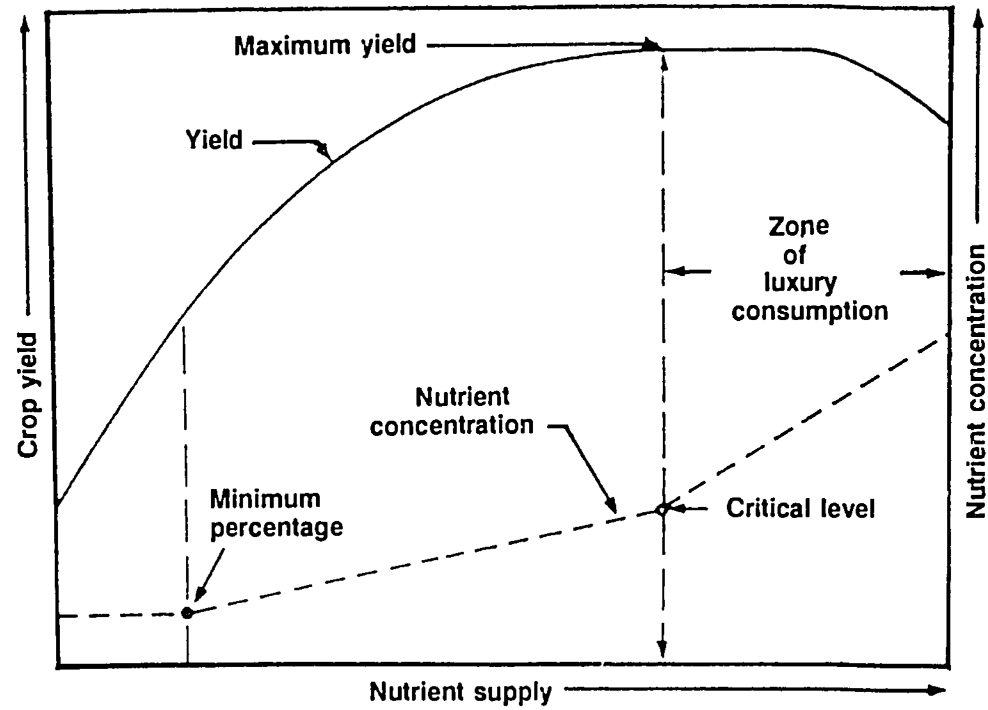

Fig. 8.16. Relation between nutrient supply, crop yield, and nutrient concentration in plants (Brown 1970).

the test plants to the treatments are evaluated and used as the bases for assessing the fertility status of the soil and in determining what and how much nutrients are to be added to support good yields.

Field tests are expensive, time-consuming, and difficult as they involve controlling climatic conditions and other factors. They are useful, however, in confirming laboratory and greenhouse studies and in calibrating soil and plant tests. On the other hand, greenhouse tests are simple and more rapid biological tests but the results have to be calibrated against field tests since the laboratory/greenhouse conditions (pot cultures or seedling cultures) only simulate natural field conditions.

Microbiological methods make use of certain microorganisms which show certain behavior with respect to some mineral nutrient deficiency. *Azotobacter* is used to indicate calcium, phosphorus, and potassium deficiency by their growth on cultures prepared from the soil to be tested. *Aspergillus* is used to test phosphorus and potassium. The growth of these microorganisms, based on colony development or mycelial growth, is measured and correlated with the value of nutrients from the soil samples. These tests are quick, simple, and require very little space but they are limited only to a few nutrients.

Improvement and Maintenance of Soil Fertility

The physical properties of soil may be improved by plowing, intertillage, organic material application (compost, manure, and green manure), and crop cultivation. There are two basic ways to improve soil chemical properties. The first involves fertilization or the application of adequate amounts of nitrogen, phosphorus and potassium, organic materials, liming of acidic soils, and application of deficient elements (Fig. 8.17). The

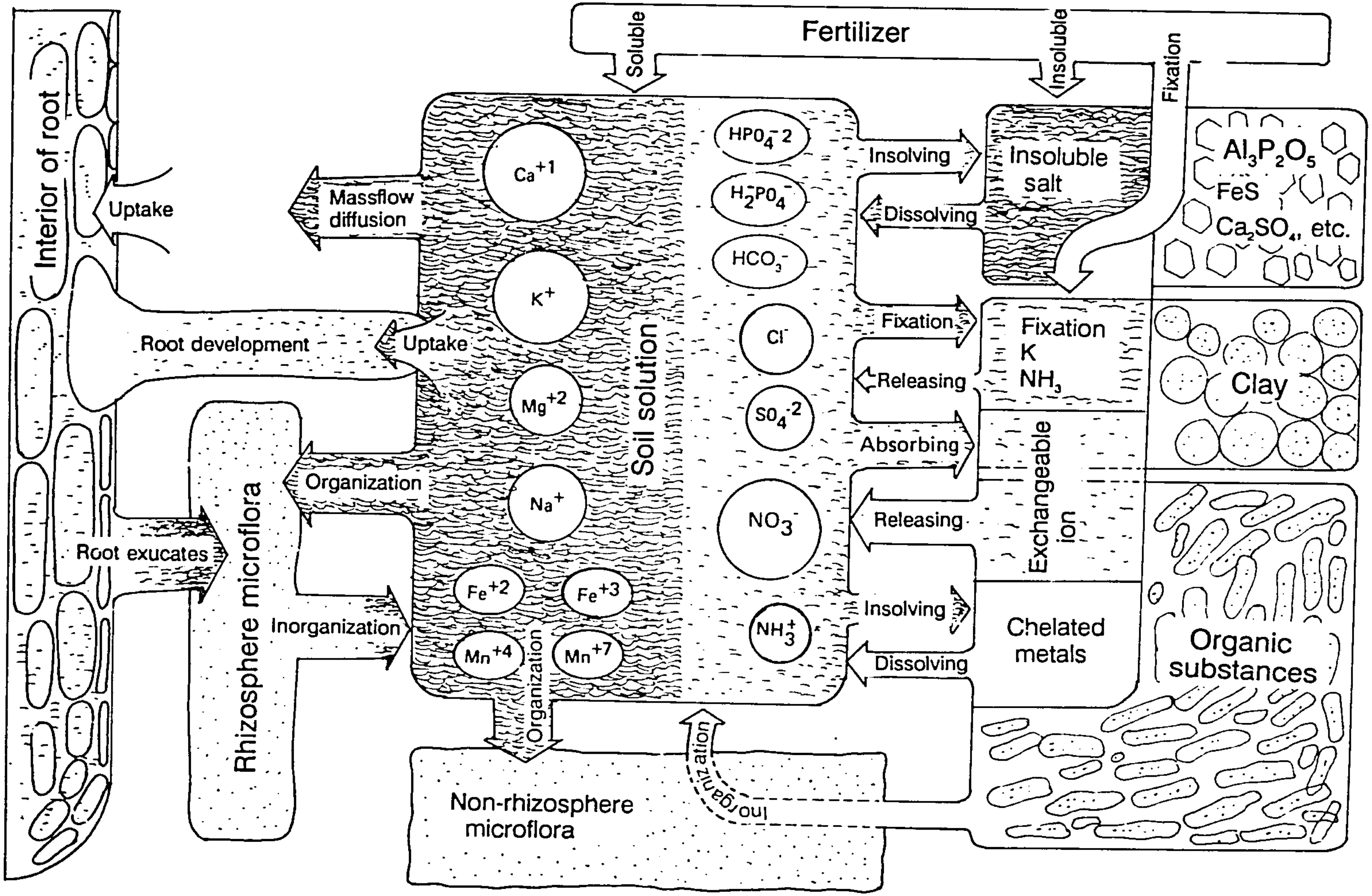

Fig. 8.17. Whereabouts of fertilizer.

second method involves the removal of inhibited elements for plant growth by adjusting soil pH and reducing toxic heavy metals.

Other methods to maintain soil fertility are soil-erosion control and crop rotation. Lastly, soil microbial properties may be improved by keeping the soil free of disease-causing microorganisms and rotating crops with paddy rice.

Part III - Fertilizers and Fertilizer Management

Fertilizers are either organic or inorganic substances applied to the soil to supply the nutrient elements required for plant nutrition. Fertilizer materials can be classified into three major groups based on the nutrient supplied: nitrogen, phosphorus, and potassium. This classification is based on the fact that these elements are the main components of the fertilizers used at present. However, it cannot include all kinds of fertilizers because some contain more than one of the three major elements, and others contain some minor elements.

Nitrogen Fertilizers

Ammonia is the most important source of nitrogen in the fertilizer. It is produced through a synthetic process in which hydrogen reacts with nitrogen. This reaction triggers the formation of nitrogen-containing synthetic compounds. The various nitrogen compounds can be grouped into four categories: ammoniacal, nitrate, slowly available materials, and other inorganic fertilizers (Table 8.7). The fertilizer materials being used in large amounts are briefly discussed below.

Table 8.7. Average composition of some common chemical sources of nitrogen fertilizer.

Source	Percentage						
	N	P_2O_5	K_2O	CaO	MgO	S	Cl
Ammonium sulfate	20.5	—	—	—	—	23.4	—
Anhydrous ammonia	82.2	—	—	—	—	—	—
Ammonium chloride	28.0	—	—	—	—	—	—
Ammonium nitrate	32.5	—	—	—	—	—	—
Ammonium nitrate with lime (ANL)	20.5	—	—	10.0	7.0	0.6	—
Ammoniated ordinary superphosphate	4.0	16.0	—	23.0	0.5	10.0	0.3
Monoammonium phosphate	11.0	48.0	—	2.0	0.5	2.6	—
Diammonium phosphate	20.0	54.0	—	—	—	—	—
Ammonium phosphate sulphate	16.5	20.0	—	—	—	15.0	—
Calcium nitrate	15.5	—	—	27.0	2.5	—	0.2
Calcium cyanamide	22.0	—	—	54.0	—	0.2	—
Potassium nitrate	13.4	—	44.2	0.5	0.5	0.2	1.2
Sodium nitrate	16.0	—	—	—	—	—	0.6
Urea	46.0	—	—	—	—	—	—
Urea-sulfur	40.0	—	—	—	—	10.0	—

Anhydrous ammonia (NH_3). This contains 82% N. It is a gas at normal pressure and a liquid under high pressure. A special equipment is needed to inject it in the soil to avoid loss through evaporation (volatilization). High pH increases volatilization, and soil moisture content below and above field capacity also increases loss of this nutrient. Heavy soils retain ammonia better than light soils. The high amount of organic matter also increases ammonia retention. Although the initial effect is to increase the pH, ammonia ultimately decreases it.

Nonpressure nitrogen solutions. These solutions contain 40%-43% liquid N. These are produced from urea and ammonia nitrate solutions plus water. Nonpressure nitrogen solutions are commonly referred to as UAN solutions. These solutions are easier to handle and apply than other nitrogen materials, such as ammonia or dry products. They can also be applied more uniformly and accurately through various irrigation systems. However, they can cause burning injury when sprayed on the leaves.

Urea. This is a popular, dry N carrier. It is more expensive than NH_3 because of the transportation cost and additional production steps involved to increase its nitrogen content (46%); but it can be stored, handled, and applied without the use of a special equipment.

The N in the urea is also lost through volatilization. About 20%-30% of the N is lost when urea is applied on the soil surface and is not moved into the soil by water. When added to the soil, urea hydrolyzes to ammonium carbonate which readily decomposes to NH_3 and carbon dioxide. The hydrolysis is enhanced by the enzyme urease which is found in the soil.

Ammonium nitrate. This material supplies both ammonium and nitrate ions which are readily available. Nitrogen content ranges from 33%-34%, depending on the grade of the material. It has excellent handling qualities. Since ammonium nitrate readily absorbs moisture, it must be stored under fairly dry conditions to maintain its physical condition. Some ammonia gas volatilize when ammonium nitrate is applied to alkaline soils. To reduce this loss, proper application methods must be observed. Likewise, combustible substances, such as fuel, should be kept away from ammonium nitrate to avoid fire or explosions.

Ammonium sulfate. This is one of the oldest chemical sources of ammoniacal nitrogen. It contains 20.5% N and 23.4% sulfur. It has good handling and storage qualities because it does not absorb moisture readily and is chemically stable. It is also a good source of sulfur. The sulfate ions make this fertilizer more acidic than ammonium nitrate, and continued use without lime will decrease soil pH to a level that may reduce soil productivity. This acid-forming reaction, however, can be useful in high-pH soils and for acid-requiring crops, such as potato.

Ammonium phosphate. This fertilizer supplies phosphorus in addition to nitrogen. Monoammonium and diammonium phosphates are in available forms. The phosphorus and nitrogen in the material are also water-soluble; hence, it is preferred in the manufacture of liquid fertilizers. Ammonium phosphate contains 12%-15% N and 25%-27% P.

Slow-release nitrogen compounds. Most of the nitrogen in fertilizers is easily lost through volatilization, leaching, and plant absorption. To reduce nitrogen losses, some fertilizer materials, like urea-formaldehyde compounds and sulfur-coated urea compounds, have been developed. These slow-release nitrogen compounds contain 32%-

38% nitrogen. These fertilizer materials are useful to plants which stay long in the soil, such as lawn grasses or turf. However, they are quite expensive, so their use is limited to the above specialty crops.

Phosphatic Fertilizers

The main source of phosphorus fertilizers is rock phosphate (the mineral apatite). The rock can be acid- or heat-treated to make the phosphorus soluble. There are several sources of phosphorus fertilizer (Table 8.8); the most commonly used are discussed here.

Phosphoric acid. The material used for this fertilizer is produced by treating rock phosphate with sulfuric acid. The fertilizer produced contains 54% P_2O_5. It can be injected directly to the soil; but since a special equipment is needed, the acid is more frequently added to the irrigation water instead.

Superphosphates. These are the traditional phosphorus fertilizers produced by treating rock phosphate with small amounts of sulfuric acid. This fertilizer material has only 16%-20% available P_2O_5. Although its phosphorus content is low, it is high in sulfur and calcium. A higher grade superphosphate (triple superphosphate) can be manufactured by treating a high grade rock phosphate with phosphoric acid. It has 40%-47% available P_2O_5 and is included in high-analysis fertilizers.

Ammonium phosphate. This is produced by reacting ammonia with phosphoric acid or by combining phosphoric and sulfuric acids. Diammonium phosphate (21% N and 53% P_2O_5) is used in large quantities especially in the manufacture of high-analysis fertilizers. Ammonium phosphate sulfate (16-20-0) which is completely water-soluble is also widely used. However, this may make the soil/acidic because of the ammonia. The release of free ammonia may also injure seeds that are very close to the fertilizer, particularly on alkaline soil.

Table 8.8. Phosphorus carriers.[a]

Fertilizer	Chemical Form	Available P_2O_5 (%)
Superphosphates	$Ca(H_2PO_4)_2$; $CaHPO_4$	16-50
Ammoniated	$NH_4H_2PO_4$; $CaHPO_4$	16-18
Superphosphate	$Ca_3(PO_4)_2$; $(NH_4)_2SO_4$	(3-4% N)
Ammonium phosphate	$NH_4H_2PO_4$ (mostly)	48
		(11% N)
Ammonium polyphosphate	$(NH_4)_3HP_2O_7$	58-60
	$NH_4H_2PO_4$	(12-15% N)
Diammonium phosphate	$(NH_4)_2HPO_4$	46-53
		(21% N)
Basic slag	$(CaO)_5$ o P_2O_5 o SiO_2	15-25
Steamed bone meal	$Ca_3(PO_4)_2$	23-30
Rock phosphate	fluor and chlor apatites	25-30
Calcium metaphosphate	$Ca(PO_3)_2$	62-63
Phosphoric acid	H_3PO_4	54
Superphosphoric acid	H_3PO_4; $H_4P_2O_7$	76

[a]Brady 1984

Basic slag. This is a by-product of steel production and is commonly used in European countries. It has a readily available phosphorus and is alkaline. It is especially effective on acid soils, apparently because of its high calcium hydroxide content.

High analysis phosphate. Two promising very high-analysis phosphate fertilizers are calcium metaphosphate and super phosphoric acid. These are very important materials in the production of liquid fertilizer and other high analysis fertilizers. Their high concentrations make them less expensive to transport.

Potassium Fertilizers

The underground salt beds are the primary source of potassium. Salt lakes also yield brine deposits rich in potassium. Kainit and manure salts are the most common sources of crude potash. Practically all of the potassium fertilizers are water-soluble. Table 8.9 lists the common potasssium fertilizer materials, the most common of which are briefly described here.

Potassium chloride. This salt is known commercially as muriate of potash. Muriate is a common name of hydrochloric acid. The fertilizer contains 40%-50% potassium (48%-60% K_2O) and is the most widely used potassium fertilizer. It is used in the soil (direct application) and for the manufacture of NPK (complete) fertilizers.

Potassium sulfate. This is a white material containing 40%-42% potassium and 48%-50% K_2O. It behaves in the soil in essentially the same way as muriate; but it has the advantage of supplying sulfur, which is more widely deficient in soils than chlorine.

It is useful to potatoes and tobacco which are sensitive to large applications of chlorides.

Table 8.9. Common potassium fertilizer materials.[a]

Fertilizer	Chemical Form	K_2O (%)
Potassium chloride[b]	KCl	48-60
Potassium sulfate	K_2SO_4	48-50
Potassium magnesium sulfate[c]	Double salt of K and Mg	25-30
Manure salts	KCl mostly	20-30
Kainit	KCl mostly	12-16
Potassium nitrate	KNO_3	

[a]Brady 1984.

[b]All of these fertilizers contain potash salts other than those listed

[c]Contains 25% $MgSO_4$ and some chlorine.

Potassium magnesium sulfate. This is a double salt of potassium chloride and potassium sulfate with small amounts of chlorine. It contains 19%-25% K. Although rather low in potash, it is useful in soil with magnesium deficiency. The magnesium in the material is readily available.

Mixed Fertilizer

These fertilizers contain at least two of the fertilizer elements and usually all three. When the three major elements are present, the fertilizer is called a complete fertilizer. The amounts of the three major elements N, P, and K in the fertilizer are indicated in percentages by three numerals designating the fertilizer grade. For instance, a 14-14-14 complete fertilizer contains 14% N, 14% P_2O_5 and 14% K_2O. Common grades of complete fertilizer are 14-14-14, 12-24-12, and 5-10-16. The complete fertilizers are available in granules and are water-soluble. The different grades are produced to suit special requirements for N, P, and K.

Sources of Micronutrients

- Boron — the most common source of boron is sodium tetraborate. Various levels of hydration of the tetraborate salts result in boron concentrations ranging from 11%-21% boron. Some boron fertilizers are Fertilizer Borate-68 (21% B); and Solubor (20%-21% B).
- Cobalt — Cobalt sulfate is a source of this element. A cobaltized superphosphate is also used in some countries.
- Copper — the usual source of copper is the copper sulfate salt which contains 25.5% sulfur. Copper ammonium phosphate is used for soil application or as foliar spray. It has 30% copper.
- Iron — Ferrous sulfate with 19% iron is commonly used as a spray solution in foliar applications. Iron chelates are also widely used. Their iron content ranges from 5%-14%. The main advantage of these chelates is their stability in the soil.
- Manganese — Manganese sulfate (26%-28% Mn) is commonly used to correct deficiencies in the element. It is applied on the soil or on the leaves. There are also chelated forms of the manganese fertilizer.
- Molybdenum — Ammonium molybdate (54% Mo) and sodium molybdate (39% Mo) are the sources of this element. Molybdenum trioxide (66% Mo) is incorporated in the pelleting of seeds.
- Zinc — A common material is zinc sulfate with about 35% zinc. Chelates of zinc are also available sources with 9%-14% zinc.
- Chlorine — the chlorides of ammonium, calcium, magnesium, potassium, and sodium contain readily available chlorine which ranges from 49%-74%.

Organic Sources of Nutrients

Organic materials such as dried poultry and cattle manures, peats, composted organic residues, and dried domestic wastes are commercially available. Some food processing by-products such as ground bone meal, dried blood, oil seed meals, and fish scrap are also available.

Organic materials contain low amounts of nutrient, but they slowly release available essential elements which can improve the physical condition of the soil. The average plant-nutrient content of some natural organics is shown in Table 8.10.

Likewise, green manure is a good source of organic nutrients and organic matter. Plants which can be used as green manure include Ipil-ipil (*Leucaena leucocephala* (Lam.) de Wit.), Stylo (*Stylosanthes guyanensis* Aubl. Sw.), and *Crotolaria* sp. Ipil-ipil can yield as much as 20 t of dry leaves per ha per year, while stylo can yield 10 t/ha per year of dry matter. *Crotolaria* sp. can produce 2.42 t/ha per month of dry matter. There are other sources of green manure. Table 8.11 shows the average nutrient composition of some green-manure crops.

Fertilizer Management

Factors determining fertilizer needs. When a fertilizer is applied, it gets in contact with the soil and the crop and undergoes some changes. The fertilizer reacts with the soil and its efficiency to supply nutrients either increases or decreases depending on some conditions.

Table 8.10. Average composition of some natural organic materials.[a]

Source	Percent			
	N	P_2O_5	K_20	CaO
Blood, dried	13.0	—	—	0.5
Cocoa meal	4.0	1.5	2.5	0.5
Fish scrap (dried)	9.5	6.0	—	8.5
Peat	2.7	—	—	1.0
Soybean meal	7.0	1.2	1.5	0.5
Cattle	1.5	1.0	0.94	0.2
Poultry	4.0	1.9	2.32	1.3

[a]Average values from a number of references.

Table 8.11. Average composition of some green-manure crops.[a]

Material	Oven Dry Basis (%)			
	C/N	N	P	K
Sesbania aculeata	—	2.18	—	—
Sesbania speciosa	18	2.51	—	—
Crotolaria juncea	—	1.95	—	—
Crotolaria usarmoensis	—	5.30	—	—
Vigna sinensis (cowpea)	—	3.09	—	—
Melitotus indica	—	3.36	0.22	1.27
Pisum sativum (pea)	—	1.97	—	—
Acasia ferruginea (leaves)	—	2.96	0.13	0.88
Acacia arabica (leaves)	—	2.61	0.17	1.20
Desmodium trifolium	—	2.93	0.14	1.30
Colopogonium mucunoides	—	3.02	—	—
Water hyacinth	18	2.04	0.37	3.40
Azolla sp.	—	3.68	0.20	0.15
Algae	—	2.47	0.12	0.37

[a]Misra and Hesse 1983.

The weather also influences the soil, crop, and fertilizer. Any factor of weather that tends to limit plant growth will also reduce fertilizer efficiency and the crop's response to the fertilizer. Certain guides can be used to determine the kind and amount of fertilizer to be applied for maximum utilization, as follows:

1. Kind of crop — The economic value, the nutrient removal, and the absorbing ability of the crop should be considered.

High-value vegetables can be fertilized heavily to ensure high yields. In this kind of vegetables, fertilizer cost is a minor consideration. The excess nutrients applied are not wasted but used to build up the fertility of the soil for the succeeding crops.

The crop removes nutrient from the soil. The amount of nutrient removed depends on the kind of crop. A high-nutrient removal needs high fertilizer application to compensate for the nutrient loss. The nutrient-supplying power of the soil (fertility) should also be considered in determining the kind and amount of fertilizer to be used. The amount of nutrients removed from the soil is also affected by the crop's specific nutrient need. Table 8.12 shows the nutrient removal of some vegetable crops.

2. Chemical condition of the soil — This factor is evaluated in relation to the total and available nutrients in the soil. A total analysis determines the entire amount of a particular element in the soil, regardless of form and availability. This analysis indicates only the potential of the soil to supply a certain nutrient. A more useful analysis is one that determines the amount of available nutrient.

Table 8.12. Nutrient removal from the soil by different vegetable crops.[a]

Crop	Yield (kg/ha)	Nutrient Removal (kg/ha)		
		N	P_2O_5	K_2O
Beans				
Bush	12,000	80[b]	30	100
Pole	14,000	120	35	150
Soybeans	1,800	160[b]	60	115
Peas (pods)	2,000	125[b]	30	75
Cowpea pods	2,400	150[b]	40	110
Asparagus	4,000	120	50	140
Broccoli	50,000	220	100	230
Cabbage	70,000	250	90	320
Cauliflower	50,000	200	80	250
Celery	30,000	180	80	300
Lettuce	25,000	60	220	120
Onions	30,000	90	40	120
Spinach	20,000	95	35	125
Cucumber	30,000	50	40	80
Tomato	40,000	110	30	150
Carrot	30,000	125	55	200
Potato	30,000	130	60	180
Radish	12,000	100	50	300

[a]Potash Pocket Book.

[b]A part comes from fixed nitrogen.

A method of analyzing available nutrients is the group of tests called ***rapid or quick tests.*** These tests are very useful as guides to fertilizer recommendations when they are done properly and correlated with knowledge of the crop, soil characteristics, and other environmental conditions. (Refer to section on Soil Fertility Evaluation for other tests.)

Theoretically, the amount of fertilizer needed is the difference between the crop's nutrient requirement and the amount supplied by the soil. It is difficult to quantify this, since the plant and the soil are constantly changing and interacting with many other factors. Field experimentation, soil testing, plant analysis, and information on deficiency symptoms can be used as bases for reliable fertilizer recommendations for a specific crop and soil type.

Time of application. The kind of crop, climate soil, and nutrient can influence the time of fertilizer application.

Vegetable crops differ in their growth and development patterns. Moreover, each crop has a different growth duration. The need for nutrients therefore will vary depending on the crop, especially as regards the growth and development of the plant part that is of economic importance.

Rainfall affects the availability of the nutrients to the plant, between the time it is applied and the time the nutrients are used by the plant. Temperature also affects the release of nitrogen, phosphorus, and sulfur from organic matter. Likewise, it affects nitrification and absorption of phosphorus and potassium by plants.

The soil factor is important because soils have different percolation rate, fixing capacity, and nutrient availability.

Generally, fertilizers are applied at planting or before planting (basal application). Fertilizers from organic sources are applied much earlier; so that they will decompose partially, and the nutrients will become available to the plants. Fertilizers are applied not only at planting but also during the growing season (side-dressing or topdressing). The frequency and amount of application depend on the crop, soil, and climate. Table 8.13 shows an example of application recommendations for some vegetable crops.

Method of application. One important factor to consider in the efficient use of fertilizers is the placement of the material in relation to the plant. The fertilizer should be placed in the soil zone where it will serve the plant to the best advantage. There are three important considerations in determining the proper application method:

1. The efficient use of the nutrients from the time of plant emergence to maturity
2. Prevention of salt injury to the seedling
3. Convenience of the grower

The method of application, therefore, should see to it that nutrients are available to the plants at all times during its growth. The right amount of nutrients should also be made available to the developing crops. The common methods of application are as follows:

- Broadcast — The fertilizer is applied uniformly over the field before planting. It is then incorporated by tilling or cultivating.

- Banding — The fertilizer is applied in bands on one side, both sides, or below the seeds or transplant. Care should be taken not to injure the seedlings through contact with the fertilizer.

Table 8.13. Frequency and method of fertilizer application for priority vegetables in the Philippines.[a]

Crop	Frequency and Method of Application
Beans	During the dry season, all required fertilizers should be applied at planting time. During the wet season, half of N and all of P and K should be applied at planting; and the second half of N should be side-dressed three weeks after seeding. Application is by band placement.
Cabbage	All of the P and K and half of N should be applied in bands during planting. The remaining half should be side-dressed a month after planting.
Melon	Before planting, fully decomposed animal manure or compost should be applied. Commercial fertilizer should be placed in bands during planting. First side-dressing is done when the plants have already produced vines about 1 m long and the second side-dressing is done when the first fruit is about the size of an egg.
Onion	All the required P and K and half of the N should be applied at planting time. Side-dressing of the remaining half of N should be done as bulbing begins.
White Potato	Chicken manure and ashes should be applied at planting time. One-half of the inorganic fertilizer requirement should be applied at planting time and the other half, when the plants are about 20 cm tall.
Sweet Potato	One-half of the required amount is applied at planting time. The first side-dressing is done 10 days from planting and the second, 30 days from planting.
Tomato	All required P, 1/2 K, and 1/2 N should be applied at planting time. The remaining half of the required N and K should be side-dressed a month after transplanting.

[a]Philippines Recommends for Fertilizers 1981.

- Topdressing or side-dressing — Topdressing means broadcasting the fertilizer on the crop, while side-dressing means applying the fertilizer beside the rows of the crop. Both are done after crop emergence.

- Fertigation — This is the application of fertilizer through the irrigation water. Nitrogen and sulfur are the principal nutrients commonly used. Potassium and highly soluble forms of zinc and iron can also be readily applied this way. When an element forms a precipitate with another substance commonly found in the irrigation water, it is not advisable to use this method. Phosphorus and anhydrous ammonia may form a precipitate in water with high calcium and magnesium content so they are not used in fertigation.

- Foliar application — This method can be used with fertilizer nutrients readily soluble in water. It is also used when there is a soil-fixation problem. In this method, however, it is difficult to apply sufficient amounts of the major elements. Nutrient concentrations of 1%-2% can be applied without injury to foliage. This method, therefore, is commonly used only to apply the minor elements or the supplements of the major elements.

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CHAPTER 9

Water Management

Vegetables, being succulent products by definition, are generally more than 90% water. Thus, water determines the weight and yield of vegetables. The quality of vegetable products is also determined by the quality of water management. Many defects of vegetable products may be traced directly or indirectly to mismanagement of water supply in the production field.

A good proportion of investment in vegetable growing is allocated for water management, whether it is in a traditional farm where water is applied by manual labor or in an automated drip-irrigation system. Unlike field crops which can be grown under rainfed conditions, vegetables with few exceptions are always irrigated, at least partially. It is every grower's utmost concern to use irrigation water in the most efficient way. It is equally important to provide adequate drainage facilities in the field because most vegetables cannot tolerate prolonged waterlogged conditions.

In the humid tropics, vegetable crops may be classified according to adaptation to the wet or dry seasons roughly corresponding to their adaptation to excess or deficiency of moisture. These two seasons differ in prevailing temperature, humidity, and rainfall as shown in Fig. 9.1a-c. The dry season, taking all environmental factors into consideration, is generally more favorable for growing vegetables than the wet season. Hence, all tropically adapted vegetables can be grown successfully during this season, provided that irrigation water is available. Without irrigation, less vegetable crops can be grown.

Rainfed dry-season crops are normally limited to those that are early maturing (i.e., they can be harvested in 60 days or less) and relatively tolerant to excess moisture during the early stage and drought at a later stage. These crops must be sown towards the end of the wet season; so that, enough residual moisture is available for germination and crop establishment. Crops that are suitable for this type of culture are mungbean, cowpea, radish, and early-maturing determinate tomato.

With adequate drainage, some crops perform even better during the wet season than during the dry season. These are yard-long bean, winged bean, and leafy vegetables. However, these are exceptions. As a rule, irrigated dry-season crops provide the bulk of vegetable supply in the tropical environment.

Consequences of Poor Water Management

Lack or excess of water is caused by improper water management. Plants react to these extreme conditions by abnormal growth even before definite signs of stress become visible. In many cases, definite signs of stress are only observed when irreversible damage to the crop has alredy occurred, either in quality or yield.

Deficiency in water can cause direct, as well as indirect damage. Direct damage consists of poor stand when water stress occurs during germination; and yield reduction or decline in quality, such as deformity in the fruits of cucumber and beans, when water stress occurs later in the growing season. Indirect damage may consist of calcium deficiency which causes blossom end rot in tomato or tip burn in Chinese cabbage.

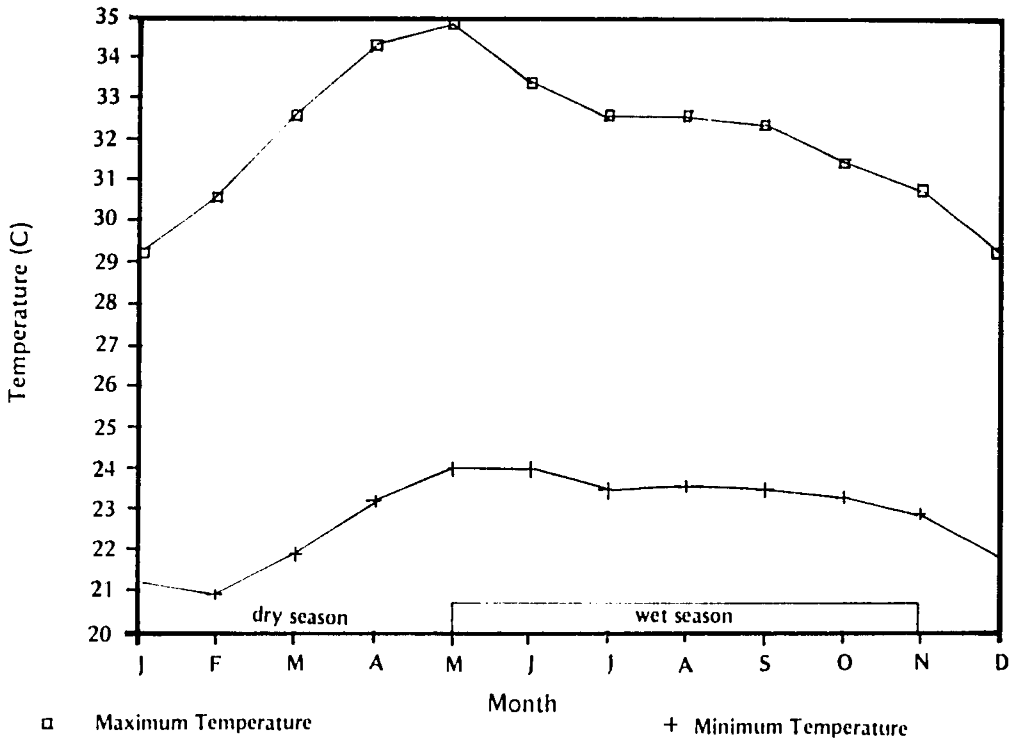

Fig. 9.1a. Average monthly temperature in Los Baños, Laguna, Philippines.

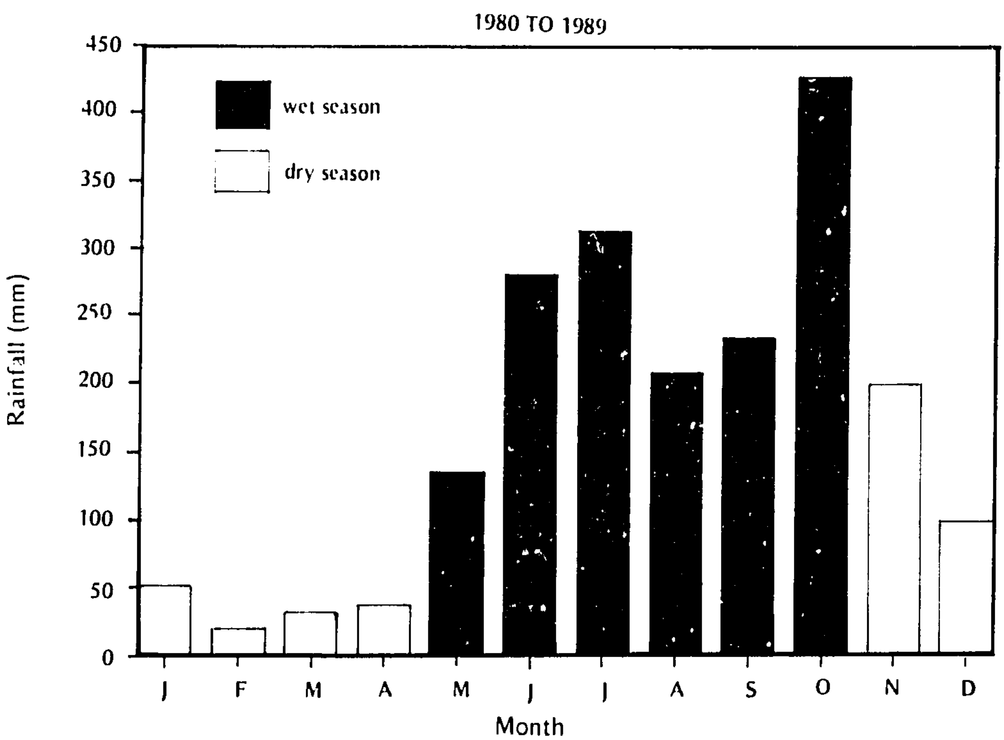

Fig. 9.1b. Total monthly rainfall in Los Baños, Laguna, Philippines.

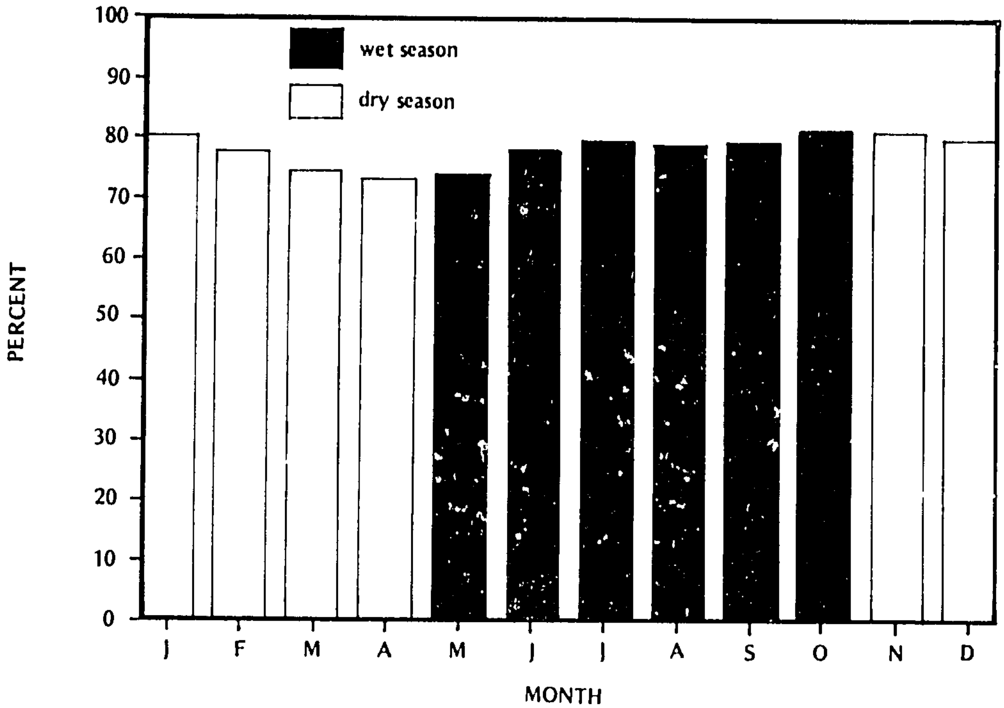

Fig. 9.1c. Average monthly relative humidity in Los Baños, Laguna, Philippines (1980-1989).

Excess water can also cause direct damage, such as leaching of fertilizers, reduced root development, and development of adventitious roots. Indirect damage due to excess water consists of root rot and other diseases, which are favored by high soil moisture.

Abrupt changes in water supply are also harmful. Defects, such as cracking of tomato and bitter gourd fruits, or carrot and radish roots can be traced directly to fluctuations in moisture supply which take place during the fruit or root enlargement stage.

However, it is also not practical to maintain a good supply of moisture throughout the growing season. This is expensive, unnecessary, and may cause some problems. For example, seedlings are deliberately exposed to moisture stress (hardened) before transplanting to prevent transplanting shock. Crops in the early vegetative stage may be unable to develop a deep root system if light watering is made regularly. Consequently, the crop is prone to root injury during cultivation and unable to utilize nutrients that are in the deep layers of the soil. Tall crops, such as okra, eggplant and sweet corn may also tend to lodge. Tomatoes in the fruit-maturation stage may suffer from fruit rotting when irrigation is applied at this stage.

Proper water management means applying adequate quantities of water at the right time. It includes the delivery of water (irrigation) and removal of excess water (drainage). The correct practice is determined by soil and weather conditions, as well as the crop. There are even varietal differences in response to water management.

Irrigation

Determining Irrigation-Water Requirement

The irrigation-water requirement of a crop is determined by consumptive use and irrigation efficiency. ***Consumptive use*** or evapotranspiration is the sum of transpiration (water entering plant roots and used to build plant tissue and water being passed through the leaves into the atmosphere) and evaporation water lost to the atmosphere in gaseous form from soil and water surfaces and from plant surfaces.

Water deposited by dew, rainfall, or sprinkler irrigation and subsequently evaporating without entering the plant system is part of consumptive use. Consumptive use can apply to water requirements of a crop, a field, a farm, or several farms in one area. When the consumptive use of the crop is known, the water use of large units can be calculated. Hence, the term consumptive use, and subsequent discussions refer to the crop.

Consumptive use is influenced by weather conditions, irrigation practices, length of the growing season, stage of crop development, and other plant factors. A typical consumptive-use pattern during the growing season is shown in Fig. 9.2. Most crops which have a rapidly expanding root and vegetative systems follow this basic curve. The zero points on the scale of maturity are obtained by extrapolating the curve to zero.

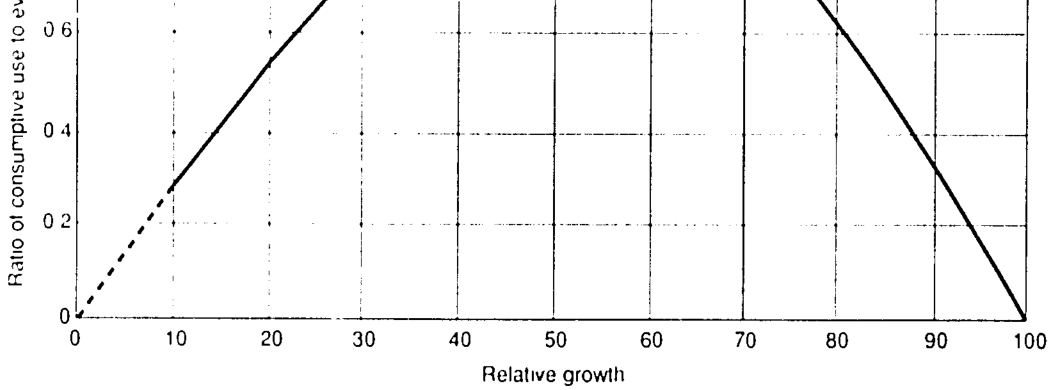

Fig. 9.2. Generalized curve showing the relationship between the ratio of consumptive use to evaporation (K) and relative growth of a crop.

The horizontal axis of Fig. 9.2 refers to the relative growth stage in relation to the time of senescence or death of annual crops. It can be translated into a scale of time. For example, if tomato reaches senescence in 100 days from emergence, then 50 in the abscissa means 50 days. The vertical axis is the ratio (K) of consumptive use to evaporation rate as measured by the United States Weather Bureau pan.

Fig. 9.2 can be used to obtain an estimate of consumptive use from pan evaporation data. For example, if at 40% of the growing season, the pan evaporation rate is 7 mm/day, then the consumptive use is 0.9 x 7 = 6.3 mm/day. The value of 0.9 was obtained from the curve at 40% relative growth stage. This method of estimation is relatively simple but is not very accurate. It allows estimation of consumptive use at different stages of crop growth. Average seasonal values of K is estimated to be 0.75 for tomato and 0.65 for dry beans.

There are other methods of estimating consumptive use. The direct method requires successive soil moisture determination in the root zone. A fast and relatively accurate indirect method requires the use of a device called a lysimeter.

A second factor that determines the quantity of water needed for irrigation is ***irrigation efficiency***. Field irrigation efficiency includes water application efficiency (Ea), water storage efficiency (Es), and water distribution efficiency (Ed). The formulas for these efficiency values are as follows:

$$Ea = 100\ Ws/Wf$$
$$Es = 100\ Ws/Wn$$
$$Ed = 100\ (1 - y/d)$$

Where: Ws = water stored in the root zone during irrigation
Wf = water delivered to the farm
Wn = water needed in the root zone prior to irrigation
y = average numerical deviation in depth of water stored from the average depth stored during irrigation
d = average depth of water stored during irrigation

Of the three efficiencies above, the application efficiency (Ea) is most important in surface irrigation, while distribution efficiency (Ed) is most important in sprinkler irrigation. For surface irrigation using the furrow method in soils with proper slope, application efficiency (Ea) ranges from 40% in sandy soil to 65% in heavy clay soil. The efficiency is reduced in steep slopes or rolling land. Application and distribution efficiencies in sprinkler systems are about 80-85%. For trickle irrigation systems, all efficiencies are close to 100%.

Irrigation water requirement is equal to consumptive use of the crop divided by application efficiency. From the example of 6.3 mm/day consumptive use as shown above, the irrigation water requirement for heavy soil with proper slope using the furrow method is 6.3/0.65 = 9.7 mm/day. Through the sprinkler method with application efficiency of 85%, the irrigation water requirement is 6.3/0.85 = 7.4 mm/day.

Scheduling of Irrigation

The frequency and depth of water application are determined by weather and soil conditions, the development stage, and depth of the root zone specific for the crop (or variety). In cool, damp weather and in fields with heavy to loam soil, infrequent (weekly) watering may be enough for an established crop. However, the vegetable field may need daily watering in a newly seeded or transplanted crop in hot, dry conditions in sandy soils.

The waterholding capacity of the soil is a major factor that determines frequency of irrigation. Soils composed of coarse particles (sandy) hold less water than soils that are made up of fine particles (clayey). A sandy soil must, therefore, be watered more frequently than a clay soil.

The rooting depth of crops, on the other hand, must be considered in determining the amount or depth of irrigation. In an average loam soil, 1 cm of water applied at the surface will wet the soil to a depth of 4-5 cm. The depth will be more in sandy soils and less in clay soils. The actual depth of the soil that is wet by irrigation can be determined by using a soil sampling tube or auger.

The depth of irrigation (amount of water applied to a given area) can be determined in a sprinkler system by measuring applications in a glass set halfway between the sprinkler and its maximum reach. For furrow irrigation, this can be measured roughly by ponding water in deep furrows and gauging the depth of the furrow. For drip irrigation, the irrigation depth can be measured very accurately by determining the volume of water discharged by the drippers.

For purposes of determining depth of irrigation, Table 9.1 shows the classification of crops according to depth of root zone. To interpret this table, it should be considered that close to 70% of soil moisture extracted by the roots come from the top 50% of the root zone depth (Fig. 9.3). This is where the root hairs and small roots, the portion of the root system that are mainly responsible for water absorption, are concentrated.

Table 9.1 Average effective root-zone depth of vegetable crops in deep, well-drained soils.

Crop	Root-Zone Depth (cm)
Shallow-rooted crops	less than 50 cm
bush beans	45
lettuce	30
onion	30
radish	45
Medium-rooted crops	51 - 100 cm
cabbage	60
carrots	90
cauliflower	60
celery	60
sweet corn	90
cucumber	90
eggplant	90
garlic	60
pepper	90
squash	90
Deep-rooted crops	more than 100 cm
melon	155
okra	110
tomato	120
snap beans	110

Thus, for cabbage (shown in Table 9.1) to have a root zone depth of 60 cm, the soil to be wet by irrigation must be at least 30 cm. deep (50% of 60 cm). It may not be necessary to wet the entire root zone depth of 60 cm. Nevertheless, these dimensions

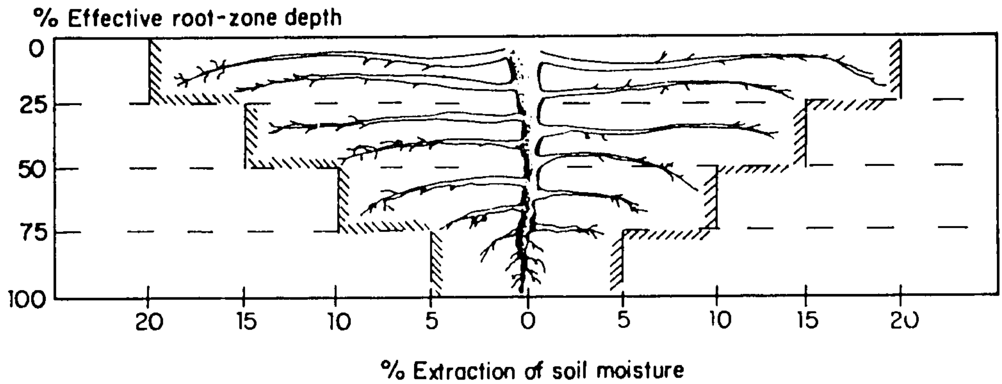

Fig. 9.3. A typical extraction pattern of the roots of an upland crop. (The Committee for Irrigation Water Management 1982).

must be used only as a guide, because the actual depth of the root zone is affected by the maturity of the crop, as well as the depth of irrigation itself. Light (shallow) irrigation only wets a thin layer of the top soil; consequently, the root zone will be concentrated within this thin layer.

Methods of Applying Irrigation Water

Choosing the most suitable method of applying irrigation water depends on soil texture, topography, water supply, and the crop. Irrigation water is applied to vegetables through the following methods: 1) overhead, 2) surface, 3) drip, and 4) subirrigation. The first two methods are the most common, with the furrow method (surface) generally preferred. The last two methods are relatively new and not yet commonly practiced even in developed countries.

Overhead irrigation. In this method, water is applied in the form of spray or artificial rain. In nonmechanized farming, this is done by using watering cans (Fig. 9.4). The water source is usually a river, a shallow well, or tap water. Since the method is labor-intensive, the farm size per person is limited to approximately 500 m^2 if the water source is adjacent to the farm.

The nozzle of the watering can consists of a perforated tip (Fig. 9.5a). The size of the perforation is small when watering is done on seedbeds and bigger as the plant grows. With established plants a special nozzle capable of delivering water quickly without causing damage to the plant is used (Fig. 9.5b). Nozzles are easily detached from the can to facilitate cleaning, as the nozzles become easily clogged with debris, especially when water is obtained from a river or a canal.

In relatively large farms that are operated manually or with small machines, the vegetable field is laid out in such a way that the water is conveyed close to the vegetable plots to shorten the walking distance during watering (Fig.9.6).

In medium size to big farms where labor is expensive, sprinkler irrigation is applied through a pipe system under pressure. In the hills where springs serve as the source of water, pressure is provided by gravity (Fig.9.7). In the flat lands regardless of water source, pressure is generated by pumps (Fig.9.8).

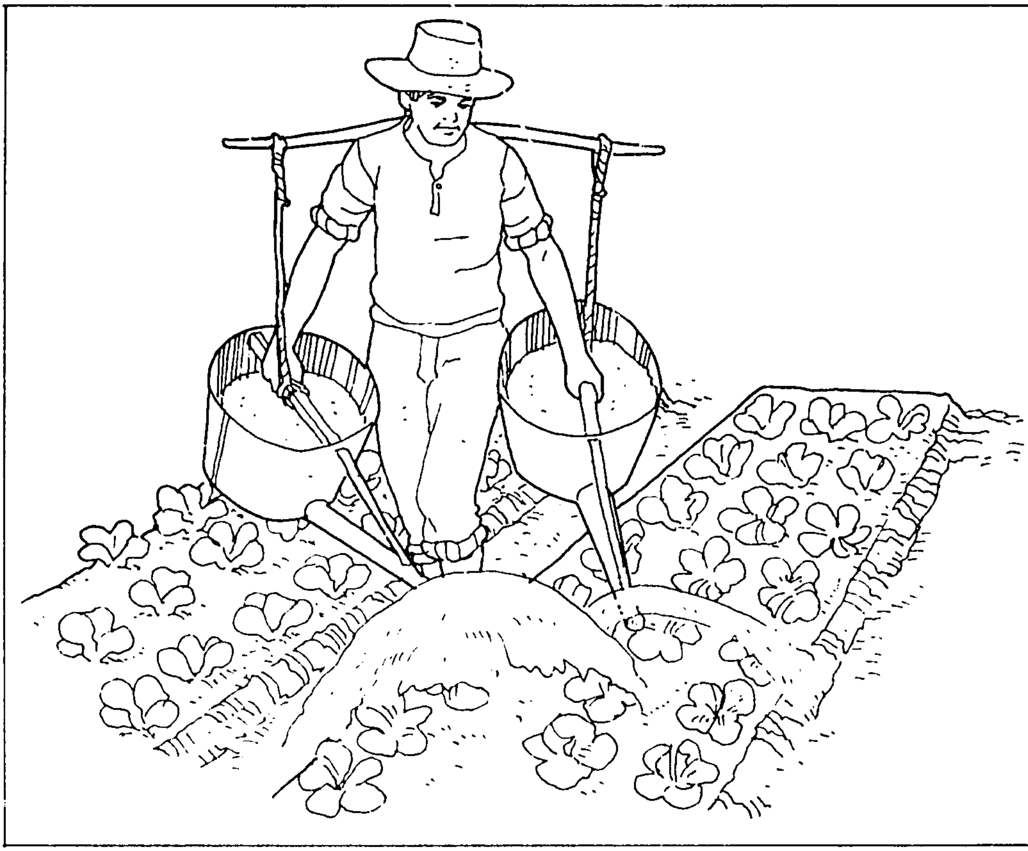

Fig. 9.4. Overhead irrigation using the traditional watering can.

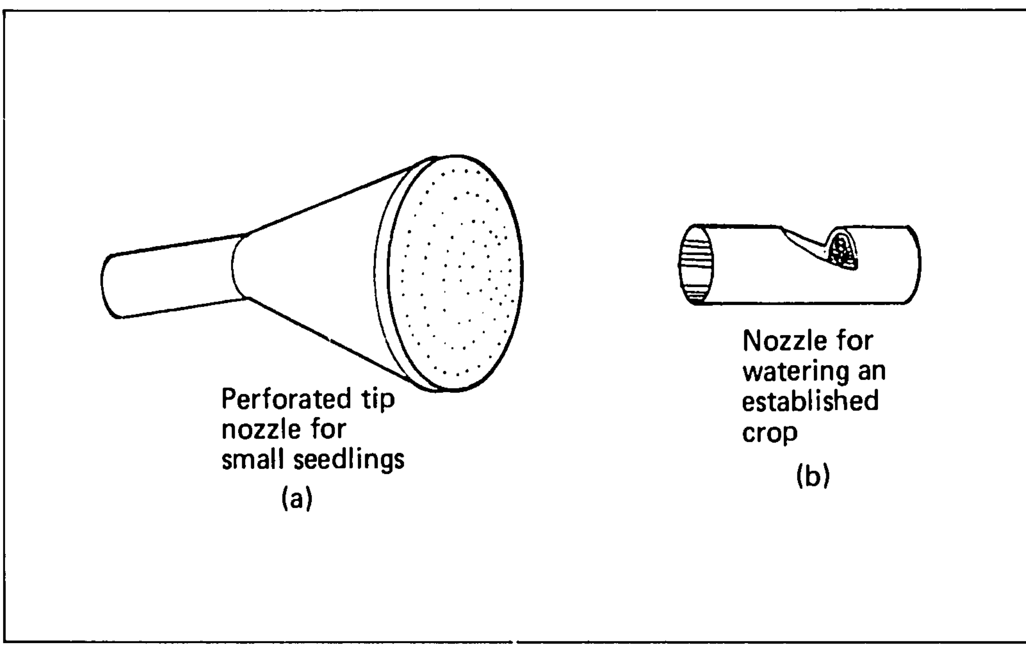

Fig. 9.5. Nozzles for the watering can.

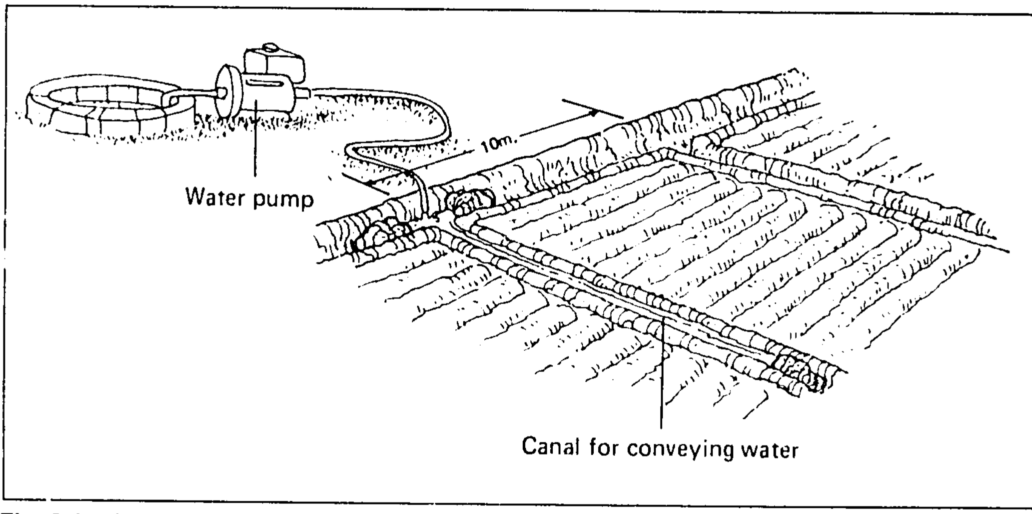

Fig. 9.6. Layout of vegetable farm showing irrigation canals. During the monsoon season, the canals serve as drainage.

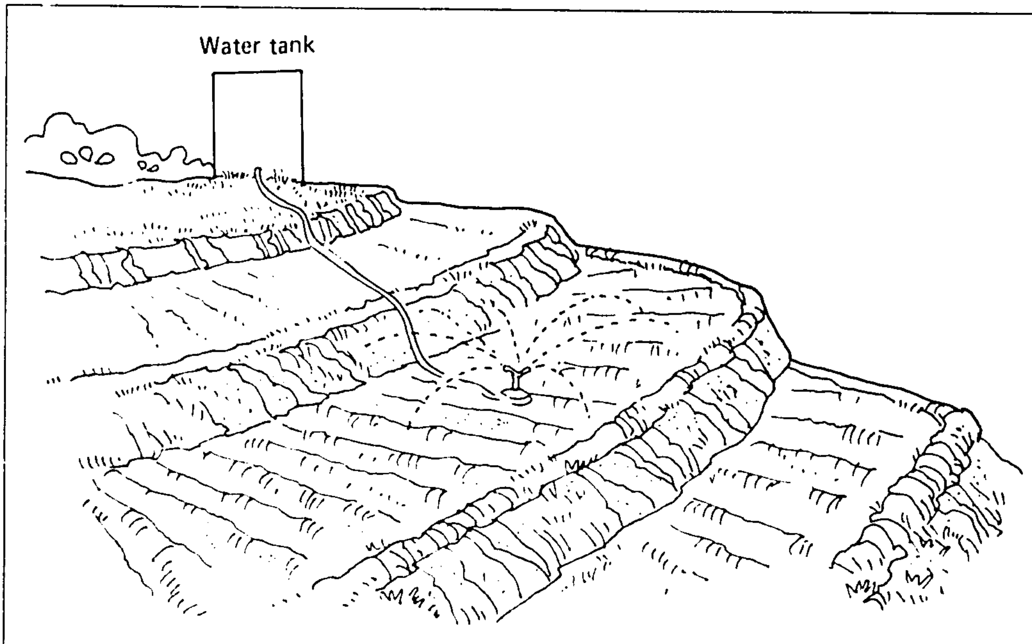

Fig. 9.7. Overhead irrigation in the hills using gravity to pressurize the water pipes.

Artificial rain is generated by special devices such as perforated sprinkler lines, rotating sprinklers, or microsprinklers (Fig.9.9). Perforated sprinkler lines are more suited for orchards and nurseries in fairly large operations. On the other hand, microsprinklers are better suited for growing seedlings than for field production of vegetables.

Rotating sprinklers are the most common among artificial rain devices for vegetable crops because it is the most flexible. It consists of a head with one or more nozzles, which is rotated by the action of the water passing through and which waters a circular portion of the field around the sprinkler. It is capable of applying water at a relatively slow rate while using relatively large nozzles. This factor is particularly favorable in water

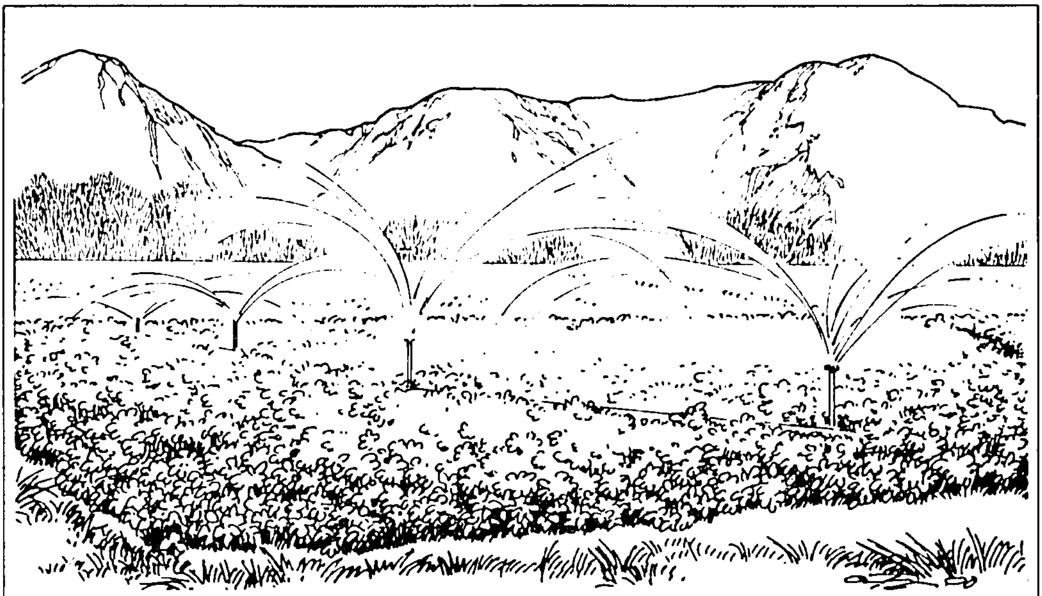

Fig. 9.8. **A rotating head sprinkler irrigating green beans.**

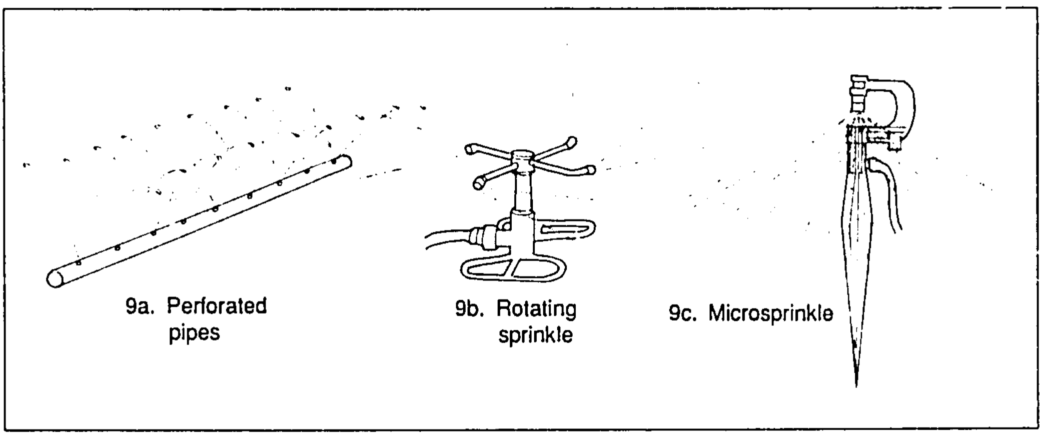

Fig. 9.9. **Devices for generating artificial rain.**

containing silt and debris, since less stoppage of sprinklers is experienced. Application rates less than 2.5 mm/hour are possible with these sprinklers. This slow rate is desirable in heavy soils with low infiltration rates (less than 4 mm/hour) and advantageous to the small farmer who may be doing irrigation work along with other field activities.

Rotating sprinklers operate under a wide range of pressures and discharges. Table 9.2 summarizes the characteristics of sprinkler irrigation systems using different operating pressures. The application rate is determined by the infiltration characteristics of the soil (Table 9.3). The application rates are slightly lower than those for surface irrigation, as there should be no ponding of water at the soil surface.

An illustration of a plan for a sprinkler irrigation system is shown in Fig.9.10.

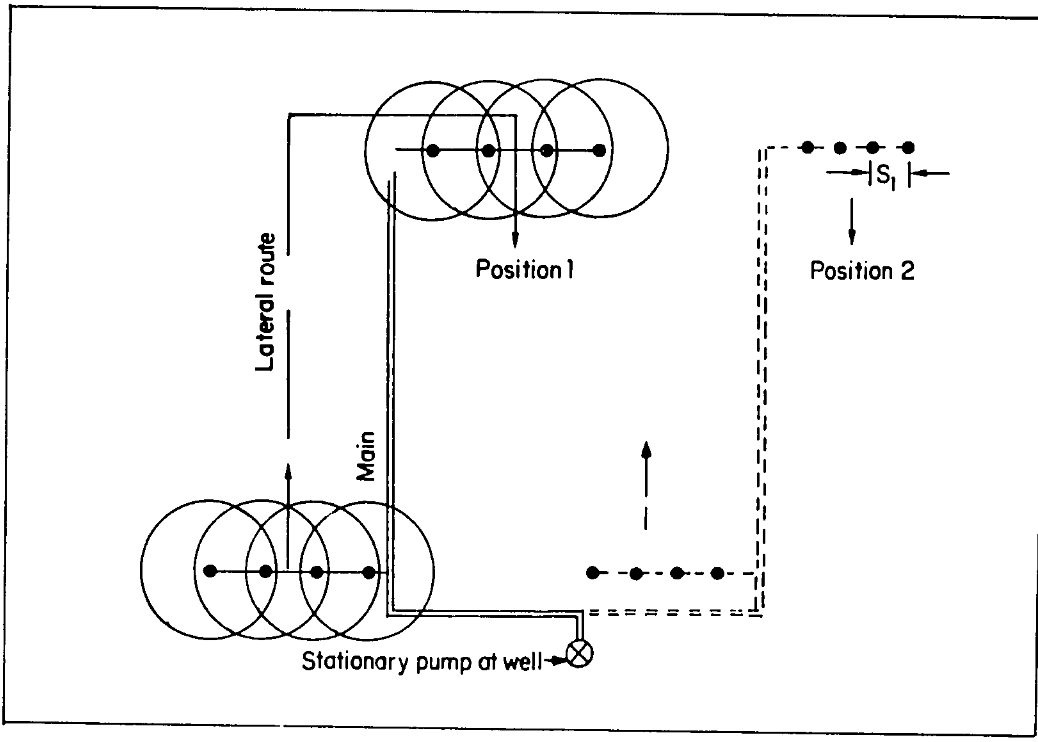

Fig. 9.10. Layout plan for sprinkler irrigation system. The laterals are moved to successive positions.

Table 9.2. Typical characteristics of rotating sprinklers according to their operating pressures.[a]

Characteristic	Low Pressure	Medium Pressure	High Pressure
Operating pressure, atmospheres	1 - 2	2 - 5	5 - 10
Nozzle diameter (mm)	1.5 - 6	6 - 20	20 - 40
Discharge (1/s)	0.06 - 1	0.25 - 10	10 - 50
Diameter of coverage (m)	6 - 35	25 - 80	80 - 140
Sprinkler spacing (m)	9 - 18	18 - 54	54 - 100

[a]The Irrigation Water Management Committee 1982.

Table 9.3. Intake rates for overhead irrigation.[a]

Soil texture	Intake Rate (mm/hour)
Clay	1 - 5
Clay loam	6 - 8
Silt loam	7 - 10
Sandy loam	8 - 12
Sand	10 - 25

[a]The Irrigation Water Management Committee 1982.

The following conditions favor the use of sprinkler irrigation:

1. For sandy or porous soil which loses a lot of water through percolation
2. In shallow soils with topography that prevents proper levelling for surface irrigation methods
3. In steep slopes where soil can be easily eroded if water is supplied by the surface method
4. When the water flow is too small to distribute water efficiently by surface irrigation

The other uses of sprinkler irrigation are the following:

1. For crops that require light and frequent irrigation, such as bulb crops and leafy vegetables; for very closely spaced crops or those that are planted on the broadcast method
2. For frost protection
3. For control of some insects, such as thrips, which do not thrive very well on wet foliage
4. For application of fertilizers, pesticides, and soil amendment
5. For temperature reduction during hot days to improve the quality and yield of some crops

Some disadvantages of sprinkler irrigation are as follows:

1. Initial cost of equipment is high.
2. Operating costs are higher than in surface irrigation. Maintenance of sprinklers can be a problem if water is laden with debris or silt.
3. In the humid tropics, it may favor the development of diseases and weed growth, as it wets the whole field.
4. It reduces the efficiency of pesticides applied to the foliage of the plants.
5. Large evaporation losses are sustained because sprinklers wet the entire soil surface, as well as the leaves of plants.
6. Winds disturb the flow pattern, resulting in unequal distribution of water.

Surface irrigation. For vegetable crops that do not specifically require frequent and light irrigation, such as solanaceous vegetables, cucurbits and legumes; surface irrigation is preferred over sprinkler irrigation. Surface irrigation can be applied to vegetable crops raised on the furrow and flooding methods.

Furrow irrigation is done by running water through small channels (furrows) while it moves down or across the slope of the field (Fig. 9.11). The water sips into the bottom and sides of the furrows to provide desired wetting. It is applicable only for row crops in fields with uniform slopes of from 0.25% to preferably not greater than 2.5%.

Spacing of furrows are determined by the spacing of the plant rows: one furrow is provided for every plant row. However, soil characteristics must also be considered because the lateral movement of water from furrows depends primarily on the texture of the soil - the wetting pattern being broader in clays than in sands. To obtain complete wetting of sandy soils to depths of 1.2-1.8 m, the furrows should not be placed more than 50 cm apart. In uniform clay soils, complete wetting to the same depths might be obtained by furrow spacings of 120 cm or more.

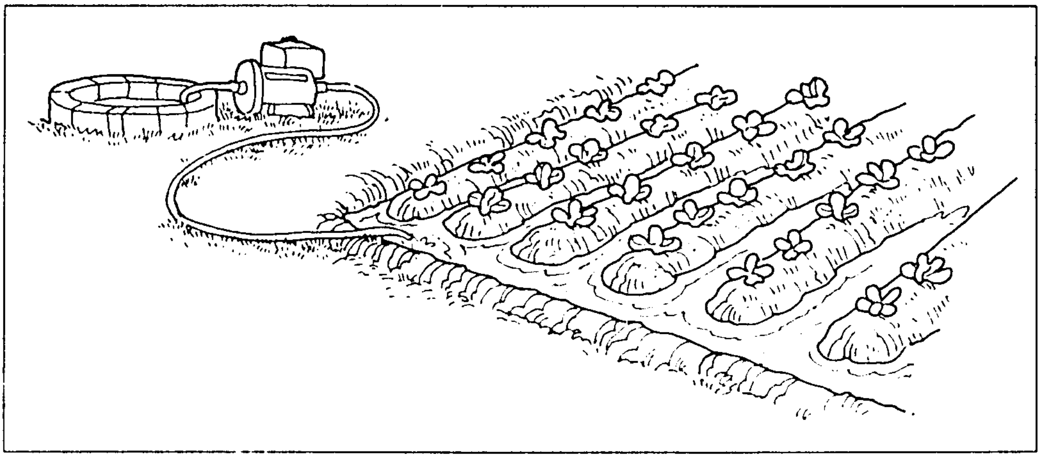

Fig. 9.11. Furrow irrigation.

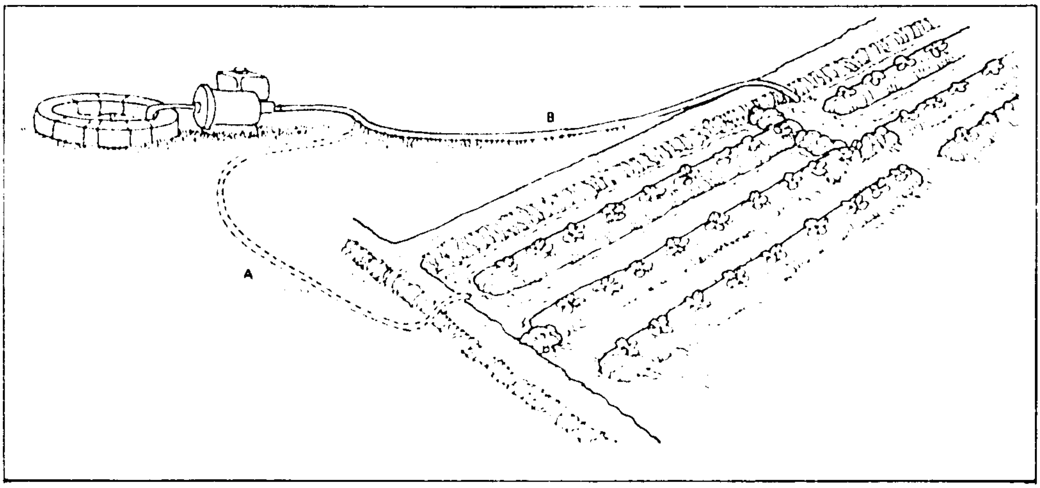

Fig. 9.12. Furrow irrigation when rows are too long or the slope is too steep. (A) Final position of water pipe; (B) second position.

The length of furrows is determined by the slope, soil texture, and desired depth of irrigation. Water losses may occur from percolation if the furrows are too long. On the other hand, operating costs tend to increase with shorter furrows. Recommended lengths of furrows for various conditions are shown in Table 9.4. If the vegetable field is longer than the desired furrow length for the purpose of irrigation, a system of furrow irrigation shown in Fig. 9.12 may be done.

A variation of the furrow method is the use of small rills or ***corrugation*** for irrigating closely spaced crops. Like furrow irrigation, the space between corrugations is closer in light soils and farther apart in heavy soils. The length is shorter with steep slopes to achieve even water distribution. Unlike furrow iirrigation, the corrugation method can be used on comparatively steep slopes of up to 8% and on irregular fields of uneven topography. It is used primarily on fine-textured soils with low water-intake rate and on crops with close spacing.

The ***flooding method*** is applicable in areas which have flat to uniform and gentle slopes, with abundant and inexpensive irrigation water. Relatively large irrigation streams are required. Compared to furrow irrigation, the flooding method does not require elaborate land preparation; it is most applicable in fields that have been previously used for

Table 9.4. Recommended lengths of furrows for different soil types, furrow slopes, and depths of irrigation.[a]

Furrow Slope (%)	Furrow Length (m)						
	Net depth of water application (cm)						
	Clays		Loams		Sands		
	7.5	15	5	10	5	7.5	10
0.05	300	400	120	270	60	90	150
0.10	350	440	180	330	90	120	190
0.20	370	470	220	370	120	190	250
0.30	390	500	280	400	150	225	280
0.50	380	500	280	370	120	190	250
1.00	270	400	250	300	90	150	220

[a]The Irrigation Water Management Committee 1982 .

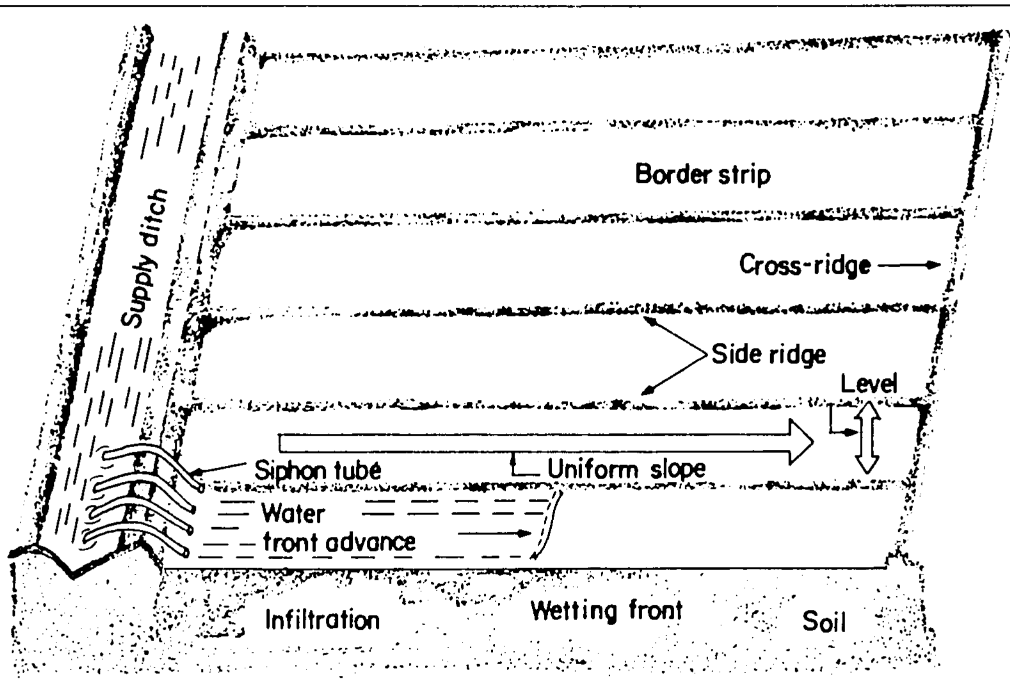

Fig. 9.13. A schematic sketch illustrating the layout of an impounding border-irrigation system.

paddy rice and for closely-spaced vegetables, such as garlic, with zero tillage. The flooding method can be done in several ways; however, for vegetable crops the border-strip flooding technique is most applicable.

Border strip flooding (Fig. 9.13) is one way of controlling flood irrigation to achieve better water distribution and economy. A field is divided into a series of strips, 5-15 m wide and 75-300 m long, depending on the slope and soil texture. It is used only in fields with smooth uniform slopes preferably not over 3%. It is not desirable on fine-textured soils with low water-intake rate.

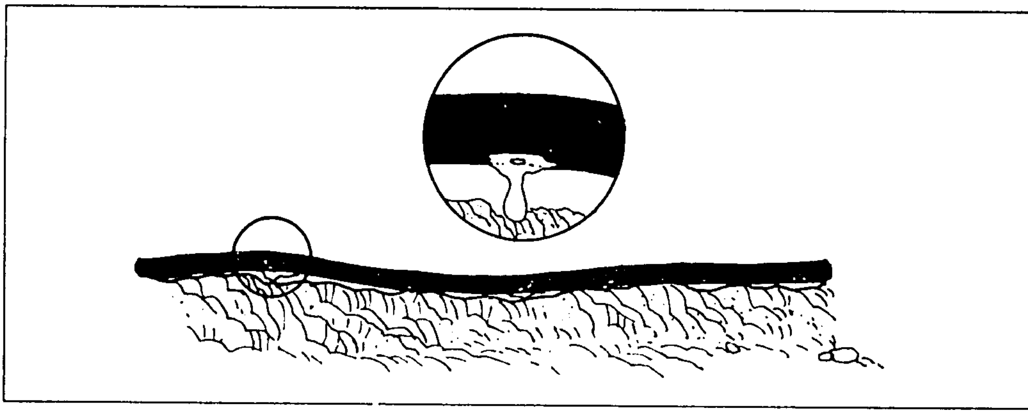

Fig. 9.14. Emitter for drip irrigation.

Drip irrigation. Also known as trickle irrigation, this method refers to the application of water to the soil through small orifices or emitters which are designed to discharge water at rates of 1-8 liters/hour (Fig. 9.14). The emitters are installed close to the plant, wetting only these areas leaving the rest of the field dry — unlike sprinkler irrigation and flooding which wet the entire field. Water is,therefore,used efficiently.The other advantages of drip irrigation are as follows:

1. Sanitation — The foliage is kept dry and spread of soil diseases and weed seeds through surface flow of water (as in furrow or flood irrigation) is prevented. With the controlled release of water, the soil is not waterlogged, a condition which may favor the development of some diseases.
2. Flexibility in farm operations — Cultivation, spraying, and harvesting can be done even while irrigating because the field is kept dry, except the area close to the plant.
3. Uniform water distribution.
4. Ease in combining irrigation with fertilizer and pesticide application.

Savings are thus realized in terms of labor (for irrigation, weeding, fertilizer and pesticide application), water, fertilizer, and pesticides. In many instances, these can offset the high initial cost of equipment for the drip irrigation system.

A typical drip irrigation system is shown in Fig. 9.15. From the pump, water flows to the filtration system which removes sand, silt, weed seeds, and other foreign matter. The water is then evenly distributed to the laterals and flow through the emitters. The pressure of the submain line is controlled by the pressure regulator at preset pressure appropriate to the system. Fertilizer and pesticide injectors are installed optionally before the filter.

Subirrigation. This is the least common method of irrigation because of its high initial cost and limited land suitable (usually peat) for it. Water is supplied by an underground system and reaches the plant by capillary movement. The drip irrigation system can be installed underground to serve as subirrigation. The conditions that favor the use of subirrigation are the following:

1. Soil must permit rapid lateral and downward movement of water, yet is capable of moving the moisture from the water table throughout the major position of the root zone.

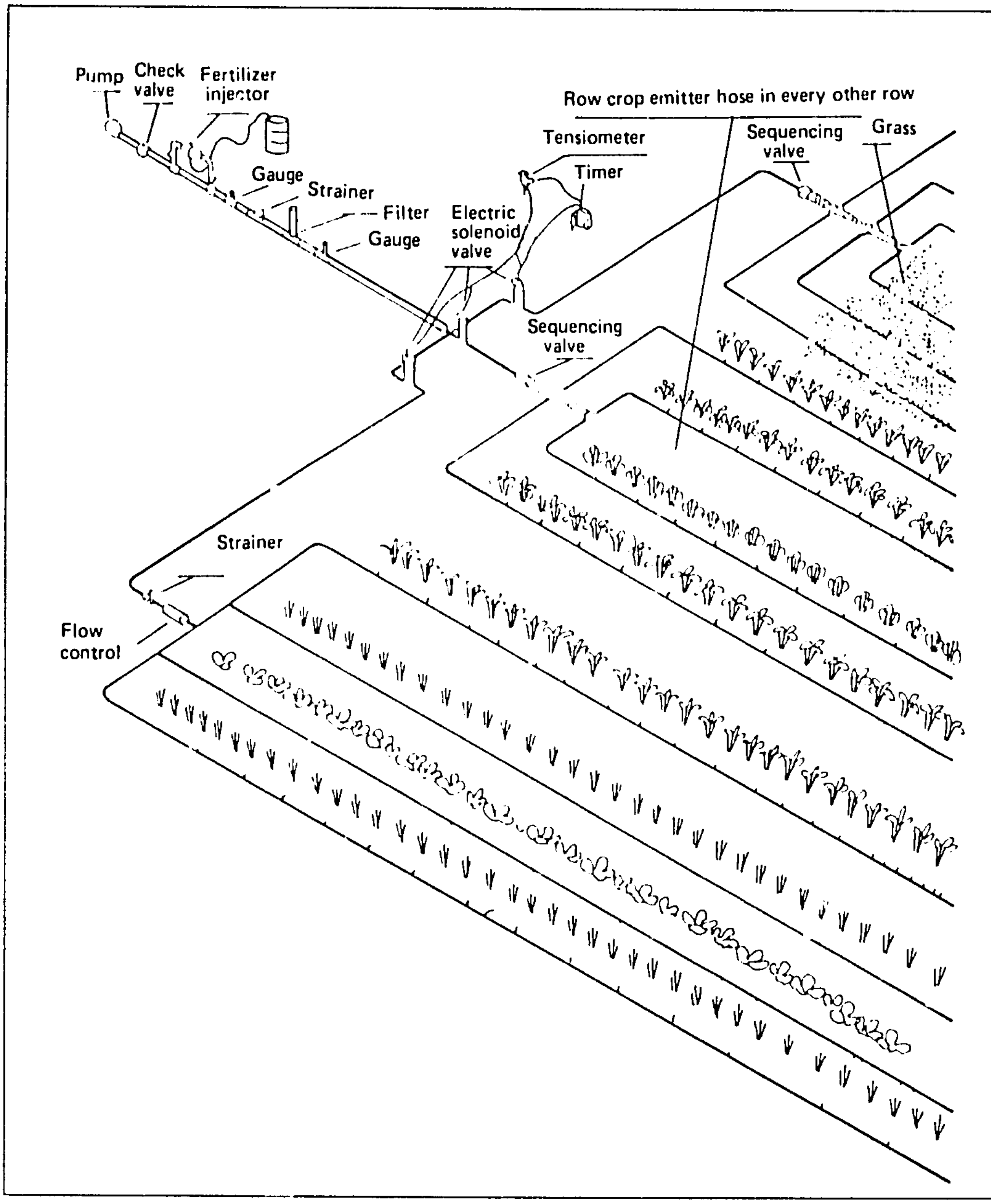

Fig. 9.15. Drip irrigation layout.

2. The topography of the land should be smooth, uniform, and approximately parallel to the water table.

Water Quality for Irrigation

The properties of water that determine its suitability for irrigation are 1) salinity which can be measured by electrical conductivity (EC) or salt content, 2) alkalinity which is expressed in terms of sodium concentration, and 3) toxic components, specially boron. Standards for irrigation water are shown in Table 9.5. Class 1 water is considered excellent to good, suitable for most plants under most conditions. Class 2 water is considered good to injurious, probably harmful to the more sensitive crops. Class 3 water is considered unsuitable under most conditions and probably harmful to most crops. Vegetable crops have different adaptations to salinity conditions as shown in Chapter 3.

Table 9.5. Standards for irrigation water.

Water Class	Electrical Conductivity (micromhos/cm)	Salt Content (ppm)	Sodium (%)	Boron (ppm)
1	0 - 1000	0 - 700	60	0.0 - 0.5
2	1000 - 3000	700 - 2000	60 - 75	0.5 - 2.0
3	over 3000	Over 2000	75	over 2.0

Sources of Irrigation Water

There are two main sources of water for irrigation: ***ground water*** and ***surface water***. Ground water comes from an underground source (such as natural springs and artesian wells) that may or may not require pumping to bring to the surface. The cost of ground water depends on the depth of pumping, as well as the distance of the water source to the field.

Surface water comes from rivers, lakes, and other natural water formations. Rain water may be artificially impounded on strategically constructed reservoirs. Large irrigation systems utilize surface water by constructing dams to elevate the water level and facilitate distribution by gravity. Surface water is a cheap source of large quantities of water.

Recycled municipal water when properly treated, can also serve as irrigation water. However, this is more commonly used for industrial crops, such as cotton, rather than for food crops.

All irrigation water should be tested for salinity and toxic components before these are used.

Drainage

Excess water, whether it comes from irrigation or from natural sources, must be removed from the field to ensure normal crop growth. Poorly drained soil does not only harm the crop directly, but also causes problems with scheduling of mechanical farm operations and promotes the development of diseases.

Sources of Excess Water in the Farm

The sources of excess water in the farm may be precipitation, irrigation, overland flow, underground seepage from adjacent area, artesian flow from deep aquifers (porous rock containing water), floodwater from channels, or water applied for special purposes, such as leaching salts from the soil, or for temperature control. In humid areas, the major source of excess water is precipitation which ponds on the field surface or percolates into the soil to become ground water. Where there is poor surface drainage on flat land, temporary flooding occurs and a large percentage of the rainfall infiltrates into the soil.

When the total quantity of water introduced into the soil or accumulated on field surface from various sources exceeds the total quantity disposed of through natural drainage processes, the water table rises and injures the crops. It is then necessary to install artificial drains to reduce surplus water on the surface or under the ground to some predetermined level which is not damaging to the crop.

Properly drained soils warm up more quickly than saturated soils in the spring. Good drainage permits earlier planting and better germination. When drainage lowers a high water table, it increases the active root-zone depth and allows plants to develop their natural root pattern. When excessive soluble salts are present in the soil profile, good subsurface drainage reestablishes percolation of water in the soil profile and permits leaching of these salts.

The optimum depth of the water table is not constant for all areas but varies with soil texture, depth of soil and subsoil layers, crops grown, and salinity. In fine-textured soils and subsoils the height of the capillary fringe (edge) above the water table may be a controlling factor. This is specially true when harmful soluble salts are present and are moved to the soil surface through capillary action.

In coarse-textured soils or soils underlaid by coarse-textured sands or gravels, capillary action may be slight, and the capillary fringe may extend very little above the water table. Under conditions when salts are present, a water table within less than 1.8 m from the ground surface may be damaging to plant growth. However, the critical depth of the water table is determined by the position of the capillary fringe.

Drainage Methods and Applications

Surface drainage. This method eliminates ponding, prevents prolonged saturation, and accelerates the flow to an outlet without siltation or erosion of soil. In some cases, orientation of row crops with the land slope may accomplish this purpose. In other cases, the use of a diversion is necessary, as shown in Fig. 9.16. Combinations of both surface and subsurface drainage, such as land grading and smoothing over subsurface drains, often provide better and more economical results.

Surface drainage systems include both collection and disposal ditches. The cross section, slope, pattern, and small spacing of ditches are essential factors of design where the system, or parts of the system, primarily collect and remove surface water from a field or small land area. Ditches for surface drainage are usually designed to remove the runoff produced by an ordinary rain to prevent damage to the crops grown in the drainage area.

Subsurface drainage. This is defined as the removal of excess ground water. Surface ditches are necessary to remove excess runoff from precipitation and dispose surface flow from irrigation; but these should be designed to complement the subsurface drainage system. Surface drainage reduces the amount of water to be removed by the subsurface system and permits better control of the water table. Subsurface drainage lowers the high water table caused by precipitation, irrigation water, leaching water, seepage from higher lands, irrigation canals, and ditches. It also eliminates ground water under artesian pressure.

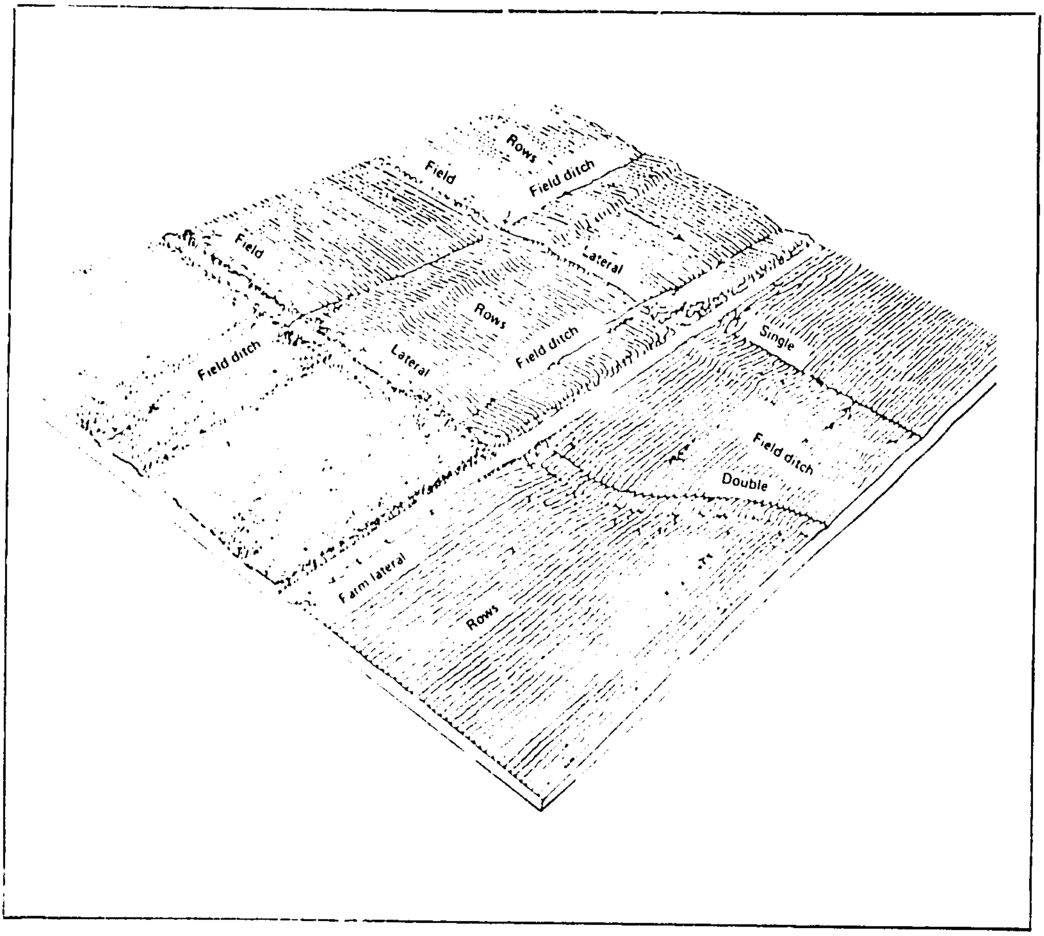

Fig. 9.16. Typical layout of an individual farm drainage system.

Subsurface drainage may consist of the following:

1. **Tile drains**—Made of concrete or clay, this type of drain is almost permanent if the tiles are of good quality and carefully installed (Fig. 9.17). They should be covered with not less than 60 cm of earth to prevent breakage by equipment. A 10-cm inside diameter is generally the smallest size recommended for clay and clay loam soils.
2. **Pole drains**—Ditches that are 60-100 cm deep and 30 cm wide are dug. Poles or bonded brush woods with diameters of 5-10 cm or 2-3 cm, respectively, are then placed at the bottom of the ditch as in Fig. 9.18.
3. **Stone drains**—Drainage by means of stones is accomplished in a way somewhat similar

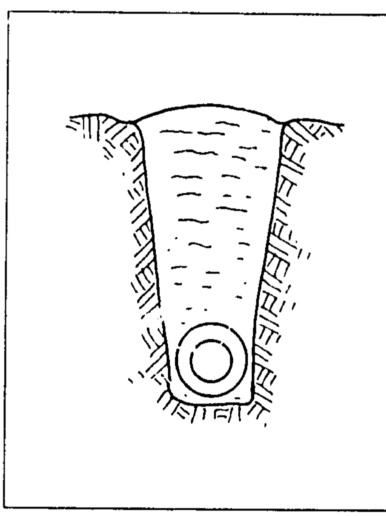

Fig. 9.17. Tile drains.

to that by poles. If large flat stones are available, they are placed at the sides of the ditch with one over the top, thus forming a small channel which is more durable than the poles (Fig. 9.19).

4. **Box drains**—Box drains, usually made of low-grade, locally available lumber that are free of shakes and rot, are used extensively in many areas where tile is hard to get or is considered too costly (Fig. 9.20).
5. **Bamboo drains**—Bamboo drains are usually used for drainage on flower beds, grasses, and other shallow-rooted plants. Bamboo poles that are 5-10 cm in diameter are split in half and notches are made 20-30 cm apart. Then the poles are

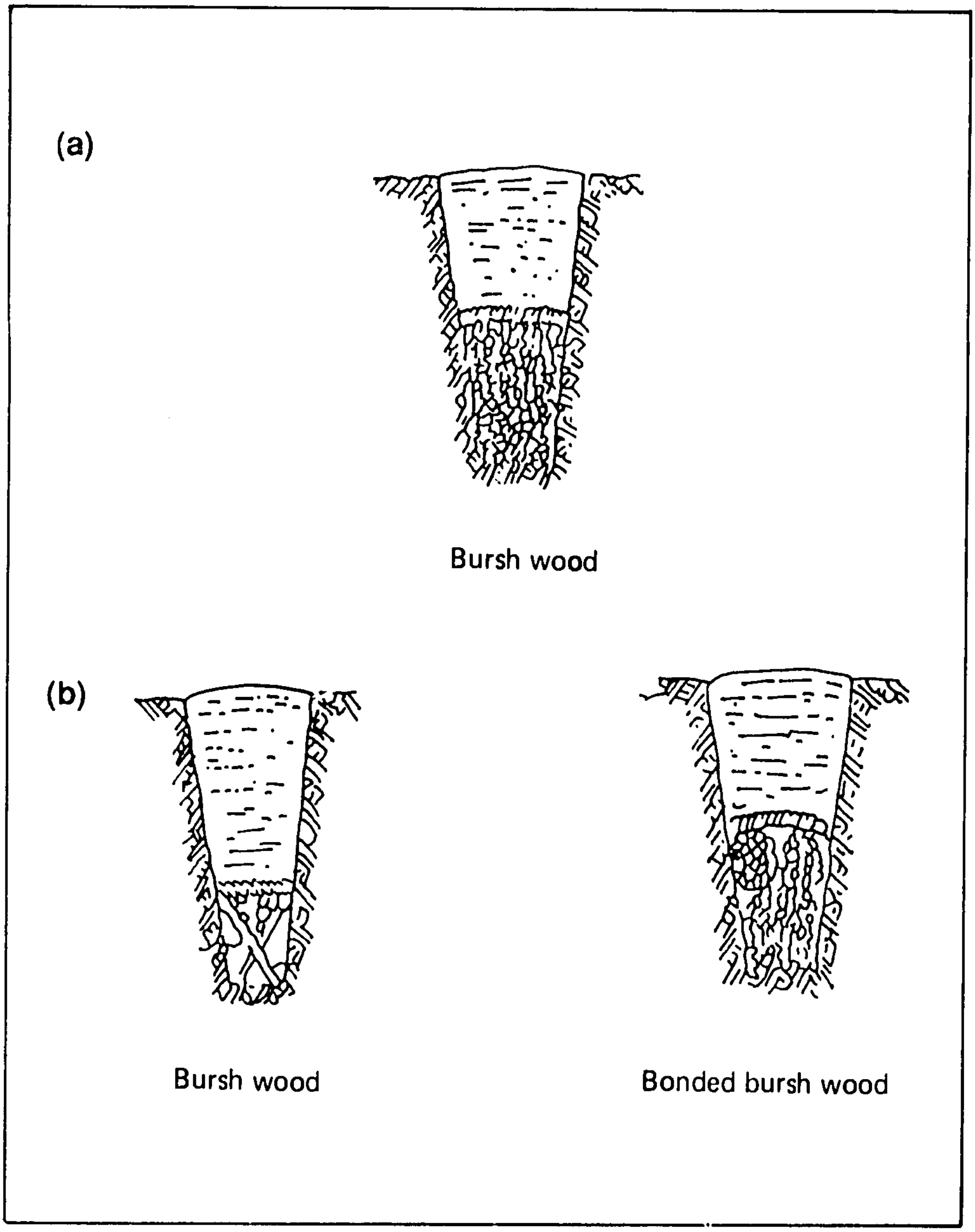

Fig. 9.18. **Pole drains.**

closed and the notches covered with nylon cloth. The poles are then connected like a pipe and buried 30-40 cm deep (Fig. 9.21). Bamboo drains can last for 5-10 years.

Types of Drainage Systems

The arrangement of the drains in the field is called the drainage system. The appropriate system depends on conditions in the site. A good system must:

1. fit the farming system
2. cause water to flow readily from land to ditch without harmful erosion or deposition of silt
3. have adequate capacity to carry the flow
4. be designed for construction and maintenance with appropriate equipment locally available.

The main types of drainage systems are the natural system, interception system, and parallel system (Fig. 9.22). The parallel system has two common modifications: the gridiron system and herring-bone system (Fig. 9.23).

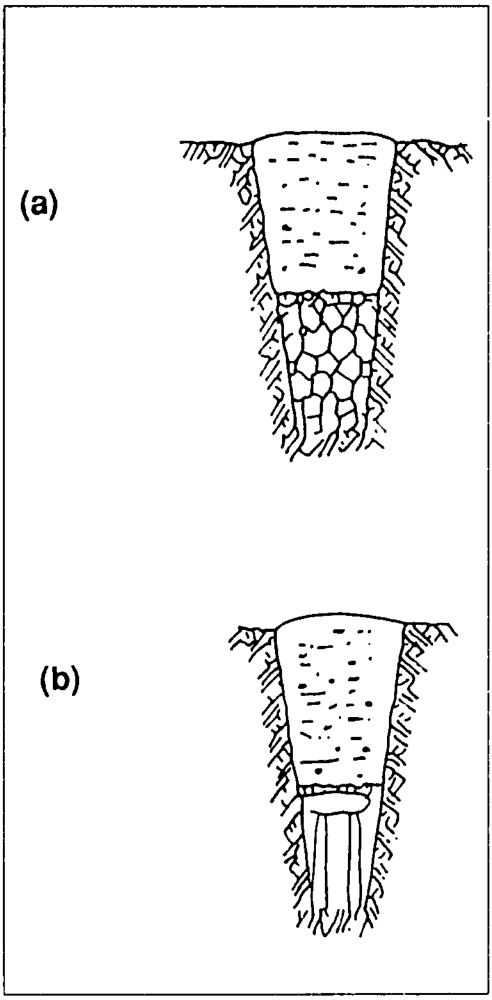

Fig. 9.19. Stone drains.

- **Natural or random system.** The drainage lines follow natural depressions and are not equally spaced. Drainage may not be complete. This is suited to the drainage of small areas.

- **Interception system.** The interceptor drain system is installed near the upper edge of a wet area. It is necessary when an impermeable strata is found near the surface, preventing the natural flow of subsurface drainage water.

- **Parallel system.** The herring-bone system is suited to areas that have a concave or a narrow draw with land sloping to it. The main line is installed along a line defined by the low area; the laterals are installed at an angle pointing to the direction of water flow on both sides of the main line. The gridiron system follows the same layout as the herring-bone system, except that the laterals enter the main line from only one side.

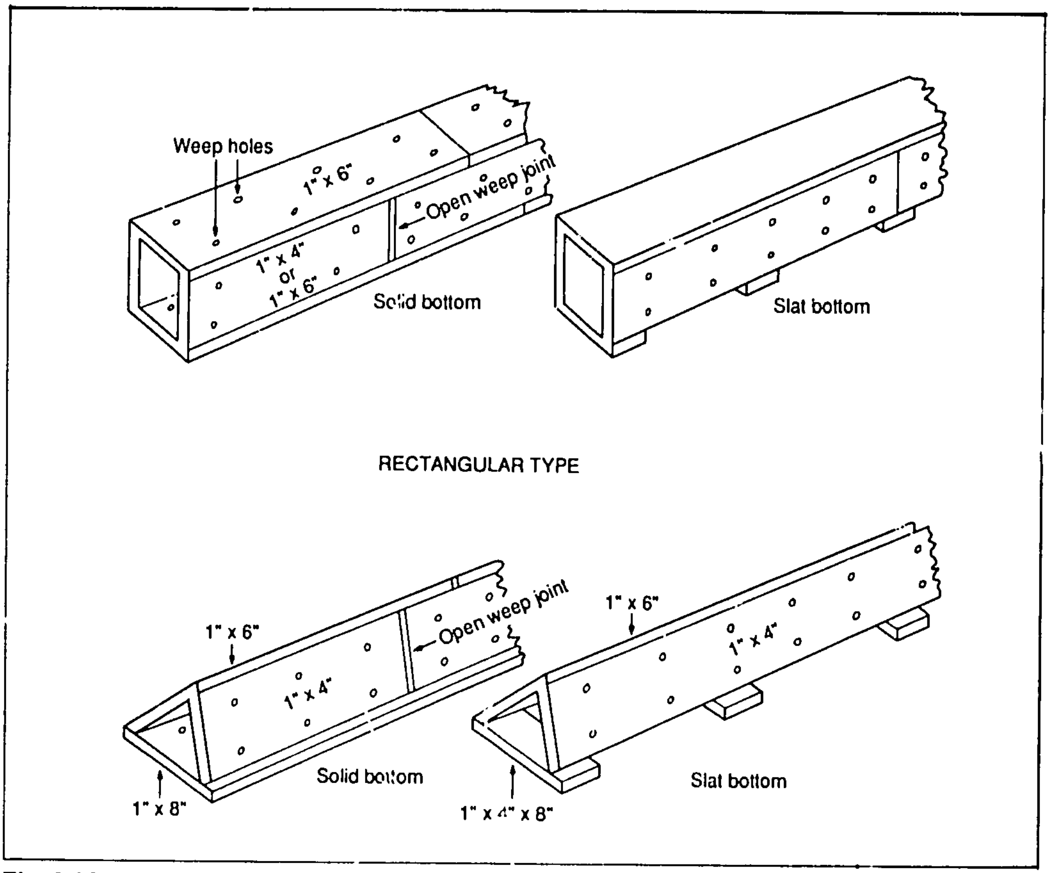

Fig. 9.20. Box drains approximating 4- and 5-inch tile capacity. (Note 1/2 - 3/4 inch weep holes about 1 ft horizontally and 2 inches vertically.

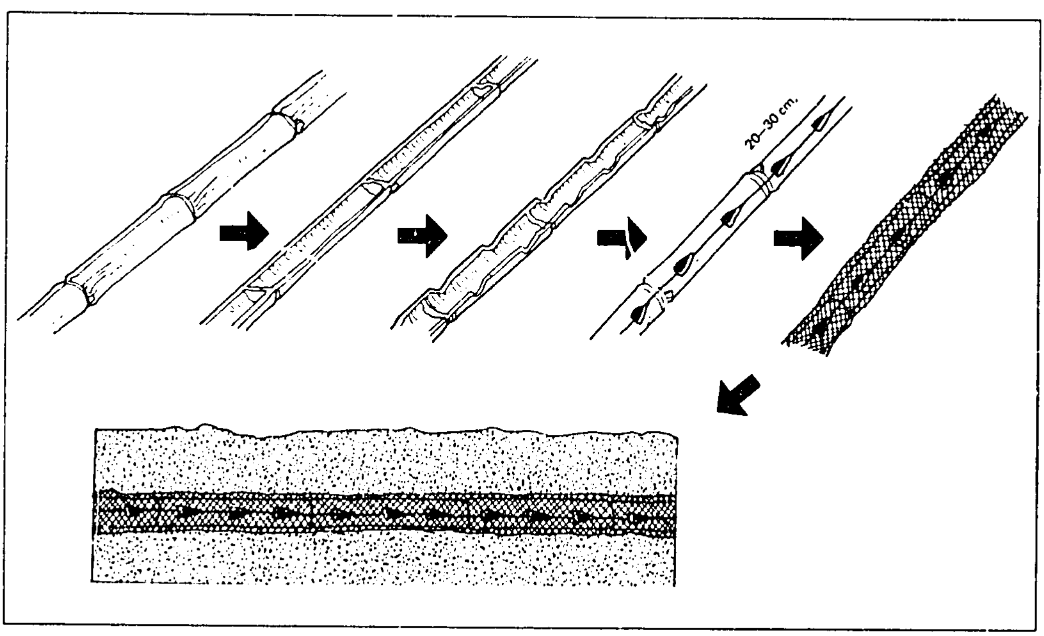

Fig. 9.21. Preparing and installing bamboo drains.

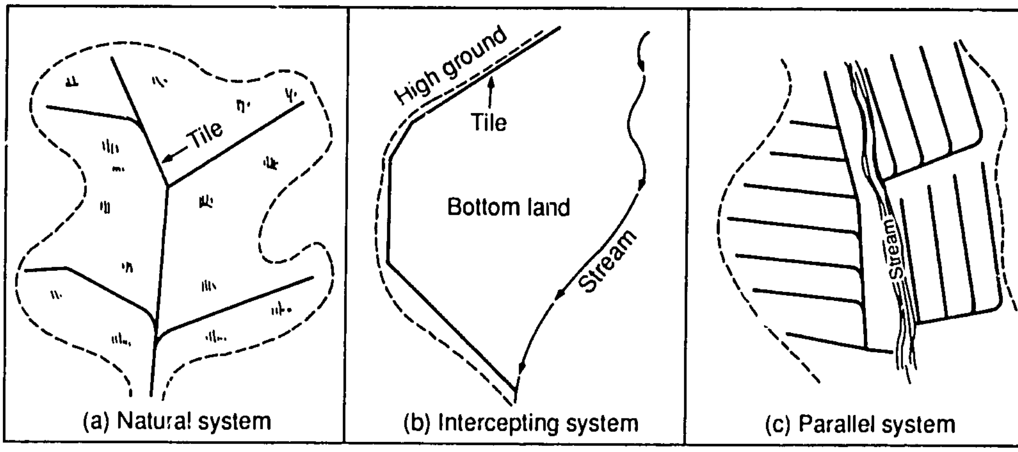

Fig. 9.22. Main types of drainage systems.

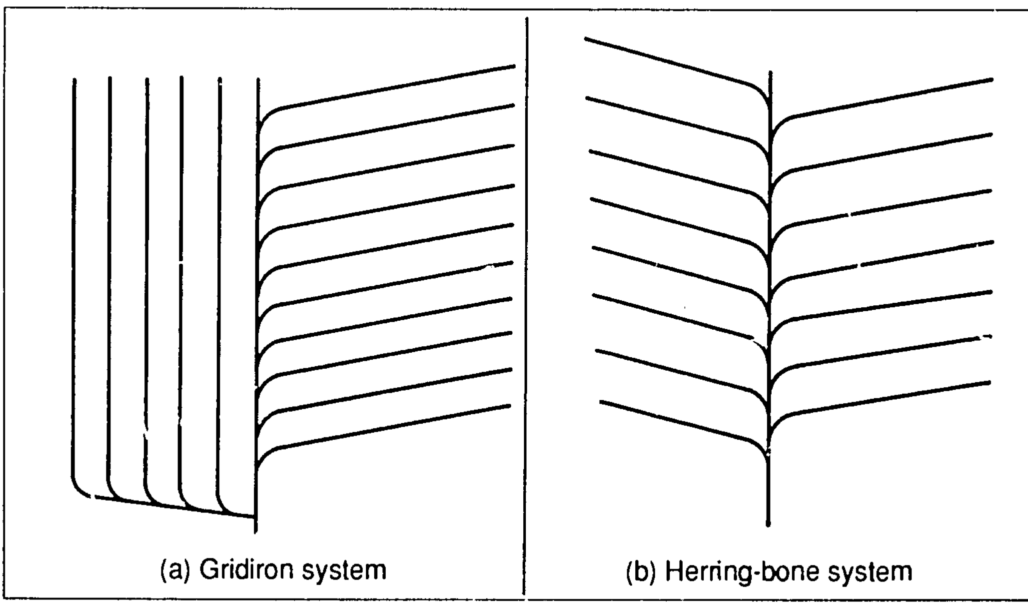

Fig. 9.23. Two much-used types of parallel systems.

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CHAPTER 10

Crop Protection

Vegetables are susceptible to injury and damage caused by pathogens, weeds, and insects which can occur separately or all at the same time. A vegetable grower must be able to control these pests effectively in order to have a profitable crop. The process by which he does this is called ***crop protection***.

Traditionally, crop protection is done by controlling pests individually. Chemical sprays were developed against pathogenic microorganisms and harmful insects. This method, however, only gives temporary relief because the pesticidal sprays also adversely affect the beneficial organisms. The pest problem then becomes serious in the long run.

An effective crop protection approach therefore must consider the interrelationships of all the important factors in the biological environment of the crop. A scientific grower must not only understand the nature of specific pests, but also that of all the other organisms and factors that may affect them.

Part I: Diseases Caused by Bacteria, Fungi, and Nematodes

The goal of vegetable farmers is to have productive, disease-free plants. Diseased vegetables grow and yield poorly. ***Disease*** is defined as any detrimental plant disturbance that interferes with its normal structure, function, or economic value (Fig. 10.1).

Diseased plant roots will often be rotten, stunted, or swollen; stems may be cankered, discolored, distorted, elongated, or stunted; leaves may be blighted, discolored, distorted, mottled, or spotted; flowers and fruits may be blighted, discolored, distorted, mottled, spotted, or stunted. Most diseases can be diagnosed by studying their symptoms. Plant disease clinics are designed to diagnose diseases primarily by their symptoms.

Vegetable diseases often limit production. Economic losses may be minor or life-threatening. Losses may occur at the seedling stage when infected plants die. Populations are reduced during the season when the entire plants are killed, when portions of the leaves are diseased, or when flowers, fruits, or seeds become infected. Quality is lost when spots or blotches are evident on the produce. In some cases diseases are most critical during transit and storage.

Diseases are caused by abiotic (nonliving) and biotic (living) factors (Fig. 10.2). Abiotic factors that cause diseases include air pollutants, light, moisture, nutrients, pesticides, pH, and temperature. Living disease-causing pathogens belong to groups of organisms classified as bacteria, fungi, mycoplasmas, nematodes, parasitic higher plants, and protozoa (Fig. 10.3).

Viruses, which consist of an outer protein coat and an inner core of nucleic aid, and viroids (without outer protein coat)are often considered as biotic pathogens although they do not increase in number without a host and do not have cell organelles or walls.

The following sections review some of the most important characteristics of bacteria, fungi, and nematodes. This is followed by sections on disease assessment and management, and characteristics of seed rot and seedling damping-off. The last sections cover the most important diseases of Chinese cabbage, mungbean, pepper, soybean, sweet potato, and tomato.

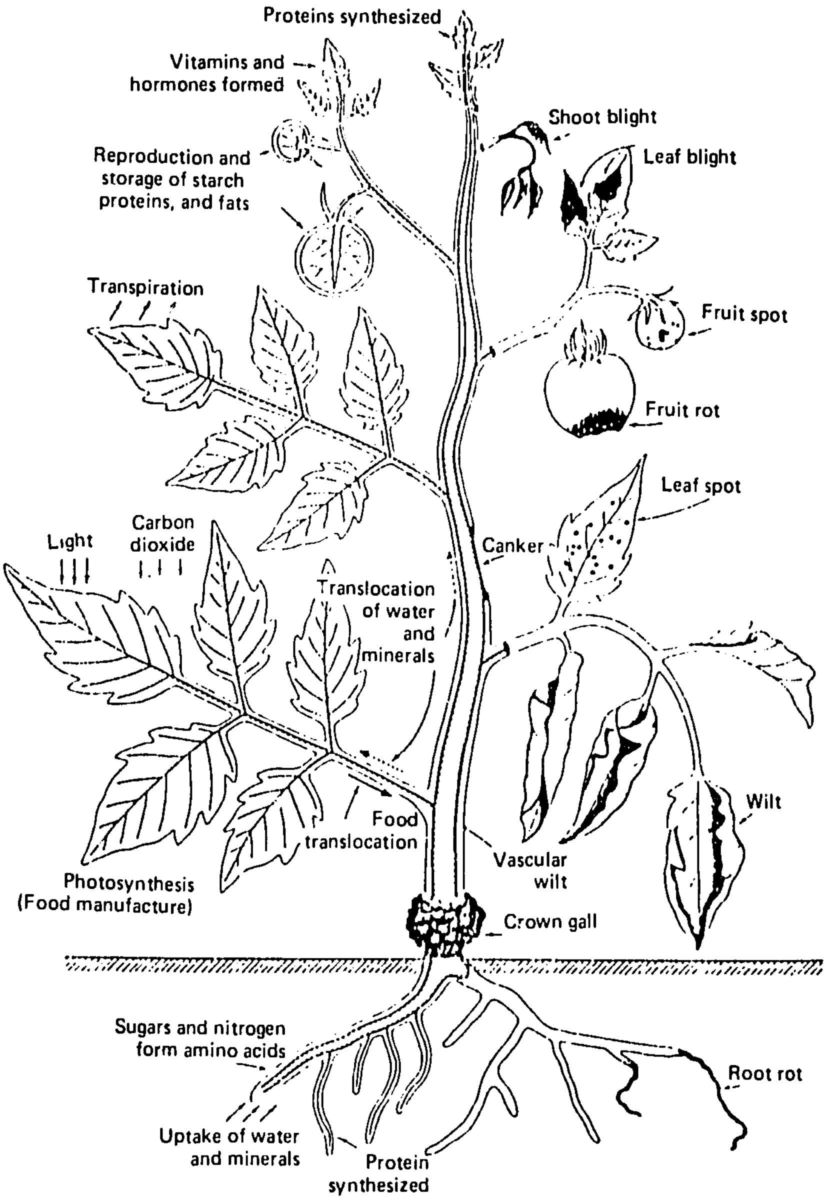

Fig. 10.1. Schematic representation of the basic functions in a plant and of the interference with these functions caused by some common types of plant diseases.

Plant-Pathogenic Bacteria

Bacteria are microscopic organisms. Approximately 200 of the 1,600 species of bacteria are known to cause plant diseases. Most plant-pathogenic bacteria can be grown on different kinds of nutrient media (facultative saprophytes). Bacteria are simple microorganisms usually consisting of a single prokaryotic cell that may be rod-shaped, spherical, ellipsoidal, spiral, comma-shaped, or filamentous (threadlike).

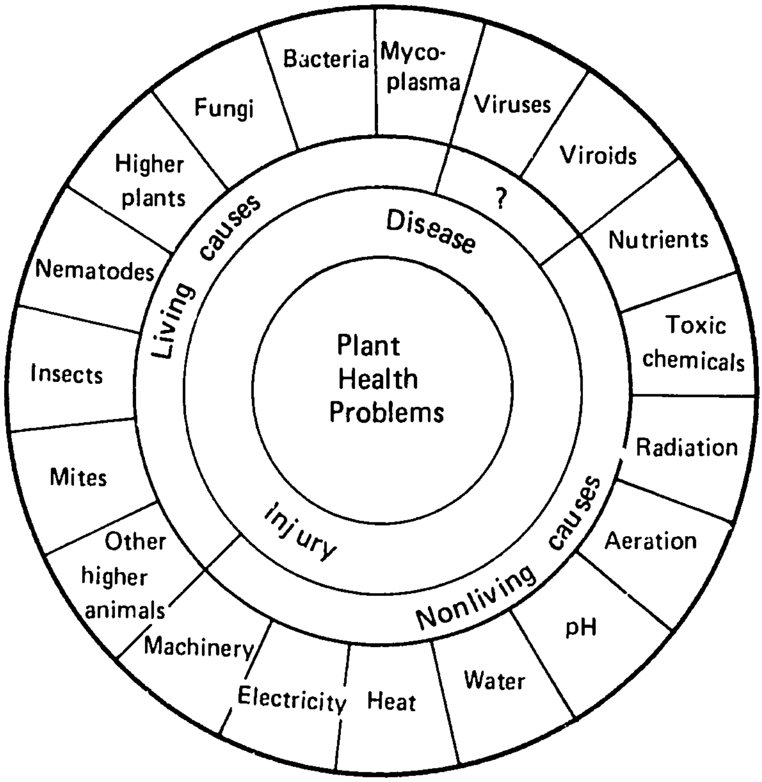

Fig. 10.2. Biotic and abiotic factors that cause plant injury and disease.

Some bacteria have flagella that make them mobile. Bacterial diseases occur worldwide and often cause economic losses when the host is susceptible and environmental conditions are favorable. Bacterial diseases are often destructive enough to kill the host plant.

Classification and identification. According to Bergey's *Manual of System Bacteriology* (1974), all organisms that lack an organized and bounded nucleus belong to the Kingdom Prokaryotae which has several subdivisions. The pathogenic bacteria are classified under three of the sixteen parts of class I. The main characteristics of the plant-pathogenic genera of bacteria are as follows (Fig. 10.4).

- *Agrobacterium*—The bacteria are rod-shaped, 0.6-1.0 by 1.5-3.0 µm, aerobic, and gram-negative. They are motile by means of one to six peritrichous flagella; when only one flagellum is present, it is more often lateral than polar. When growing on carbohydrate-containing media, the bacteria produce abundant polysaccharide slime. The colonies are nonpigmented and usually smooth. These bacteria live in

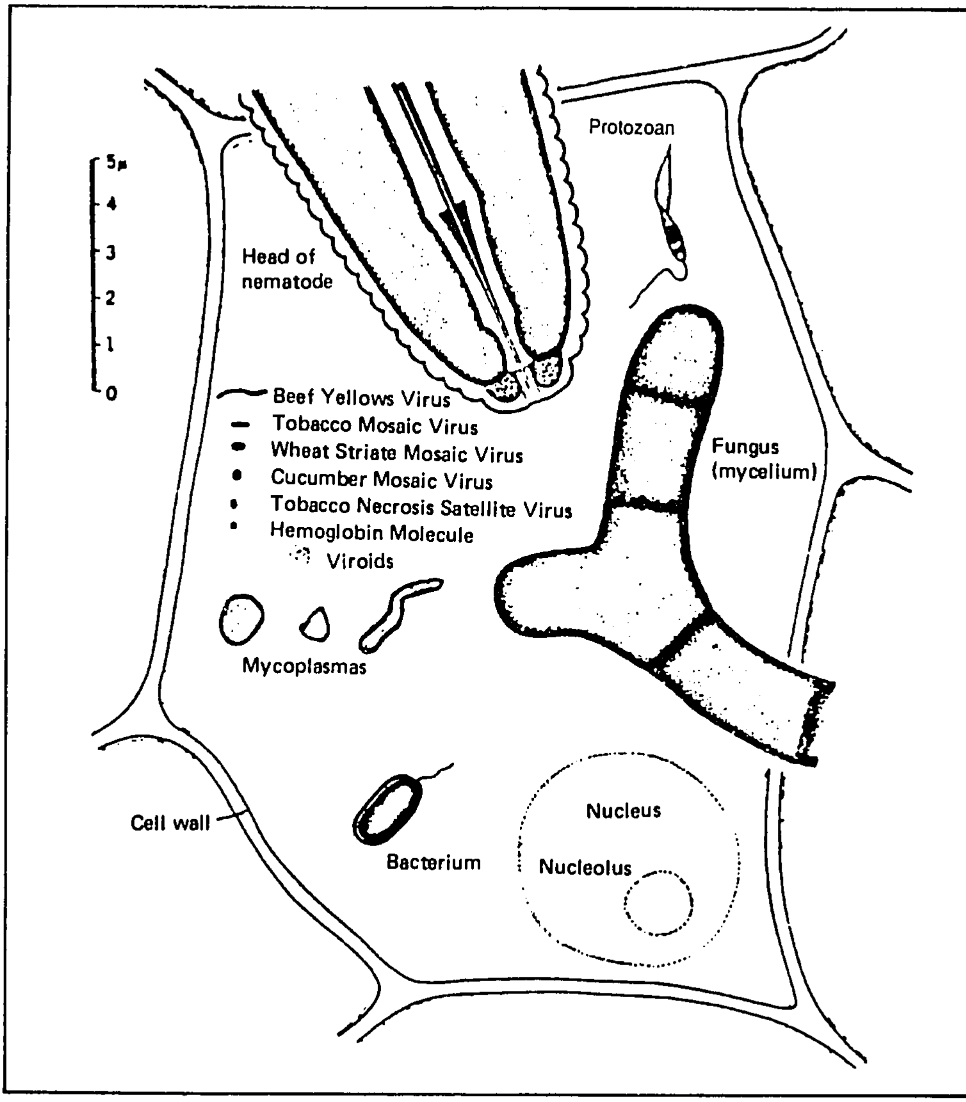

Fig. 10.3. Schematic diagram of the shapes and sizes of certain plant pathogens in relation to a plant cell. (Agrios 1978)

the rhizosphere and soil. Most vegetables are susceptible to pathogenic members of this genus which causes crown gall.

- *Corynebacterium*—They are straight to slightly curved rods, 0.5-0.9 by 1.5-4.0 μm. The bacteria are gram-positive and generally nonmotile, but some species are motile by means of one or two polar flagella. Species of *Corynebacterium* cause diseases in animals and plants. Recently, a new genus, *Clavibacter*, has been suggested and many of the species of *Corynebacterium* are now species of *Clavibacter*. *C. michiganense* causes bacterial canker of tomato.
- *Erwinia*—They are straight rods, 0.5-1.0 by 1.0-3.0 μm. They are motile by means of several to many peritrichous flagella. *Erwinias* are the only plant pathogenic

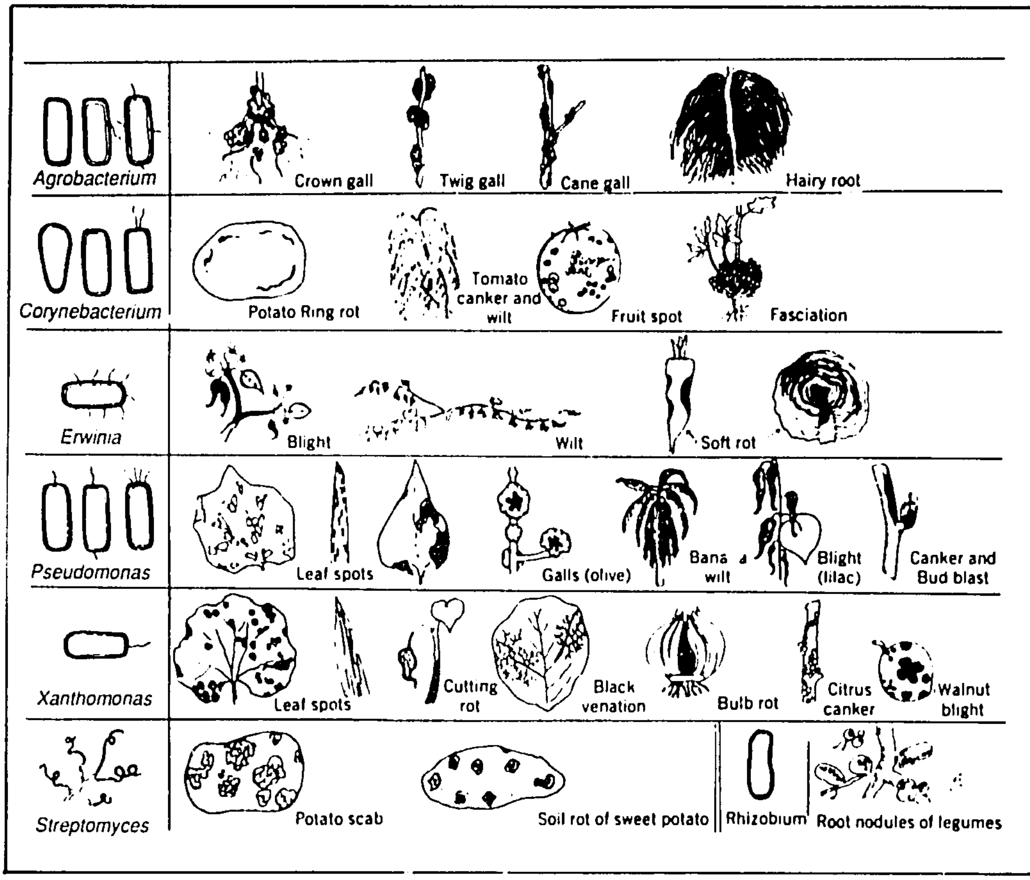

Fig. 10.4. Genera of bacteria, and the kind of symptoms that they cause. (Agrios 1978)

bacteria that are facultative anaerobes. Some authors retain the name "Erwinia"for *Erwinias* that cause necrotic or wilt diseases (e.g. *E. amylovora, E. tracheiphila*), but include the soft-rotting *Erwinias* (*E. carotovora*) in a new genus, *Pectobacterium*. This group causes soft rot on most vegetables.

- *Pseudomonas* — They are straight or curved rods, 0.5-1.0 by 1.5-4.0 µm, gram-negative, and motile by means of one or many polar flagella. Many species live in the soil, in fresh water, or in marine environment. Most pathogenic *Pseudomonas* species infect plants; few infect animals or humans. Numerous vegetable diseases, including bacterial wilt of tomato, are caused by species of *Pseudomonas*.
- *Xanthomonas*— They are straight rods, 0.4-0.7 by 0.7-1.8 µm and motile by means of a polar flagellum. Growth on agar media is usually yellowish. Most are slow growing. All species are plant pathogens and are found only in association with plants or plant materials. Many diseases including bacterial spot of pepper and tomato are caused by members of this genus.
- *Streptomyces* —They are slender, branched hyphae without cross walls, 0.5-2.0 µm in diamater. At maturity the aerial mycelium forms chains of three to several spores. On nutrient media, colonies are small 1-10 mm in diameter at first with a rather smooth surface but later with a weft of aerial mycelium that may appear granular, powdery, or velvety.

The many species and strains of the organism produce a wide variety of pigments that color the mycelium and the substrate; they also produce one or more antibiotics active against bacteria, fungi, algae, viruses, protozoa, or tumor tissues. All species are soil inhabitants with gram-positive stain. Sweet potato pox and scab on white potato are two examples of diseases caused by species of *Streptomyces*.

Morphology. Most plant-pathogenic bacteria are rod-shaped, although species of *Streptomyces* are filamentous. There are also bacteria-type organisms of uncertain affiliation that are amorphous or helical-shaped. The rod-shaped bacteria range from 0.6-3.5 m in length and from 0.5-1.0 m in width. The cell walls of most species are inside a viscous, gummy material called ***slime layer or capsule.***

Most have delicate, threadlike flagella which are usually considerably longer than the length of the bacterial cells. In filamentous species of *Streptomyces* the cell consists of nonseptate branched threads, which are usually spiral and produce conidia in chains on aerial hyphae.

Single bacterium appears hyaline or yellowish-white under the compound microscope. When a bacterium is allowed to grow (multiply) on the surface of a solid medium, its progeny produce a visible mass called a ***colony***. Colonies of different species may vary in size, shape, form of edges, elevation, color, etc., and are sometimes characteristic of a given species. Colonies of most species are whitish or grayish, but some are yellowish, reddish, or with a tint of other colors. Some produce diffusible pigments while growing on a solid medium.

Ecology and spread. Populations of plant-pathogenic bacteria increase mostly inside the host plant, although some propagate outside of the host as saprophytes. For example, the population of the causal agent of bacterial spot of pepper, *Xanthomonas campestris* pv. *vesicatoria*, increases in the plant host, but declines rapidly in the soil.

Other pathogens, like *Pseudomonas solanacearum* (bacterial wilt of tomato), increase in number within the host plant, but gradually decline when they are released into the soil. If susceptible hosts are replanted, the bacterial population in the soil will increase. Other bacteria, especially species that cause soft rot of many types of vegetables, may survive in the soil for some time without reduction in number.

In the soil, bacteria survive mostly on plant material which protects them from various adverse factors. Bacteria can survive in or on seeds, other plant parts, insects, or other debris found in soil. Bacteria also survive epiphytically on plant buds and on leaves; it is also associated with wounds of plant exudates. Bacteria are transferred from plant to plant or to other plant parts primarily by water; but insects, other animals, and man are also carriers.

Signs and symptoms. Signs of bacterial diseases are rarely evident, although under certain conditions, bacterial ooze can be seen on stem cankers, stem cuttings taken from wilted plants, and on rotten produce. Symptoms of bacterial diseases include leaf and fruit spots, soft rots, scabs, cankers, and overgrowths (Fig. 10.4). Symptoms due to bacterial diseases are often difficult to differentiate from those caused by fungal pathogens. Bacteria need to be isolated from diseased tissues and reinoculated onto the host plant to determine if the disease is caused by a bacterium.

Disease cycle of soft rot (*Erwinia carotovora* var. *carotovora*). The bacteria overseason in infected debris, in the soil, and in the pupae of some insect maggots (Fig. 10.5).

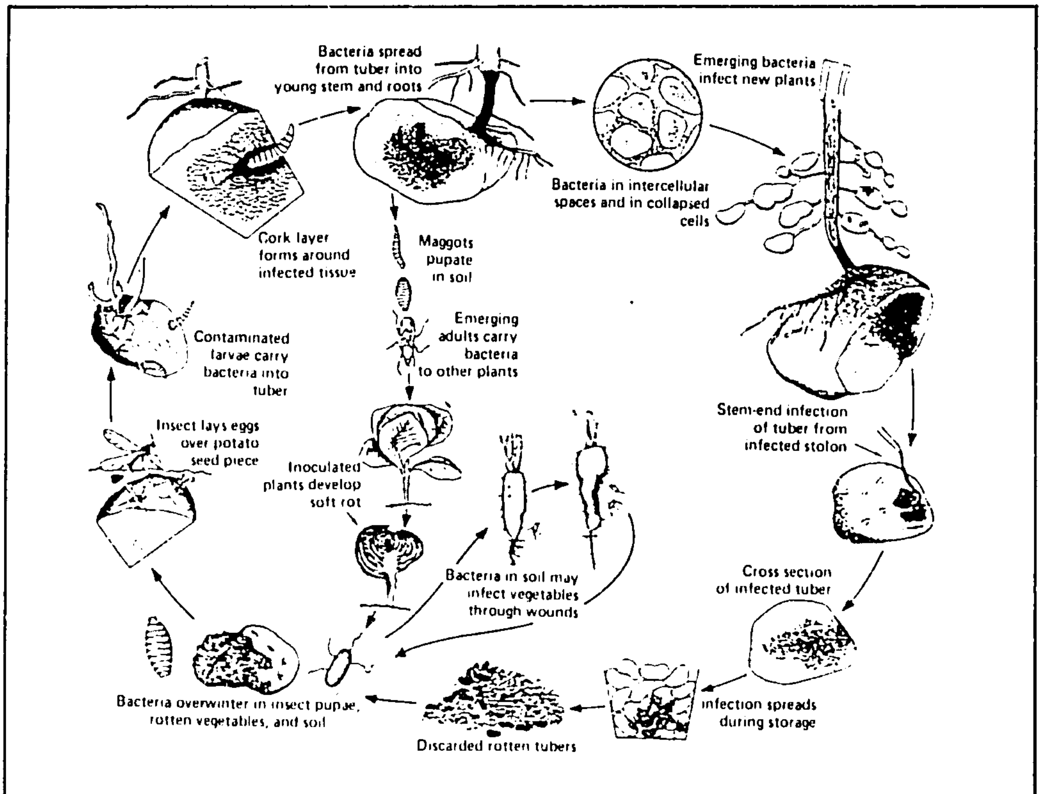

Fig. 10.5. Disease cycle of bacterial soft rot of vegetables caused by *Erwinia carotovora*.

Initial infection usually occurs through wounds from insects or mechanical damage. The bacteria grow and multiply on the liquids released by cells of the wound and secrete pectolytic and cellulolytic enzymes which soften the cell walls and eventually break the entire tissue.

Insects are attracted to the rotting tissue and carry the bacteria to other hosts, or the bacteria may remain inside the insect until they are transmitted. They may overseason in the soil or plant debris where they can survive until the next season.

Plant-Pathogenic Fungi

More than 100,000 fungi species are known, most of which are saprophytic (living on dead organic matter). About 100 species cause diseases in man and approximately 10,000 species cause diseases in plants Most vegetable diseases are caused by fungi; and these diseases are critical in the field, in transit, and in storage. The quality and quantity of vegetable production can be reduced up to 100% by some fungal diseases.

Classification and identification. Many classification schemes for fungi have been developed over the years, the most recent of which was that by Hawksworth et al. (1983). Fungi are considered a kingdom with two divisions: Myxomycota which have an amoebic or plasmodium growth stage and Eumycota which have typical mycelium although some are unicellular.

Within Eumycota there are five subdivisions that characterize the fungi. Members of Mastigomycotina have uni- or multi-cellular mycelia often with motile gametes. Members of the Zygomycotina have aseptate mycelium with a sexually formed resting spore called a ***zygospore***, while those in the Ascomycotina have septate mycelium and form ascospores by sexual reproduction. Members of the Basidiomycotina have septate mycelium with hyphal clamp connections and form basidiospores by sexual reproduction. Members of the Deuteromycotina have septate mycelium, but lack any sexually reproduced spores.

It is not always easy to identify the fungi that cause diseases, especially since there are over 10,000 species that are known to cause diseases on plants. The most significant characteristics used to identify fungi are the type of spores and fruiting structures seen under the microscope. Shapes, sizes, colors, and arrangement of both spores and fruiting structures are also important considerations in identification, since some books identify diseases based on host occurrence. The plant host may also be a helpful factor.

Morphology. Most fungi have a mycelium which is their vegetative body made up of elongated, continuous filaments. Individual filaments are called ***hyphae*** which are 5-100 µm thick. Fungi lack conductive tissue and chlorophyll. They use several structures for dispersal and survival. Most fungi are characterized by their spores and the fruiting structures associated with the development of spores. These fruiting structures come in various shapes and sizes (Fig. 10.6).

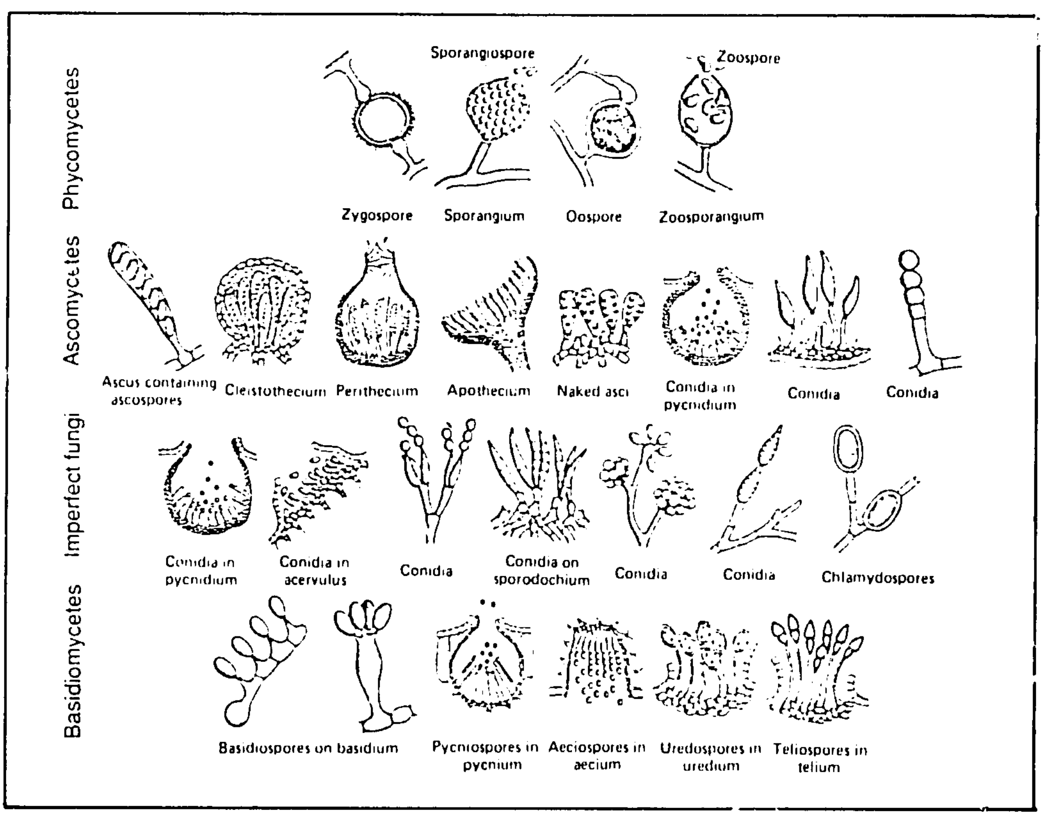

Fig. 10.6. Representative spores and fruiting bodies of the main groups of fungi.

Ecology and spread. Plant-pathogenic fungi are found in the air, soil, and water. Some grow and multiply only in their host plant (obligate parasites), while others live only part of their lives in their host and grow by living as saprophytes on plant residue. Most fungi have specialized survival structures like chlamycospores, certain fruiting bodies, and sclerotia that allow them to live under adverse conditions. Fungi are spread by spores moving in air currents, by growing in the soil, and as mycelium in association with transplants, perennial plants, insects, and seeds.

Signs and symptoms. Signs of fungi include the presence of pustules which produce spores, galls that later become dusty when mature, aggregated mycelia, spores and sclerotia. Fungal mycelium may also be associated with lesions or rot under moist conditions. Symptoms caused by fungi vary and may resemble symptoms caused by bacteria. Plant parts below the ground including seeds, emerging seedlings, and roots may become discolored and frequently rot. Aboveground parts display lesions of various shapes and sizes that may occur on any part of the plant from the cotyledonary, primary, to secondary leaves, and on the grain or fruit

Many diseases occur inside the stems, showing little outward evidence that the plant is diseased until it lodges, or when at harvest the discolored, rotten interior of the stalk or stem becomes evident. An overall wilting of the plant may occur with some vascular wilt fungi.

Disease cycle of soft rot (*Rhizopus* sp.) (Fig.10.7). The pathogen infects the fleshy organs of vegetables and other plants in the field, in transit, and in storage. The fungus overseasons as zygospores (sexually produced spores with thick walls) which germinate under conducive environmental conditions to produce sporangiospores.

These spores land on wounded storage tissue, germinate, grow, and cause the plant tissue to rot. Once sufficient growth has occurred, more sporangiospores are produced which reinfect more host tissue to cause multiple infections. Zygospores are produced when the food supply is diminished or when environmental conditions are unfavorable.

Plant-Pathogenic Nematodes

Nematodes are known as roundworms, threadworms, or eelworms. They live in soil, bottom of lakes, oceans, and rivers. They are second in number to insects in the animal world. Most nematodes feed on decaying organic matter (saprophagous), but others feed on small animals including other nematodes (predacious). Only a few nematodes are plant pathogens.

Crop losses due to nematodes on a worldwide basis is about 5%; however, losses may be as much as 25%-50% within a specific region or up to 100% in heavily infested fields. The significance of nematodes is often underestimated because they sometimes produce nondescript symptoms, and the losses they cause are difficult to quantify.

Classification. Their taxonomic position is in the Phylum Nemata. Two classes, Secernentea and Adenophorea, are separated based on morphological characteristics. Within each class there are several orders and subfamilies all of which are distinguished by their morphological features. To identify nematodes, they must first be isolated from infected plant roots or soil and then observed under a dissecting microscope. There are specific books and manuals that use morphological characteristics for identification.

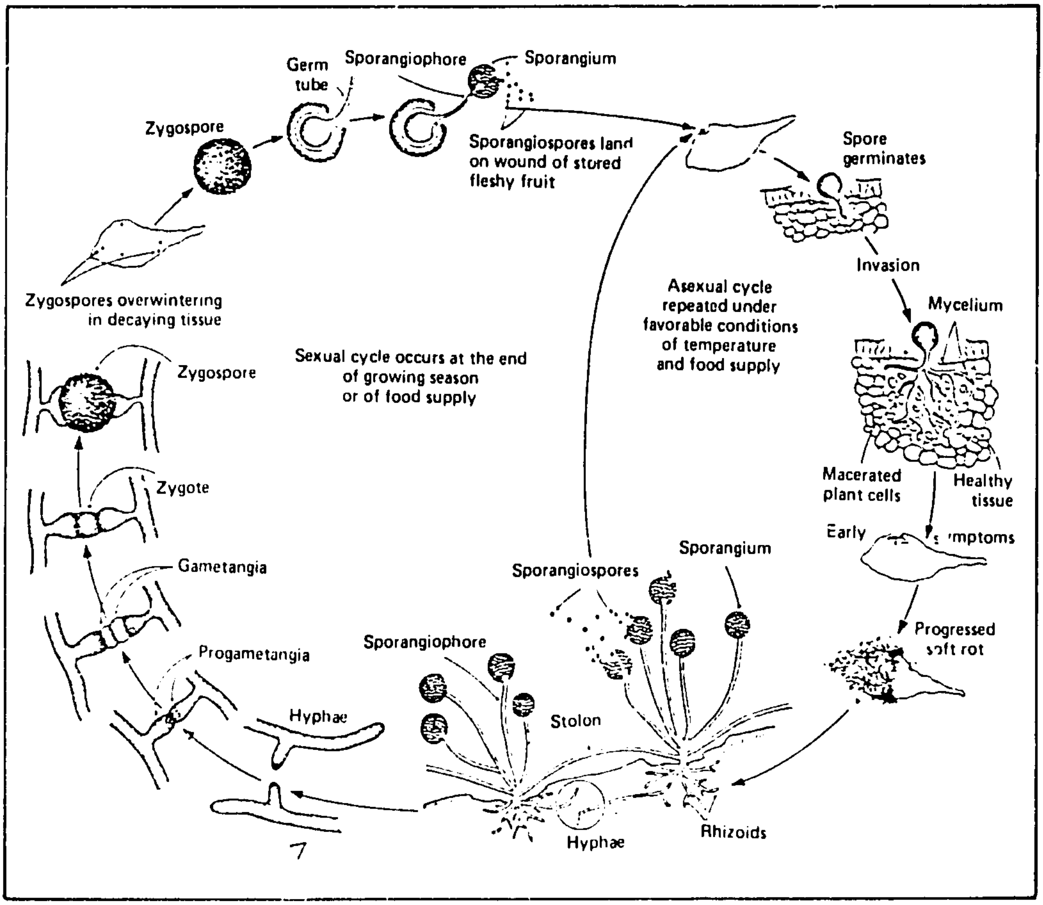

Fig. 10.7. Disease cycle of soft rot of fruits and vegetables caused by *Rhizopus* sp.

Morphology. They are typically elongated and their unsegmented cylindrical bodies become progressively smaller towards the head and tail (Fig. 10.8). The plant parasitic groups are found in the soil and vary in size from 0.5-2.0 mm; most can only be seen and studied under a microscope. Some nematodes become nearly round or kidney-shaped during their life cycle.

Ecology and spread. Plant pathogenic nematodes are specialized obligate parasites. Species differ in the kinds of plants that they attack. Some have a very wide host range, while others attack a limited number of host plants. Hosts of nematode species are often related botanically.

Nematodes are grouped according to their feeding positions and their mobility or nonmobility while feeding. According to feeding positions, they are 1) ***ectoparasites*** when they feed on the outside of roots by inserting only the style into the host cells; 2) ***semi-endoparasites*** when they feed by inserting part of their anterior end into the host cells; and 3) ***endoparasites*** when their entire body is embedded within the plant root.

According to mobility while feeding, nematodes may be migratory (moving from one feeding site to another) or sedentary and immobile (feeding at only one site). Within each mobility group, nematodes can be ectoparasites or endoparasites.

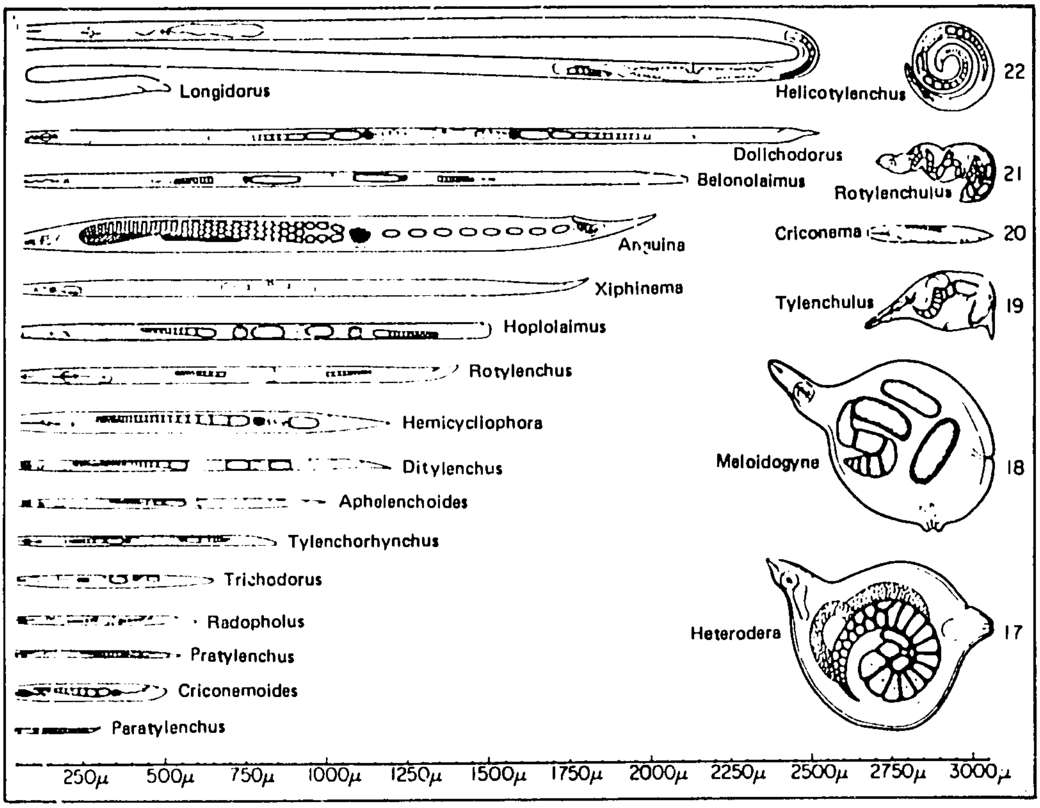

Fig. 10.8. Morphology and relative size of plant parasitic nematodes. (Agrios 1978)

As they feed or move through the tissues of their host, they cause mechanical injury by removing cell contents or destroying cell walls. They also cause chemical injury by injecting saliva-like substances that can suppress cell division in the apical meristem of the root, cause death of cells, form necrotic lesions; or result in the formation of giant cells and galls.

These injuries decrease the plant's ability to take up water and nutrients from the soil and thus lead to deficiencies in fruits, leaves, and stems. Plant-parasitic nematodes are usually a component of double or multiple infections. Nematodes play a complex role in their interactions with other microorganisms. Some act as vectors of other plant pathogens, such as viruses; while others cause wounds which degrade the general health of the plant and make it susceptible to infection.

Nematodes depend on soil water for survival and growth. Larvae and eggs of *Meloidogyne* species die in dry soil, but can survive in soil with 100% humidity. At lower humidity, hatching is inhibited (water is removed from the eggs) and the movement of larvae is restricted. In very wet soils, hatching may be inhibited and larval movement is slowed down because of lack of 0_2.

One of the major factors affecting behavior and distribution of plant-parasitic nematodes in soil is the root. Their quality and quantity influence the nematode's growth and reproduction. Nematode populations are highest when root growth is more vigorous; as root growth declines, the number decreases. Nematode movement in the soil is restricted to localized activities near the host plant.

Nematode larvae move through soil pore spaces. If the pore spaces are too small, as in clay soils, less damage is incurred than in sandy soils. Other factors such as the osmotic effects of chemicals dissolved in water, soil pH, root exudates, presence of microorganisms that are parasites and predators of nematodes, soil oxygen, and cultural practices may build up or reduce nematode popuiations.

Signs and symptoms. Most nematodes cannot be seen without a dissecting microscope, although some may be easily visible when they are large (*Longidorus* sp.) and in a mass. Symptoms of root diseases include root knot, lesions, prolific branching, and necrotic root tips. Aboveground symptoms of plants show yellowing, reduced growth. and general lack of vigor.

Disease cycle of root-knot nematode (*Meloidogyne* sp.). Members of this genus are referred to as root-knot nematodes and are common on most vegetable crops (Fig. 10.9). The hatched second-stage larvae leave the egg mass and move through the soil, guided by substances from the root, directly toward the root tip to penetrate just above the root cap. They come to rest with their heads in the developing stele near the region of cell elongation and their bodies in the cortex.

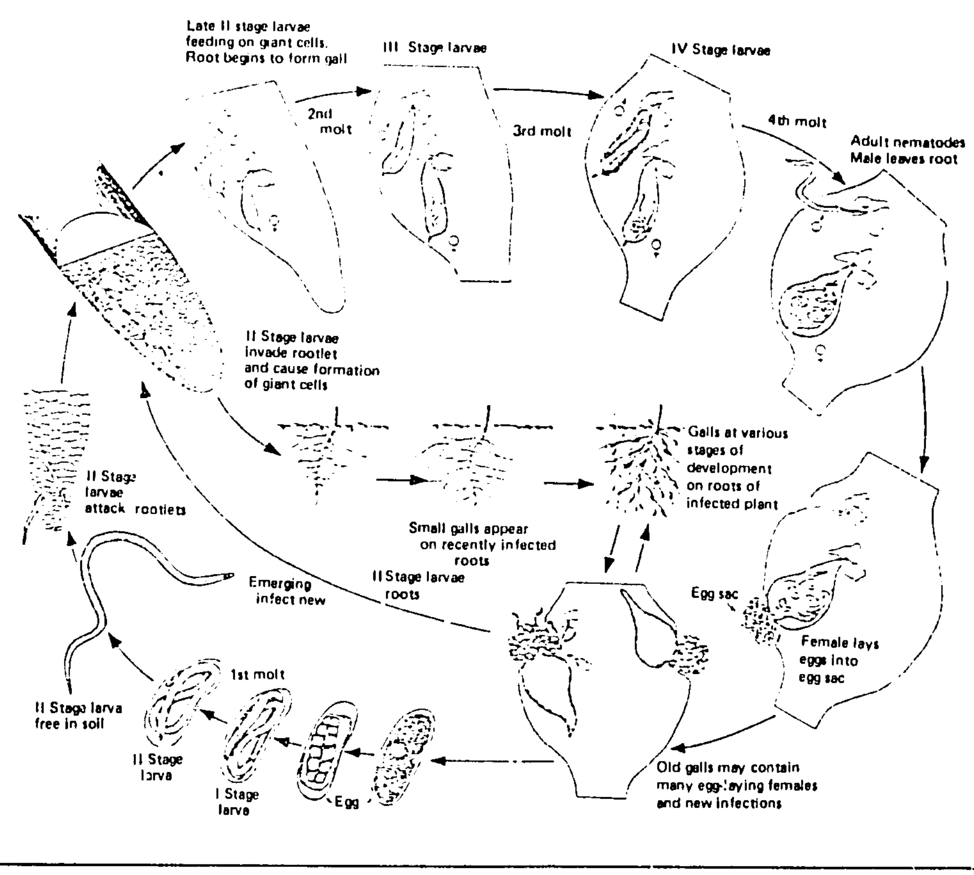

Fig. 10.9. Disease cycle of root-knot caused by nematodes of the genus *Meloidogyne*.

The cell walls are pierced by the stylet which secretes chemicals that enlarge plant cells in the vascular cylinder and increases the rate of cell division in the pericycle. Giant cells (syncytia), which cause the enlargement of the roots to form distinct galls, are formed. While the giant cells and galls are forming, the nematode continues to feed and grow into a flask-shaped adult.

Disease Development

There is a series of, more or less, distinct events that lead to disease development. This chain of events is called an ***infection cycle*** and involves physiological changes in the plant which result in symptoms (Fig. 10.10). At the same time, the host and pathogen interaction forms what is known as the ***disease cycle***.

The main events in the infection cycle include inoculation, penetration, infection, growth, and reproduction of the pathogen, followed by dissemination and overseasoning of the pathogen. This cycle can vary depending upon the causal agent, the host, and the environment. A description of the sequence of the infection cycle follows.

Inoculation. The portion of the pathogen that comes in contact with the plant is the ***inoculum***. The inoculum for bacteria are cells; for fungi, it may be fragments or mycelium, spores, or sclerotia; and for nematodes, it is the first- or second-stage larvae.

Penetration. Pathogens enter plant surfaces by direct penetration through natural openings or through wounds. Penetration may lead to infection when the host and pathogen are compatible.

- Direct penetration — Fungi penetrate their host plants directly by using a specialized hypha called a ***penetration peg***, which pierces the cuticle and cell wall. In most cases, the fungus penetrates the plant cuticle and the cell wall. Nematodes can enter plant roots through mechanical force by using their piercing stylet along with enzymatic secretions.

- Penetration through natural openings — Some bacteria and many fungi enter the plants through the stomata. Some fungi can penetrate closed stomata, but others enter only when these are open.

- Penetration through wounds — This is the primary mode of bacterial entry into the plants. Most fungi and nematodes can enter the plants through various types of wounds. The wounds may be fresh or old and may consist of lacerated or killed tissue. Fungi penetrating through wounds apparently germinate or multiply in the sap or moisture present in fresh wounds. The pathogens then invade adjacent plant cells directly or through haustoria, or secrete enzymes and toxins which kill and macerate the nearby cells.

Infection. Infection is the process by which pathogens establish contact with the susceptible cells or tissues of the host and procure nutrients. Pathogens grow and multiply within the plant tissues. Successful infections appear as discolored, malformed, or necrotic areas on the host plant. Some infections, however, remain latent, (the plant is infected, but symptoms are observed later when the environmental conditions change or when the plant's physiology is altered).

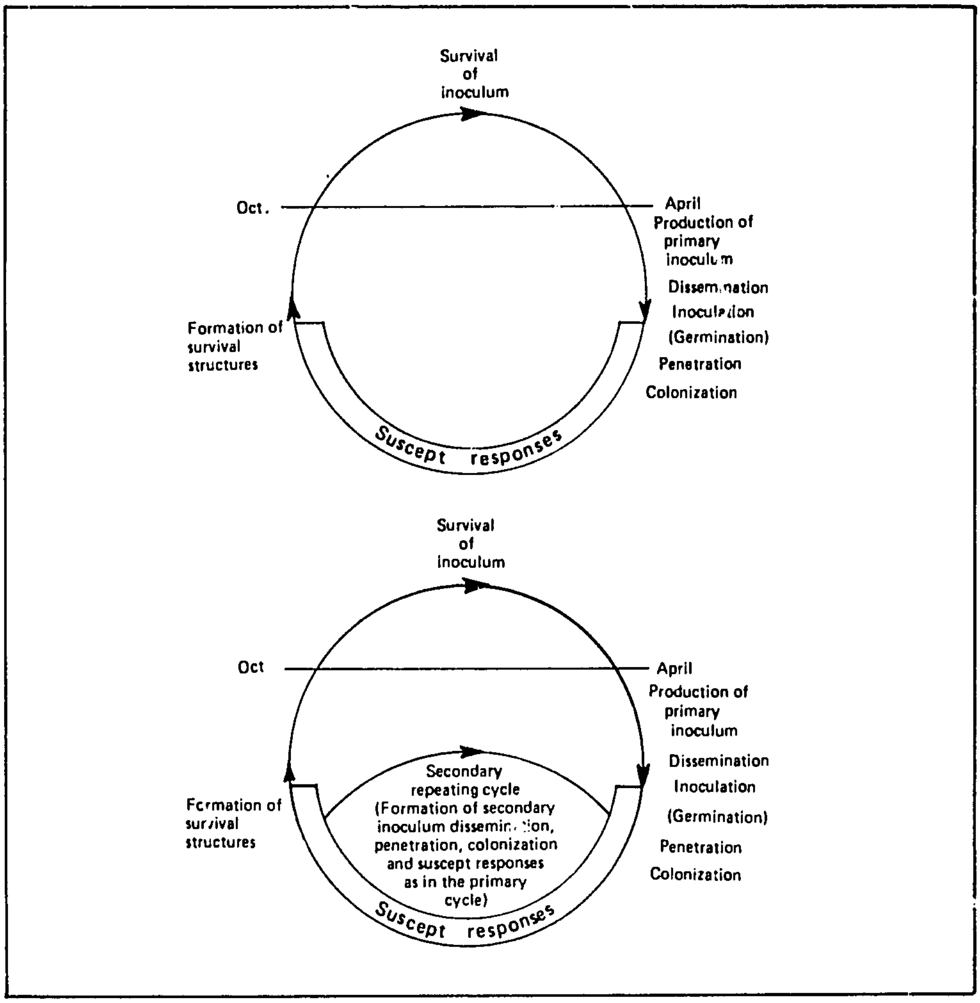

Fig. 10.10. Hypothetical cycles and component parts of a monocyclic disease (top) and a polycyclic disease (bottom), (Adapted from figures developed by W. Merill, The Pennsylvania State University.)

The time interval between inoculation and appearance of symptoms is called the ***incubation period***. The length of this period varies with the diseases and with the particular host and pathogen combination, the age of the host, and environmental conditions.

Growth of the pathogen. Individual infections developed from one initial point can result in symptoms. Growth of the pathogen spreads into healthy plant tissues until cellular conditions change or the plant is dead. Pathogens causing vascular wilts often invade plants by reproducing within the vessels. The cells or spores are carried in the sap stream and may invade vessels away from the initial point of entry.

Dissemination of the pathogen. Spread of the pathogen is usually a passive process aided by air, water, insect-contaminated seed, planting materials, man, and other animals. Most fungal spores are spread by air currents that carry them upward or horizontally, like smoke particles. The spores of some fungi, particularly those of the cereal rusts, are very hardy and occur commonly even at high altitudes (several thousand meters) above infected fields.

Dissemination over several hundreds of kilometers in favorable weather causes widespread epidemics. Wind also helps spread bacteria and fungi to other areas by blowing rain droplets containing these pathogens. It can also transport insects that harbor pathogens to new areas.

Dissemination by water is the primary dispersal mechanism of bacteria. Water (dew, irrigation, precipitation) spreads fungi in three ways:

1. Fungal propagules present in the soil are moved to the host.
2. Spores exuded in a sticky liquid are either washed downward or splashed in all directions.
3. Water droplets can pick up fungal spores in the air and wash them on plants. Although water is generally less effective than air in the long-distance transport of pathogens, it is vital since propagules need moisture for germination.

Dissemination may also be due to insects, mites, nematodes, and other vectors. Many insects become smeared with bacterial ooze or sticky fungal spores as they move among plants and carry propagules externally from plant to plant. Insects may spread pathogens over short or long distances, depending on the kind of insect, the insect-pathogen association, and the prevailing weather conditions, particularly of the wind. Mites, nematodes, and other animals also carry bacterial cells and fungal spores.

Man can transfer the pathogens over short or long distances. Within a field, pathogens may be spread through successive handling of diseased and healthy plants, by contaminated tools, through transportation of contaminated soil, etc. Man also spreads pathogens from infected transplants and seeds, contaminated containers, and imported food stuffs which are carriers.

Over seasoning and survival. On perennial plants, bacteria and fungi live in infected tissues like cankers, or infected areas of leaves, or on bud scales. Pathogens may survive in infected plant debris, in the soil, and in or on seeds and other propagative organs. In some areas, pathogens survive by continuously infecting host plants grown outdoors throughout the year, or by infecting plants grown in the greenhouse in winter and outdoors in summer. Nematodes survive in the soil in a state of reduced activity and metabolism.

Disease Assessment

Crop diseases are assessed and monitored to determine which pathogens are most prevalent, which cultivars are most susceptible, and which environmental conditions cause severe disease outbreaks. Objective assessments analyze how growth parameters affect the pathogen or disease under controlled conditions.

Subjective assessments are used in field trials at several sites over the years to measure disease incidence (number of plants infected) and disease severity (proportion of plants or plant parts infected). Visual assessment keys are classified into groups based upon observations taken from a plot, whole plants, individual leaves, or other organs.

In general, evaluating leaves with already prepared assessment keys is most successful, especially for standardizing and comparing results. Assessment keys can be specific for one disease or can be used for several diseases on the crop. Standard area diagrams have been developed to guide visual estimates of the area of plant parts infected with disease.

There are direct and indirect means of measuring disease areas on plant organs. Direct methods involve the use of photoelectric scanner techniques whereby recordings are made of areas of infected and uninfected tissues. The indirect means establish a measured image on which is overlaid the appropriate infected area by:

1. Drawing on squared paper areas which determine numbers of squares;
2. Photographic processes using diazo paper which, when exposed to strong light and then treated chemically, will reproduce the image of a leaf of the area to be established;
3. Air flow planimetry, whereby the area of an organ is established by causing it to impede the air flow into a vessel and measuring the impedance manometrically.

All assessments of disease levels should account for the growth stage of the host at the time of assessment. Such keys describe the various phases of development from emergence to maturity. Their construction and use are relatively straightforward for determinate crops. Most vegetable crops, however, are often indeterminate and biennial, making the construction of a key more arbitrary.

Epidemiology

Epidemiology is the study of how a disease develops in relation to the interaction of the pathogen, host, and environment over time. Disease-progress curves are used to visualize and evaluate disease development in a crop during a specified period of time. A monocyclic disease occurs when the pathogen has one life cycle per crop cycle. Disease within a crop season occurs due to an increased host-pathogen interaction resulting from host and pathogen growth and environmental changes. This type of development is observed with some soil-borne pathogens, some rusts, and smuts.

A polycyclic disease has more than one and usually many life cycles per crop cycle or season, and propagules of the pathogen produced after infection can reinfect the same host. This type of disease development is usually associated with airborne pathogens and is usually rapid in occurrence.

Disease Management

The practical reason for studying vegetable diseases is to develop economical disease-management control methods. Efficient, cost-effective control practices are often based upon specific host-pathogen interactions. Before deciding on how to best control a disease, it is important to understand the nature of the disease and its causal organism. Crop management, plant resistance, avoidance, exclusion, eradication, and protection (pesticides), are control categories. The first three are normally the best control methods because they are the least expensive and least dangerous to the grower.

Crop management. This includes practices such as crop rotation and sanitation. Crop rotation, like the use of paddy rice or dry fallow, can reduce the build-up of the inoculum of soilborne pathogens. Green manure, such as pangola grass or marigold and trap crops, can also reduce pathogen population.

Disease-resistant and tolerant varieties. The use of these varieties is usually the most economical method of controlling diseases. More than 85% of the vegetables planted have been bred for resistance to one or more diseases. In some cases where no resistant genes have been found, it is important to use tolerant varieties (yield is normal, but plants are susceptible). Ideally, developed varieties should be disease-resistant. However, pathogens often develop races and overcome resistance. In this case, it is often necessary to use alternative control methods.

Pathogen-free seed and planting materials. At all times it is most important to have seed or other planting materials which are initially disease-free. Certification programs and quarantines ensure disease-free planting materials.

Insect vectors and weed hosts. Insects are often responsible for spreading pathogens. Control of insects and other vectors is often necessary to maintain disease-free plants. Weeds can harbor pathogens, which allow them to overseason and survive until the next susceptible crop is planted.

Sanitation. For some diseases, it is very important to plow, burn, or remove crop debris, especially if the plants and plant parts were diseased. Addition of organic matter which increases biologic activity in the soil is known to decrease the number of soilborne pathogens. Intercropping and spatial arrangement of the crop within the field by proper row spacing and interspacing of plants can also help reduce diseases.

Chemical and seed treatments. Chemicals used to control plant pathogens include seed and foliar fungicides and soil fumigants (Table 10.1). Seed treatments, such as heat and fungicide-coating of seeds, are often used before planting. Soilborne pathogens, including nematodes, are controlled by metham sodium and methyl isothiocyanate. Methyl bromide is often used to control soilborne pathogens in the screenhouse or field soil.

Fungicide are commonly used to control foliar pathogens (Table 10.2). Spray schedules of five to seven days are often required; however, close monitoring of the disease, along with predictive models for disease development, can effectively reduce the frequency of spraying. Most fungicides are only slightly soluble in water, nonpersistent, and not very toxic to mammals. Fungicides are either protectants or systemic (the fungicide moves upward in the plant).

In most countries, pesticide use is restricted. Pesticides should always be used with safety regulations and label directions. Most fungicides may only be used up to so many days before harvest (Table 10.3).

Seed Rot and Damping-Off

Seed rot and decay in the soil can occur on any planted seed. Even after germination or after emergence, postemergence damping-off may be serious. Most diseases of this type are caused by fungi species of the *Pythium, Rhizoctonia*, and *Sclerotium* genera.

Control. The most effective control measure is to treat the seed and to spray seedlings and soil with a fungicide at frequent intervals.

Table 10.1. Registered fungicides for vegetable disease control.

Common Name	Trade Name(s)	Chemical name	Formulations	Approved Use
Anilazine	Dyrene Kemate	4, 6-Dichloro-N-(2-chlorophenyl)-1,3,5 triazin-2-amine	50% WP	Broad spectrum protective fungicide Effective against many foliage diseases. Registered for celery, cucumber, muskmelon,onion, potato, pumpkin, squash, tomato and watermelon
Benomyl	Benlate	Methyl 1-(butylcarbamyl)-2-benzimidazolecarbamate	50% WP	Protective and eradicant fungicide with systemic properties. Registered for beans (dry, lima and snap), celery, cucumber, muskmelon, squash and watermelon
Captafol	Difolatan	cis-N-(1,1,2,2-Tetrachloroethylthio)-4-cyclohexene-1,2-dicarboximide	80% WP 4 lb/gal. flowable	Broad spectrum, persistent protective fungicide. Registered for use on cucumber, muskmelon, potato, tomato and watermelon
Captan	Captan Orthrocide	N-(Trichloromethylthio)-4-cyclohexene-1,2-dicarboximide	50% and 80% WP 4 lb/gal flowable 3.5%-75% dusts	Protective and eradicative fungicide for seed treatment, soil drench, and foliar fungicide. Registered for use on beans, beets, carrots, celery, cucumber, eggplant, lettuce, muskmelon, onions, peppers, potatoes, pumpkins, rhubarb, spinach, squash, sweet corn, tomato, and watermelon
Chlorothalonil	Bravo Daconil	Tetrachloroisophthalonitrile	75% WP 6 lb/gal. flowable 20% exothermic powder	Broad spectrum fungicide registered for use on bean (snap), broccoli, cabbage, carrots, cauliflower, celery, cucumber, muskmelon, potato, pumpkin, squash, sweet corn, tomato and watermelon
Dicloran	Botran Allisan	2,6-Dichloro-4-nitroaniline	50% and 75% WP 4%-15% dusts	Used as a soil drench, foliar fungicide and post harvest treatment. Registered for use on snap beans, celery, lettuce, onion, potato, greenhouse rhubarb, cucumber, and tomatoes
Dinocap	Karathane Mildex Capryl	Mixture of 2,4-Dinitro-6-octylphenyl crotonate and 2, 6-Dinitro-4-octylphenyl crotonate	25% WP 4% emulsifiable concentrate	Specific for the control of powdery mildew. Registered for use on cucumber pumpkin, squash, and watermelon

Table 10.1 Continued.

Common Name	Trade Name(s)	Chemical Name	Formulations	Approved Use
Fentin hydroxide	Du Ter Fenolovo	Triphenyltin hydroxide	20% and 47.5% WP	Organic tin compound used as a foliar fungicide as a protective and curative treatment. Registered for use on potatoes only
Fixed Coppers	Tribasic Kocide C.O.C.S., etc.	Basic sulfates, oxychlorides, and oxides of metallic copper	53%-83% WP	Used for the control of bacterial diseases and certain leafspot problems. Registered for use on most vegetables except collards, mustard, parsley, radishes, rhubarb, sweet corn, sweet potatoes, and turnips
Folpet	Phaltan	N-(Trichloromethylthio) phthalimide	50% and 75% WP 5% and 10% dusts	Analog of captan. Registered for use on celery, cucumber, lettuce, muskmelon, onion, pumpkin, squash, tomato, and watermelon
Mancozeb	Dithane M-45 Manzate 200	Maneb + zinc ion	80% WP 4%, 8%-15% dusts	Broad spectrum fungicide for vegetables. Registered for use on asparagus, beans, carrot, celery, cucumber, muskmelon, onion, potato, squash, sweet corn, tomato, and watermelon
Maneb	Dithane M-22 Maneb 80 Manzate	Manganous ethylenebis-dithiocarbamate	70% and 80% WP 1%-20% dusts 4 lb/gal. flowable	Foliage protectant. Registered for use on asparagus, beans, broccoli, Brussels sprouts, cabbage, carrots, cauliflower, celery collard, cucumber, eggplant, endive, kale, muskmelon, onion, parsley, potato, pumpkin, radish, rhubarb (greenhouse), spinach, squash, sweet corn, tomato and watermelon
Metiram	Polyram	Polyethylene carbamate	80% WP 7% dust	Effective against several diseases but will not control powdery mildew. Registered for use on bean, celery, cucumber, muskmelon, potato seed pieces and tomato
PCNB	Terraclor	Pentachloronitrobenzene	35%-75% WP 4%-99% dusts 75%-63% paste	Used primarily as a soil fungicide and seed disinfectant. Registered for use on cabbage, peppers, potatoes, snap beans, and tomatoes
Thiram	Arasan Thylate, etc.	Tetramethylthiuram disulfide	90% WP 60% seed protectant 1%-75% dusts	Used as a seed protectant for prevention of seed decay, seedling blights, and damping-off

Table 10.1 Continued.

Common Name	Trade Name(s)	Chemical Name	Formulations	Approved Use
Zineb	Dithane Z-78 Parzate Polyram-Z	Zinc ethylenebis-dithiocarbamate	75% WP 4 lb/gal flowable 3%-15% dusts	Foliar protectant fungicide. Registered for use on asparagus, bean, beets, brocolli, Brussels sprouts, cabbage, carrot, cauliflower, celery, collard, cucumber, eggplant, endive, kale, lettuce, muskmelon, onion, pea, pepper, pumpkin, radish, spinach, squash, tomato, turnip, and watermelon

WP = wettable powder. E.C. = emulsifiable concentrate. F = flowable.

- Chinese cabbage — Seeds of Chinese cabbage and other crucifers should be either hot-water treated or certified by laboratory tests as free from black rot and blackleg-causing pathogens. A 15- to 25-minute heat treatment at 50°C will kill most pathogens. In the field, a combination of PCNB and Captan may be applied before planting by mixing it with the top 10 cm of the soil.

- Mungbean — Generally, seed treatments are not needed when high-quality seed is planted. If the seed has poor germinability or is planted in fields that had damping-off problems, in the past, then seed treatments are recommended.

- Pepper — Seeds should be treated with a fungicide slurry and flats should be sprayed with Captan. When peppers are grown for seed production or when bacterial leaf spot is a problem, then seed should be treated with a 1:4 solution of chlorox (5.25% NaOCl) and water for one to two minutes. Seed should be rinsed, dried, and treated with fungicide before planting.

- Soybean — Seed treatment is not normally needed when using quality seed. If seed quality is poor because of seed-borne fungi, then fungicides are useful and may help increase germination. Fungicides are used to treat seed.

- Tomato — Treat seed for 25 minutes at 50°C. Dry and treat with fungicide to protect against seed rot. After planting, treat soil with fungicide.

Chinese Cabbage Diseases

There are more than 30 Chinese cabbage diseases and most of these also occur on other crucifer crops. Two bacterial diseases (black rot and soft rot) and two fungal diseases (club root and downy mildew) are the most serious diseases of Chinese cabbage.

Table 10.2. Chemical control of vegetable diseases.

Crop	Disease	Symptoms	Suggested control
Peppers	Anthracnose and fruit rots in lesions	Tan or gray sunken lesions on fruit with pink fruiting bodies zineb 75% WP 2 lb/acre	Spray at 7-10 day intervals through harvest with maneb 80% WP 2 lb/acre or
	Bacterial spot	Dark brown raised lesions on leaves which turn yellow and fall. Rough, blister-like spots may develop on fruit	Use disease-free seed and apply 1.0-1.6 lb of copper (Fixed copper) per acre through flowering period, e.g., Kocide 101. After fruit set apply maneb 80% WP 2 lb/acre or zineb 75% WP 2 lb/acre
	Blossom-end rot	See Tomato	
	Cercospora Leaf spot	Small, circular, water-soaked spots on leaves enlarging to gray spots with reddish-brown	Same as anthracnose
Tomato	Early blight	Dark brown, circular spots with concentric rings on leaves. Lesions on fruit are dark brown	Use disease-free transplants. Follow crop rotation. Apply fungicides throughout the season at 7-10 day intervals using: maneb 80% WP 2-3 lb/acre or Bravo 6F 1 1/2-3 pt/acre or Difolatan 4F 4 pt/acre or Dyrene 50% WP 2-3 lb/acre or Polyram 80% WP 3 lb/acre or mancozeb 80% WP 2 lb acre
	Late blight	Water-soaked, brown to purplish irregular spots on leaves. Undersides of infected leaves develop a white mold under moist conditions. Fruits rots.	Same as Early Blight
	Gray leaf spot	Small brown spots with gray centers on infected leaves starting on oldest leaves. Leaves fall prematurely	Apply fungicides suggested for early blight
	Septoria leaf spot	Small, water-soaked circular spots on leaves and stems. Spots with gray centers and dark brown border. Small black fruiting bodies (pycnidia) develop in lesions.	Same as Early Blight
	Anthracnose	Water-soaked, sunken circular spots on fruit, usually with concentric rings. Fruit rot develops on ripe fruit	Start when first fruits develop and repeat at 10-day intervals throughout season, apply Folpet 50% WP 2 lb/acre or Bravo 75% WP lb/acre or mancozeb 80% WP 2 lb/acre or zineb 75% WP 2 lb/acre

WP = wettable powder. F = flowable formulation. 1 lb/acre = approximately 1 tbsp/gal water.
tsp = teaspoonful.

Table 10. 3. Tolerance restriction for vegetable fungicides and their suggested "cut-off dates.[a]

Fungicides	Cabbage	Peppers	Sweet Potato	Tomatoes
Benlate	X			X
Botran	X		X	X
Bravo				X
Captan		X		X
Difolatan				X
Dyrene				X
Fixed Copper		X		X
Karathane				X.5
Maneb		X		X.5
Mancozeb				X.5
Polyram		X		X
Terracolor		X	X	X
Thiram		X		X.5

[a]No number after X = no time limitation; numbers after X = days between last application and harvest.
Note: When using any of the above fungicides, check the label on the container and observe all precautions. A blank space in the above table indicates that the fungicides is not registered for the crop indicated.

Black rot (*Xanthomonas campestris* pv. *campestris*). Black rot is a very serious disease worldwide and since it spreads rapidly from one plant to another within the field, it can become very destructive.

Symptoms and disease development — Cotyledons of infected seedlings turn black, shrivel, and drop off. Initial infection on true leaves is a small wilted or yellowed V-shaped area at the margin (Fig. 10.11, See p. 285). The pathogen survives on crop debris and is seed-borne.

Control — Hot water treatment (soaking in hot water for 20 minutes at 50°C) may eliminate the pathogen. Resistant varieties have been developed and should be used whenever black rot is common in the locality.

Soft rot (*Erwinia carotovora* pv. *carotovora*). Bacterial soft rot is one of the most destructive diseases. This is prevalent from early to late in the season and develops rapidly under hot and humid conditions.

Symptoms and disease development — Initial infection is usually found on the outer petioles that are in contact with the soil at the 'wrapping' stage of the plants. The first symptoms on the petioles are water-soaking; tissues then become soft and watery or slimy as the rot progresses (fig. 10.12, See p. 285. Under low humidity, water is lost rapidly through evaporation and affected tissue dries up. The infected tissue gives off an offensive sulfurous odor which in part may be due to the growth of secondary bacteria.

Penetration normally occurs through wounds; however, uninjured plant parts may become diseased when they are water soaked or when the humidity approaches 100% and free moisture is present. Wounds are the most common avenue of infection. Harvest bruises, freezing injury, heat injury, and insect wounds are frequent predisposing factors. Several species of maggot fly are known to carry the organism.

Control — Avoid wounding plants during cultivation, harvest, packing, and storing. Spread of infection is retarded by using a sterilized trimming knife and by eliminating and disposing diseased produce before it comes in contact with healthy materials. Careful handling of the product to avoid mechanical injuries and separating injured or bruised ones are important control measures.

Sometimes the pathogen is disseminated by an insect vector, such as the striped flea beetle (*Phyllotreta striolata* Fabricius), common white butterfly (*Pieris rapae crucivora* Boisduval), and cabbage armyworm (*Mamestra brassicae* Linne).

The use of resistant cultivars is recommended. Shimizu and his colleagues (1958) cultivated 82 Chinese cabbage cultivars in the fall from 1952 to 1955 and ten cultivars in the spring from 1953 to 1955. They succeeded in breeding by interspecific crossing a Chinese cabbage cultivar, Hiratsuka No. 1, which is highly resistant to soft rot.

Alternaria leaf spot (*Alternaria brassicae*). This disease is also known as black or gray leaf mold. Losses occur from seedling damping-off and loss in quality of the produce is sustained because of spotting of the leaves.

Symptoms and disease development — The first symptoms that appear are minute dark spots on the seedling stem. The disease is later characterized by distinct spots with concentric rings on the lower leaves (Fig. 10.13, See p. 285). A dark dusty fungal growth develops on these spots during moist periods. The pathogen overwinters in seed and in residue of diseased plants. Wet conditions promote disease development.

Control — Use fungicide protectants and varieties that are less susceptible.

Club root (*Plasmodiophora brassicae*). This disease occurs worldwide and the pathogen infects most cruciferous crops.

Symptoms and disease development -- The disease causes yellowing and wilting of aboveground parts and large spindle-shaped galls on the roots. The pathogen is soilborne and persists in the soil for up to seven years. There are numerous races that occur. Soil pH of less than 7.2 favors disease development.

Control — Cultural controls, like eradication of crucifer weeds, long rotations, using disease-free seedbed and soil, and increasing the pH are all useful controls. Some chemicals, like PCNB, are somewhat effective. Development of resistant varieties is difficult to utilize in Chinese cabbage.

Downy mildew (*Peronospora parasitica*). Downy mildew is one of the most destructive foliar diseases of Chinese cabbage and other crucifers. The pathogen has a wide host range, and the reactions of the cruciferous hosts have been used to determine physiological specialization

Symptoms and disease development — The symptoms are small yellow leaf spots of indefinite size and shape. These spots later turn brown with bluish-black ace-like markings (Fig. 10.14, See p. 286). The lesions which are on the lower leaf surface are covered with a white downy mold of conidia and conidiophores. The pathogen overwinters on seed, in crucifer weeds, and perhaps in the soil. The disease is promoted by the cool, wet weather in spring, fall, and winter.

Control — Eliminating weed hosts and use of disease-free transplants along with protectant fungicides have helped control the disease. Use of resistant varieties like, 77M(3)-27 and 77(M)-35, are recommended.

Mungbean Diseases

Cercospora leaf spot (*Cercospora canescens*). Symptoms and disease development — Leaf spots are circular to irregularly shaped with tan or gray centers and reddish brown to dark brown margins (Fig. 10.15, See p. 286). Disease is favored by warm moist weather. The pathogen overseasons on crop debris and weed hosts.

Control — Use fungicide protectants and sanitation.

Sclerotium blight (*Sclerotium rolfsii*). Symptoms and disease development — Wilting, decay of basal portion of stem with white cottony mycelium on stem and soil are observed. There is abundant pink to reddish-brown sclerotia associated with the white mycelium. Sandv soil and high air and soil temperatures favor disease.

Control — This disease is difficult to control; however, it seldom causes major economic loss. Some resistance is identified. Deep plowing is recommended.

Powdery mildew (*Erysiphe polygoni*). Symptoms and disease development — Leaves have large irregular spots that are initially yellow, then turn brown. Under severe disease pressure, defoliation occurs. Often, white powdery spots of fungal mycelium and conidiophores grow over the spots and may cover the entire leaf (Fig. 10.16, See p. 286). The disease is favored by cool (20°-26°C) weather that is less humid. The fungus has a wide host range.

Control — High levels of resistance are available, but may not be present in commercial cultivars. Use fungicide protectants.

Leaf blight or web blight (*Thanatephorus cucumeris*). Symptoms and disease development—Leaves rapidly become necrotic and dry (Fig. 10.17, See p. 286). Under humid conditions, webs on fungal hyphae cover leaves of both healthy and necrotic areas. Defoliated leaves often remain attached to plant by a thread of mycelium. Warm temperatures and very high humidity favor epidemics.

Control — Total control is difficult, but use of fungicides can slow down disease development.

Scab (*Elsinoe iwatae*). Symptoms and disease development — Round to elliptical lesions occur on leaves, petioles, and stems. The center of the lesion is grayish-white while the margins are reddish-brown (Fig. 10.18, See p. 287). Lesions, 3 mm in diameter, are usually raised. Disease is favored by warm and wet weather. Apparently, this disease is serious only in Indonesia.

Control —Use protectant fungicides.

Pepper Diseases

Bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*). Bacterial spot is a serious problem in most locations where pepper is grown, especially under warm, humid environments. Early infection can result in heavy fruit infection and complete loss of the crop. Disease severity varies with the time of primary infection and may extend from loss of a few lower leaves to complete defoliation of susceptible cultivars.

Symptoms and disease development — Leaves, stems, and fruits are affected. Leaf spots first appear as small, circular, pale green spots that are often associated with water soaking (Fig. 10.19, See p. 287). Spots enlarge and the number increases; defoliation occurs. Fruit spots are conspicuous and are usually raised and looked wart-like.

The bacterial spot organism is endemic in warm, humid environments. A primary source of inoculum is the infection on volunteer peppers and tomatoes. Inoculum dispersal is aided by a continuum over time of pepper and tomato crops in many regions, and frequent wind-driven rains.

Control — Control methods for pepper are similar to those of bacterial spot for tomato. Disease control depends on the use of bacterial-free seeds and seedlings, and sprays with copper and mancozeb mixture. However, the most strictly applied spray regime is expected to be less effective than genetic resistance to the pathogen. There are currently four races and there are no commercial varieties resistant to them.

Anthracnose (*Collectotrichum gleosporioides* and *C. capsici*). Anthracnose can become very destructive in localized areas.

Symptoms and disease development—Circular sunken spots on green and ripe fruits are found with pinkish to yellowish masses of glue-like spores (Fig. 10-20a and b, See p. 287 and 288), sometimes accompanied by tiny black bristles (setae). The pathogen overwinters in pepper seed and in residue from diseased plants. Disease is promoted by wet conditions (heavy fog, dew, drizzle) and relatively high temperatures.

Control — Use fungicide protectants and less susceptible varieties.

Phytophthora blight (*Phytophthora capsici*). Under certain conditions this disease is known to reduce yields greatly because it can kill the entire plant or major branches of the plant.

Symptoms and disease development — Root rot, stem canker, leaf blight, and fruit rot are all symptoms (Fig. 10.21, See p. 288) which may be bordered by a white growth of the fungus. The disease most frequently appears in the wettest areas of a field; and its development is favored by warm, wet weather.

Control — Use resistant varieties, fungicide protection, and rotation.

Tomato Diseases

Bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*). The disease is most noticeable on the fruit, but it also causes considerable damage to the foliage and stems. Bacterial spot of tomato is most common in seasons with frequent rainy periods. The disease is very destructive on seedlings and spreads rapidly in seedbed.

Symptoms and disease development — Leaflets show small, one-eighth inch, irregular, dark, greasy-looking spots. The centers dry out and frequently tear. Stems of seedlings are also spotted. Severe infection causes defoliation. Flower parts also are infected and considerable blossoms may drop. The most striking symptoms occur on the green fruits as small, water-soaked spots which become slightly raised and enlarge (Fig. 10.22, See p. 288) until they are 3-6 mm in diameter.

At first the spots have greenish-white halos. The centers of the spots become irregular, light brown, and slightly sunken with a rough, scabbing surface. They do not extend very deeply into the fruit. Seed from infected fruit may become contaminated during extraction. Much of the primary infection can be traced to the seed, but there is some evidence that the organism can overseason in the soil.

Moist weather favors infection, and there is often widespread dissemination of the organism in the field after a driving rain. Leaf infection occurs through natural openings (stomata) or wounds. Fruits have no stomata and are infected through injury from wind-blown sand, insect punctures, or other slight wounds on the surface. Commonly, fruits are severely spotted on the windward side after a blowing rain.

Control — Baterial spot is difficult to control once it appears in the field; hence, it is important to prevent infection of the seedlings. Since the bacteria can be present on the seed, control of the disease depends on the use of bacteria-free seed. If possible, do not locate seedbeds on areas previously infected by this disease.

If permanent beds are used, disinfect the soil with fumigants. Spray the seedbed with fixed copper fungicides to control the disease. Even after the disease has appeared in the field, it can be controlled with copper fungicide if the weather is reasonably dry. Breeding for resistant varieties is most useful for controlling the disease; however, because of the races of the pathogen, resistance is not universal.

Bacterial wilt (*Pseudomonas solanacearum*). Bacterial wilt is widely distributed and damaging in the tropics, subtropics, and warm regions of the world. It can be a limiting factor in the production of tomato.

Symptoms and disease development — Tomato plants that are infected rapidly wilt (Fig. 10.23, See p. 288) especially during the warmest part of the day. Stunting frequently precedes the wilting, and leaflets and leaf stalks may curl downwards. A large number of adventitious roots are produced along the stem above the ground when the disease develops slowly. If the stem on an infected plant is cut horizontally at the soil line, a brown discoloration of the water-conducting tissues just beneath the bark is evident. A milky exudate is also apparent if the end of the cut is placed in water.

Control — Improved cultural practices and the use of clean planting materials greatly contribute to the reduction in the incidence of bacterial wilt. Recommended practices include the burning of infected plants, use of clean equipment, removal of other solanaceous crops or weeds, and allowing the soil to dry for several months. Avoidance of the disease is possible through the use of bacterial-wilt-free planting materials, rotation with nonhost plants, and flooding of the area to be planted.

Recent research in biological control with antagonistic bacteria, such as *Bacillus polymyxa*, *Pseudomonas fluorescens*, and avirulent mutants of *P. solanacearum* has shown some success. Some resistant varieties are available from the breeding programs in the Philippines, AVRDC, and some commercial breeding companies.

Cercospora leaf spot or black leaf mold (*Pseudocercospora fuligena*). Symptoms and disease development — The initial symptom is a yellow spot which turns dark as black mold develops on the spot (Fig. 10.24, See p. 289). The lesion enlarges and becomes dark brown on both leaf surfaces, and under severe infection the leaves turn dry. Black mold occurs on the upper and lower leaf surface and the lesion color is darker than leaf mold caused by Fulvium fulva. Plants grown in poorly ventilated greenhouses along with high temperatue favor infection. The pathogen overseasons on the debris of infected plants.

Control — The use of fungicide protectants and less susceptible varieties is recommended.

Early blight (*Alternaria solani*). Symptoms and disease development — Dark brown spots with dark concentric rings develop first on oldest leaves (Fig. 10.25, See p. 289). Spotted leaves die prematurely causing early defoliation. On green or ripe fruit, spots usually begin at the stem end and develop into a black leathery sunken area, often with dark concentric rings.

The pathogen overwinters in the residue of diseased plants, where it can persist for at least one year. The fungus is seed-borne and can be introduced on seed and on transplants. The disease occurs under a wide range of weather conditions. It is favored by heavy dews and rainfall and is severe on plants of poor vigor.

Control — Use of fungicide protectants and less susceptible varieties.

Late blight (*Phytophthora infestans*). Symptoms and disease development — Symptoms appear on foliage and fruit as irregular, greasy-appearing grayish areas that expand rapidly during moist conditions (Fig. 10.26, See p. 289). A white, downy mold appears at the margin of the affected area on the lower surface of the leaves. Infection of the fruit occurs most commonly on the upper half of the green fruit as grayish green, water-soaked sports enlarging to an indefinite size and shape. Affected areas become dark brown, firm, wrinkled, and with a relatively definite margin.

Diseased specimens can be put into a polyethylene bag containing a moist paper towel (supply moisture) and held for one day to promote the growth of white downy mycelium of the fungus. The fungus can be isolated and identified on V-8 juice agar. The disease may be introduced to tomato fields on transplants or may be windborne from diseased potato or tomato in nearby fields. Disease development is promoted by cool, wet conditions. The pathogen overwinters in the winter crop of potato or tomato.

Control — Do not plant tomatoes after potato in the same field. Use fungicide protectants and less susceptible varieties.

Leaf mold (*Fulvium fulva*). Symptoms and disease development — The first symptoms appear on the upper side of older leaves as yellowish, light green blotches. Purplish or olive-green mold appears on the lower side simultaneously with the yellowing on the upper leaf surface. Later, the infected lower leaves of the plant turn yellow and drop off. The purplish or olive-green color of the fungus distinguishes this disease from Cercospora leaf spot. The pathogen is spread by air currents. A humidity greater than 90% activates the fungus. The disease develops very quickly between 20°-27°C.

Control — Use fungicide protectants and resistant varieties.

Powdery mildew [*Leveillula taurica (Oidiopsis taurica)*]. Symptoms and disease development — On old leaves, a yellow and blotched area appears and later, the tissue turns brown and the leaf dries up. Dried, infected leaves usually remain attached to the stem. On both upper and lower leaf surfaces a fine, powdery growth may develop, which gives the leaves a white or purplish appearance (Fig. 10.27, See p. 290). This powdery growth constitutes the conidia and conidiophore. The spores of the pathogen can travel long distances on the air currents and are able to germinate under low relative humidities. The disease develops quickly in a warm and dry environment.

Control — Use fungicide protectants.

Southern blight *(Sclerotium rolfsii)*. Symptoms and disease development — Wilting and decay of the basal portion of stem are evident. The stem at the soil line displays a brown soft rot, usually covered with a whitish, cottony mold embedded with tiny brown sclerotia (Fig. 10.28, See p. 290). The pathogen survives from season to season as sclerotia in soil. It can be spread through running water, soil, tools and implement seedling, and as sclerotia on the seed. Disease development is enhanced by high temperature and high humidity.

Control — Sanitation is important, along with crop rotation with nonhosts, and the use of soil fungicides.

Target spot (*Corynespora cassiiola*) Symptoms and disease development — First symptoms appear as small necrotic spots which expand and are surrounded by halos. The necrotic area shows clear concentric rings much like a target spot. The lesions are larger than those of early blight. Spore identification is necessary to distinguish this pathogen from *Alternaria* that causes early blight. High temperature and humidity favor infection and development of the disease. The conidia move by wind, air, and rainfall. The pathogen overseasons in the residues of diseased plants.

Control — Use fungicide protectants and resistant varieties.Observe sanitation.

Soybean Diseases

Bacterial blight (*Pseudomonas syringae* pv. *glycinea*). The pathogen produces green fluorescent pigment on some media and grows in vitro at 24°-26°C.

Symptoms and disease development — The pathogen infects cotyledons, leaves, stems, and pods. Lesions are initially small, water-soaked, translucent, and angular. Leaf lesions enlarge to form yellow to light-brown discolored centers that are dark, red-brown or black and surrounded by chlorotic halos. Lesions coalesce to form large, irregular necrotic areas which often drop off.

Infected growing points often result in a blight that kills seedlings. Lower leaves defoliate following early infection. Infected pods may cause symptoms on seeds that are slightly discolored, shriveled, and with sunken lesions; or there may not be any symptoms at all.

The bacterium overseasons in seeds and debris from infected plants and may cause infection of cotyledons. Inoculum from these lesions spread by wind and rain and result in secondary infections on leaves, stems, and pods. Bacteria may survive on leaf and bud surfaces and later cause infection when it rains and when other environmental conditions are conducive to disease development.

Control — Plant only seed from healthy plants. Cultivate or hoe the field only when the foliage is dry. Debris remaining after harvest should be destroyed or covered completely by plowing. A three-year crop rotation is practiced to decrease inoculum. Weekly applications of streptomycin sulfate at 250 ppm control the disease. Plant introduction (PI) 68708 from Manchuria is resistant to race 1 of *P. glycinea.*

Bacterial pustule (*Xanthomonas campestris* pv. *phaseoli*). Svmptoms and disease development — Bacterial pustule is caused by *Xanthomonas campestris* pv. *phaseoli* (Smith) Dye. The pathogen enters through the stomata and causes hyperplasia, enlargement and rupture of cells, and pustule formation.

Early symptoms of pustule are small, pale green spots with elevated centers usually confined to and most conspicuous on the lower leaf surface (Fig. 10.29, See p. 290). They seldom reach more than 1 mm in diameter, yet they may become confluent and cause large brown patches of dead leaf tissue. Leaves severely affected are often torn by the wind, giving them a rugged appearance. The plant may also suffer serious defoliation. Infection on pods causes small, red-brown spots that are usually slightly raised.

Dissemination is mostly done by a driving rain, but it can be carried from plant to plant during cultivation when the foliage is wet. Inoculum may be carried by the seed and remain viable for more than two years after harvest; but bacteria also persist in debris from infected plants, as well as on various weeds, including *Brunnichia cirrhosa* and *Dolichos biflorus.* Disease development is favored by warm temperature of 30°C or higher for substantial periods during the daylight hours.

Control — Plant resistant varieties.

Rust (*Phakopsora pachyrhizi*). Soybean rust is widely distributed in the East Hemisphere and reduces yields throughout the tropical and subtropical regions of Asia.

Symptoms and disease development — Tan, dark brown, or reddish brown lesions, 2-5 m^2, occur on leaves (Fig. 10.30, See p. 291). Severe infection causes leaf yellowing, defoliation, and early maturity. Temperatures below 28°C and prolonged leaf wetness favor the disease.

Control — No commercial cultivars have high levels of resistance, but several others are known to have some resistance. Fungicides will protect plants against rust when applied frequently.

Downy mildew (*Peronospora manshurica*). The disease occurs where soybean is grown, but it does not generally cause yield reduction.

Symptoms and disease development — On the upper leaf surface, pale green to light yellow spots appear then enlarge into pale to bright yellow lesions of indefinite size and shape (Fig. 10.31, See p. 291). The lesions on the lower leaf surface are covered with tufts of grayish or pale purple conidiophores. Temperatures of 20°-22°C and humid weather favor disease. Pathogen overseasons in plant material or on seed. Over 25 physiological races were identified; however, resistance is available to all known races and it is controlled by a single gene.

Control — Use resistant cultivars, treat seeds with fungicide, and practice sanitation and crop rotation.

Purple seed stain (*Cercospora kikuchii*). The disease occurs where soybean is grown. Normally it does not cause any yield reduction.

Symptoms and disease development — The disease is most conspicuous as pink to dark purple discoloration of seeds (Fig. 10.32, See p. 291); leaves and other plant parts are also infected. Reddish, angular, pinpoint to 1 cm lesions occur on leaves. Temperatures of 28°-30°C, humid weather, and rain late in the season favor the disease.

Control — Plant moderately resistant cultivars, sow quality or disease-free seed, and treat seed with fungicide.

Anthracnose (*Colletotrichum truncatum* and several other species). Anthracnose occurs where soybean is grown. The disease reduces seed germination, seed quality, and yield.

Symptoms and disease development — Symptoms typically appear in the early reproductive stage on stems, pods, and petioles as irregularly shaped brown areas (Fig. 10.33, See p. 292). Foliar symptoms that develop after prolonged periods of high humidity include necrosis of laminar veins leaf rolling, petiole cankering, and premature defoliation. Preemergence and postemergence damping-off may occur when infected seeds are planted. Dark brown, sunken cankers often develop on the cotyledons of emerging seedlings.

Minute black fruiting bodies (acervuli) occur on infected tissues. The pathogen can overseason as mycelium in infested crop residue or in infected seeds. Inoculum from infected seeds and debris may cause preemergence and postemergence damping-off of seedlings. Stem and pod infections predominantly occur in the reproductive stages during warm, moist weather. Plants are susceptible to infection by the pathogen at all stages of development, particularly from bloom to pod fill. Infections typically occur if rain, dew, or fog provides moisture for periods of 12 hours or more.

Control — Sow disease-free seeds, treat infected seeds with fungicide, plow crop residues under, spray with fungicides between bloom and pod-fill stages, and rotate soybean with other crops.

Charcoal rot (*Macrophomina phaseolina*). The fungus is found in most soils where soybean is grown. The disease is more damaging under dry soil conditions.

Symptoms and disease development — Infected seedlings may show a reddish brown discoloration at the emerging portion of the hypocotyl. After flowering, a light gray or silvery discoloration of the epidermal and subepidermal tissues develops in the taproot and the lower part of the stem. Sclerotia form in the vascular elements and may block water flow. Frequently, sclerotia are produced in the pithy area of the stem. They may be so numerous that they give a grayish black color resembling a sprinkling of finely powdered charcoal, to the tissues beneath the epidermis.

Sclerotia on aboveground parts are first visible in stem nodes and pith tissues of the stem as profuse, small, black randomly distributed specks. Sclerotia survive in soil or in host residues; in dry soils for long periods. A large percentage of seeds may carry the pathogen in the seed coat. The disease is not evident at low temperature, but the pathogen begins to grow and symptoms appear between 28° and 35°C. The rate of infection increases with higher soil temperatures. Low soil moisture further enhances disease severity.

Control — No resistant cultivars exist. To keep soil moisture high, irrigate or flood fields for three to four weeks before planting. In severely infected fields, rotate with comparatively poor hosts, such as cereals or cotton, for one or two years; with maize or grain sorghum, for three years.

Pod and stem blight [*Diaporthe phaseolorum* var. *sojae (Phomopsis sojae* and *P. longicolla)*]. The disease occurs where soybean is grown. Warm and wet weather favors its spread.

Symptoms and disease development — Stems, petioles, pods, seeds, and less frequently leaf blades may be infected. The pathogens can first be detected in the field as pycnidia on petioles of abscised leaves or on broken branches. Dead stem may be covered with speck-sized pycnidia, usually arranged linearly or may be limited to small patches, generally near the nodes.

Pycnidia are also scattered on dry, poorly developed pods (Fig. 10.34, See p. 292). Heavily infected seeds are badly cracked and shriveled and are frequently covered with white mycelium. Speck-sized pycnidia are arranged linearly on stems, petioles, and pods on mature and diseased plants.

The pathogen overseasons as dormant mycelium in soybeans, host debris, and in infected seeds. Disease spread in the plant is caused by infection from conidia dispersed by splashed water. Only infections that are initiated in pods can infect seeds and cause seed decay. Most seed infection occurs during or after the yellow pod stage (R7). Prolonged wet periods during pod development and maturation and warm weather (above 20°C) favor the spread of the fungi from the pod to the seed. Seed decay is the most critical phase of pod and stem blight. Diseased seeds are an important source of primary inoculum for long-range dissemination.

Control — Resistant cultivars are not available. Rotate soybean with a nonhost and plow down residues. Plant disease-free seeds or use a fungicide seed-dressing.

Apply fungicides to pods from mid-flowering (R3-R4) to the late pod stage (R6-R7) to lower the incidence of seed infection, and harvest soybeans promptly at maturity.

Root rot and seedling blight (*Rhiuzoctonia solani*). The pathogen is cosmopolitan and occurs on many different plants.

Symptoms and disease development — Red brown to dark brown stem lesions are found at soil line. Stems are constricted at the lesion. Later symptoms are the brownish, stringy decay of stem. Roots are seldom affected. Wilting of plants is also observed.

Sparse, coarse mycellium may be visible. The fungus is a soil-inhabitant and a good saprophyte. Disease is favored by warm (25°-29°C), wet, and poorly drained soils.

Control — Use fungicide seed protectants, increase soil drainage, and plant less susceptible cultivars.

Root rot and seedling blight (*Pythium sp.*). The species involved cause seed decay, preemergence and postemergence damping-off, and root rot. The disease occurs in almost all soils.

Symptoms and disease development — Emergence of black wet rot of stem and roots are visible (Fig. 10.35, See p. 292). The entire plant parts below the ground are attacked. Cortical tissues may be removed and cause wilting of plants.

The fungus is a soil-inhabitant and a good saprophyte. Low soil temperatures and wet conditions (low oxygen levels in soils atmosphere) favor the disease.

Control — Plant in warm well-drained soil, avoid excess irrigation within ten days of planting, and use fungicide seed protectant.

Sclerotium blight (*Sclerotium rolfsii*). Symptoms and disease development — Wilting and decay of the basal portion of stems are observed. White cottony mycelia on stem and soil are present. There is abundant pink to reddish-brown, small, sclerotia associated with mycelium. Culture is not necessary. Sandy soil and high air and soil temperatures favor disease.

Control — This disease is difficult to control but it seldom causes major economic loss. Some resistant varieties are identified. It needs deep plowing.

Sweet Potato Diseases

Scab (*Elsinoe batatas*). Symptoms and disease development — Distinctive lesions are round or elongated with raised edges, giving a scabby appearance to petioles and stems (Fig. 10.36, See p. 292). Wrinkled, cupped, and deformed leaves result in reduction not only in the size of leaves but also in total effective leaf area for photosynthesis. Lesions also occur on the lower surface of the leaf, as well as on the petioles and stem. High temperature and high humidity favor the infection and development of the disease. The conidia of the pathogen are transmitted by air current, seedlings, and infected cuttings.

Control — Use disease-free seedlings and protectant fungicides.

Rhizopus soft rot (*Rhizopus stolonifer*). Symptoms and disease development — The disease begins as a soft, watery rot which progresses rapidly in the flesh tissue. A sweet potato root may be completely rotten within four or five days after infection becomes visible. The fleshy tissue becomes soft and stringy, and water exudes readily when the skin is broken. The tissue turns brownish in color, and a mild odor is noticeable. As the skin is broken, the grayish sporangiophores mycelium and dark-colored sporangia develop very rapidly, producing a coarse whiskery growth.

The fungus survives on crop debris between crop seasons. Infection is influenced by the environment and host reaction.Optimum temperature for growth on culture is 23°-26°C. The growth of the pathogen increases with temperature, but it is offset by an increase in protective action of the host tissue. The optimum for disease development, therefore, is lower.

Control — Sanitation along with proper environmental regulation of the storehouse is important. Avoid wounding roots at harvesting.

Black rot (*Ceratostomella fimbriata*). Symptoms and disease development — Symptoms appear on the foliage and fleshy roots. The foliage appears yellowish and sickly. On fleshy roots, depressed circular spots of various sizes develop. The spots are grayish black when dry and greenish black when moist. A shallow, dry decay extends to the depth of the vascular ring. The pathogen overseasons in diseased roots and in soil. Disease development is promoted by moist soil conditions.

Control — Select healthy roots for propagating purposes. Dip roots in fungicide, i.e., ferbam.

Fig. 10.11. Black rot (Chinese cabbage).

Fig. 10.12. Soft rot (Chinese cabbage).

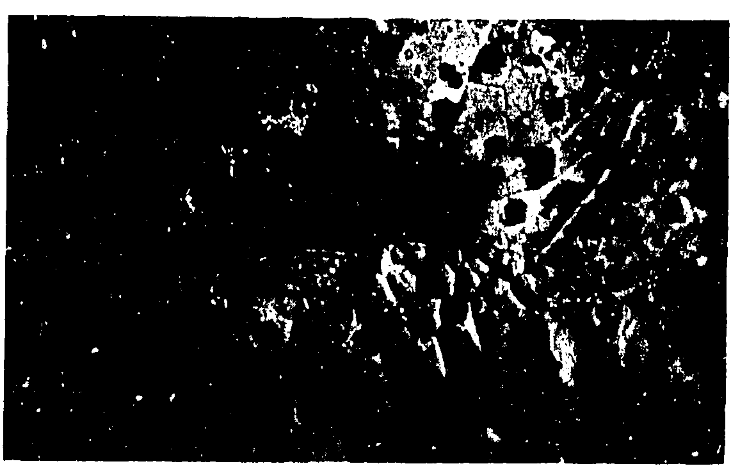

Fig. 10.13. Alternaria leaf spot (Chinese cabbage).

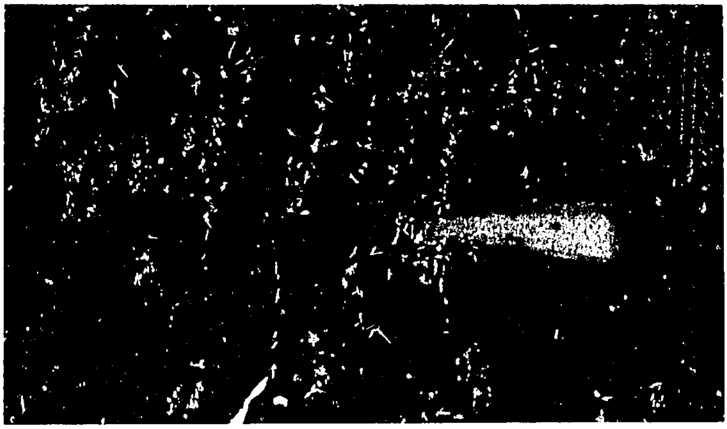

Fig. 10.14. Downy mildew (Chinese cabbage).

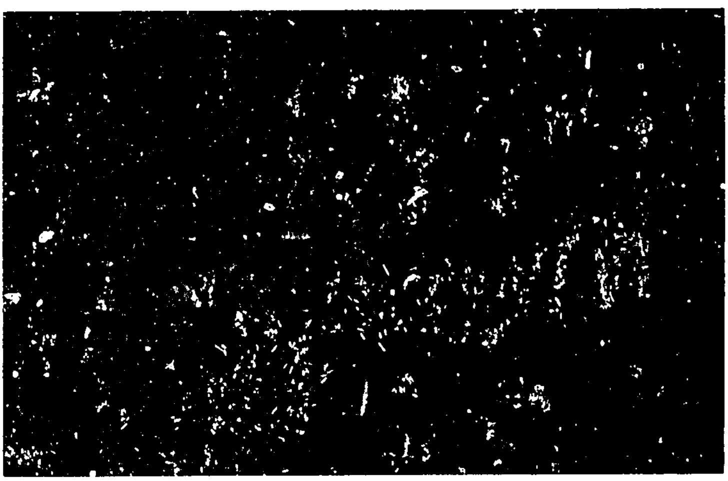

Fig. 10.15. Cercospora leaf spot (mungbean).

Fig. 10.16. Powdery mildew (mungbean). Fig. 10.17. Leaf blight (mungbean).

Fig. 10.18.
Scab (mungbean).

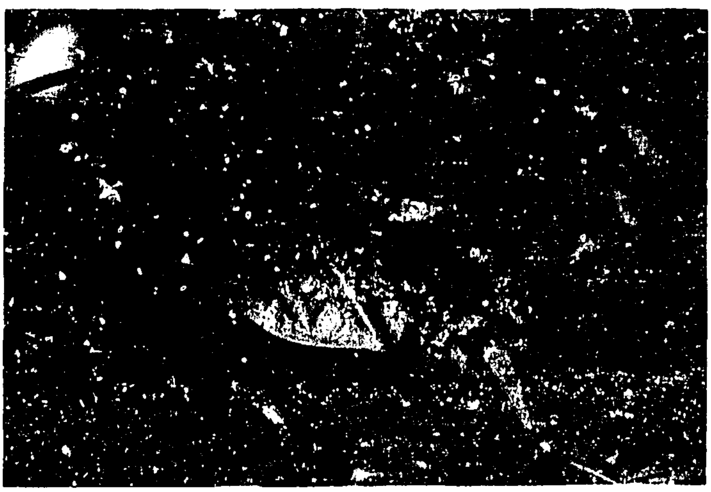

Fig. 10.19.
Bacterial spot (pepper).

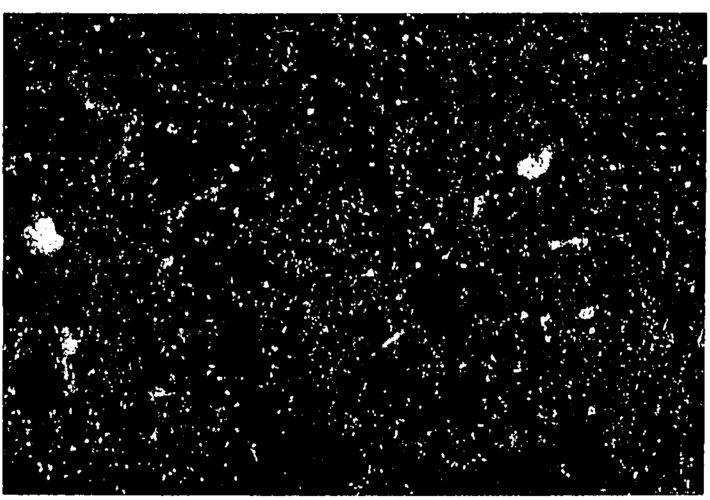

Fig. 10.20a.
Anthracnose (pepper) (fruits).

Fig. 10.20b. Anthracnose (pepper) (stem).

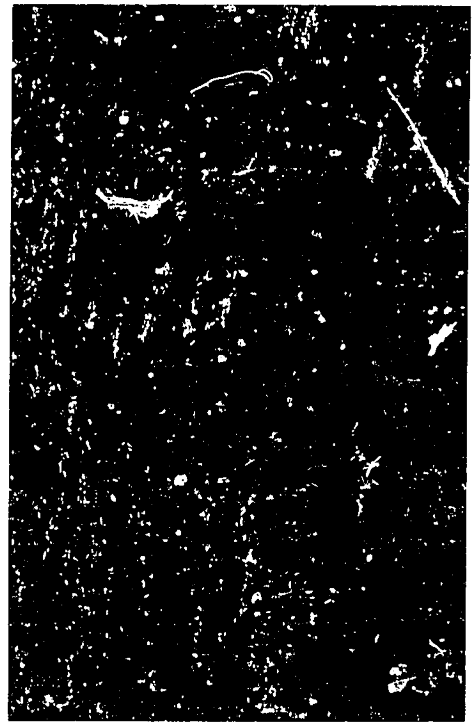

Fig. 10.21. Phytophthora blight (pepper).

Fig. 10.22. Bacterial spot (tomato).

Fig. 10.23. Bacterial wilt (tomato).

Fig. 10.24.
Early blight (tomato).

Fig. 10.25.
Cercospora leaf spot
(tomato).

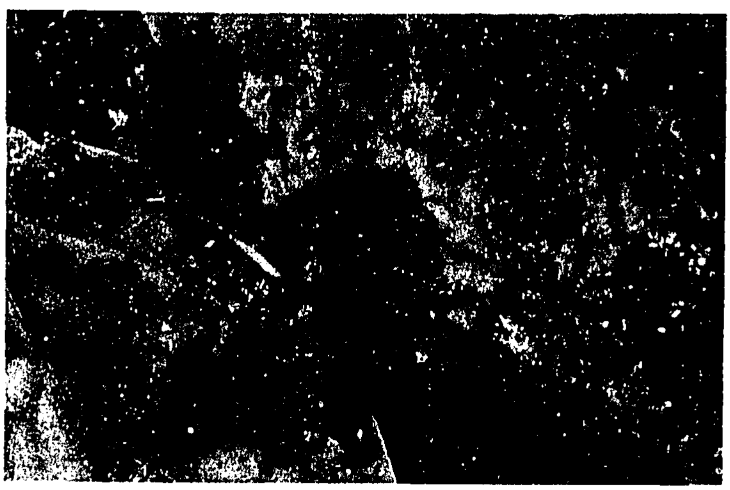

Fig. 10.26.
Leaf blight (tomato).

Fig. 10.27.
Powdery mildew
(tomato).

Fig. 10.28.
Southern blight
(tomato).

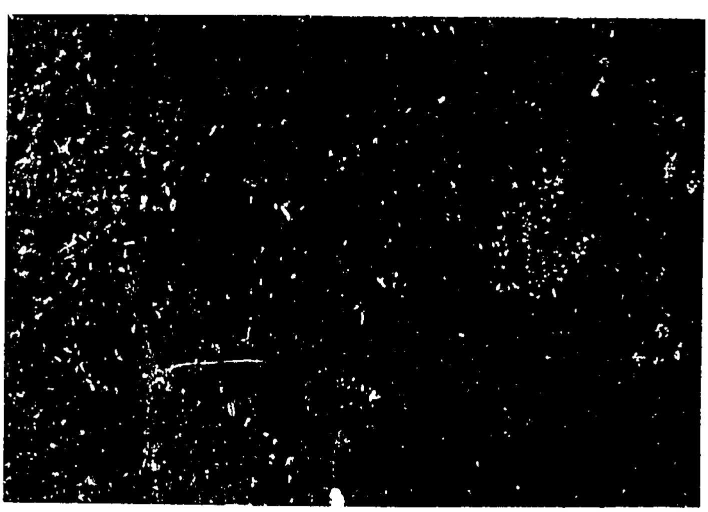

Fig. 10.29.
Bacterial postule
(soybean).

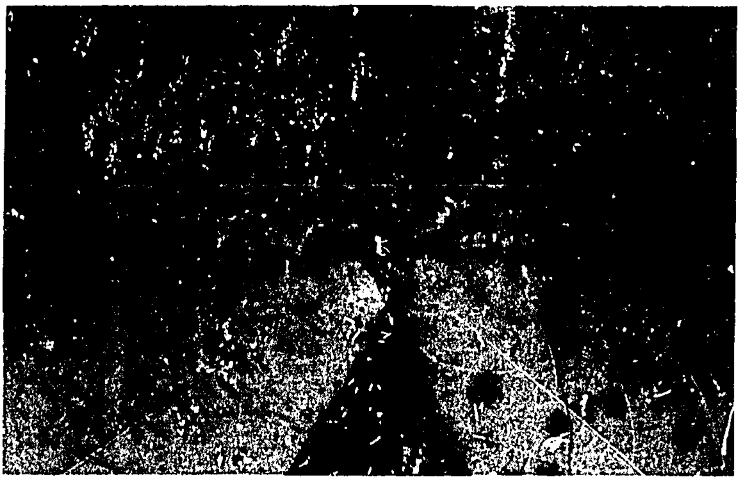

Fig. 10.30.
Soybean rust.

Fig. 10.31.
Downy mildew (soybean).

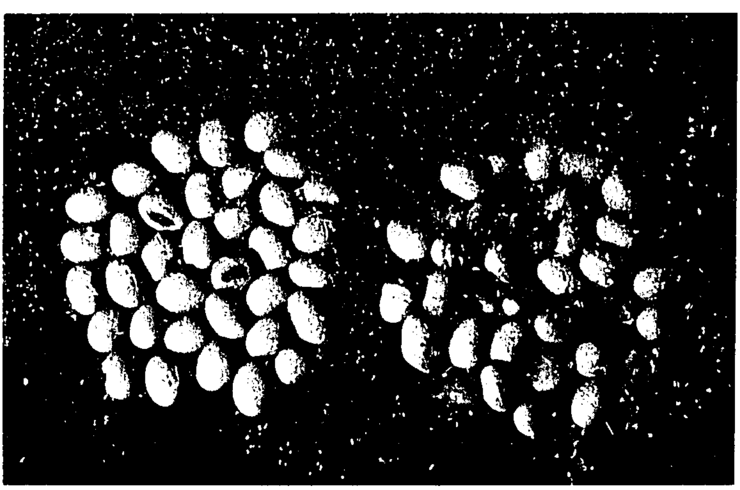

Fig. 10.32.
Purple seed stain (soybean).

Fig. 10.33. Anthracnose (soybean).

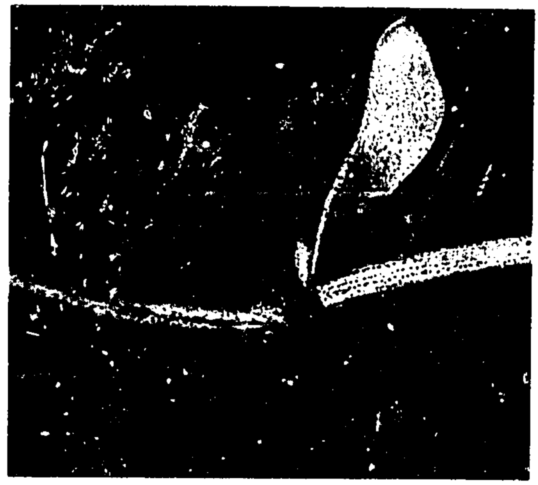

Fig. 10.34. Pod and stem blight (soy bean).

Fig. 10.35. Root rot and seedling blight of soybean.

Fig. 10.36. Scab (sweet potato).

Part II: Diseases Caused by Viruses

Viruses are extremely small agents that multiply only within living cells and are potentially pathogenic. Their small size is below the resolution power of the light microscope. They can only be seen with the electron microscope. The unit length for measuring virus particles is the nanometer (nm) also referred to as millimicron. One nanometer is one thousandth of a micrometer (μm) which is one thousandth of a millimeter.

Viruses consist of nucleic acid normally enclosed within a protective coat of protein or lipoprotein; and they are able to organize their own replication only within suitable, live host cells. The nucleic acid is the infectious component and carries the genetical information necessary for the replication of the virus. The nucleic acid of most viruses consists of ribonucleic acid (RNA), but in a few viruses it consists of deoxyribonucleic acid (DNA).

Plant viruses have different shapes and sizes. They may be isometric (spherical), bacilliform (bullet-shaped) or rod-shaped. Among the rod-shaped viruses one can distinguish between rigid and flexuous rods. Isometric particles vary from 17-85 nm in diameter. Bacilliform viruses measure from 36-380 nm in length and 18-95 nm in width. Rigid rod-shaped viruses range from 100-300 nm in length and 13-23 nm in width; whereas flexuous rods range from 470-2000 nm in length and 10-13 nm in width. The viruses are classified into 27 groups on the basis of particle size and shape and type of nucleic acid.

Plant viruses are unable to penetrate the cuticle of their host. Entry takes place through wounds. In nature, this process is usually achieved by another organism which introduces the virus from an infected into a healthy plant. The organism carrying the virus is called a *vector*, and it may be an insect, a nematode, or a fungus.

Some viruses do not have vectors, and they enter the hosts following natural mechanical damage as a result of abrasion of tissues as roots grow through the soil or of leaves rubbed together by the wind. They may also enter plants through broken leaf hairs following the manipulation of plants with tools or hands.

Many viruses are transmitted through seed, pollen, and vegetatively propagated plant parts, such as cuttings, tubers, runners, and bulbs.

Symptoms of Virus Diseases

Diagnosis of Symptoms

Symptoms are of particular importance since viruses, ordinarily invisible, can be recognized only by the effect they have on their hosts. Viruses are able to upset in almost every conceivable way the processes by which the plant grows and maintains itself. Thus symptoms may be extremely variable.

Field diagnosis based on symptoms alone should serve only as a guide. Symptoms can provide only a partial diagnosis because similar symptoms can be produced by different viruses and because the same virus can produce a range of symptoms, depending on host genotype, environment, and time of infection. A lack of symptoms does not necessarily mean that no viruses are present. It may simply mean that the infection is latent.

Under certain environmental conditions, symptoms can be masked, i.e., no visible symptoms are produced, even though a virus is present in the plant. This is also referred to as a temporarily latent infection which is generally due to environmental factors such as temperature, light, and nutrient excesses or deficiencies. Some plants, due to their genetic disposition, are tolerant to the infection of certain viruses; and no visible symptoms are produced by the presence of these viruses. Such plants are called ***symptomless carriers.***

In case of mixed infections with several viruses, their effects on the host may be additive, synergistic, or antagonistic.

Viral infection can affect the general appearance of the plant such as abnormal color, stunting (often one-sided), rosetting (shortening of the internodes, which produces a bunchy appearance), witches' broom (excessive budding and branching, stunting, and shortening of internodes), decline (loss of vigor) of the whole plant or of parts of the plant. Necrosis and plant death can also occur as a result of virus infection.

Other common symptoms are color deviation or malformation of leaves, stems, flowers, fruits, and roots.

Color Deviation

Leaves. The discoloration may be evenly distributed. Examples are chlorosis (weakening of the green color); bleaching (disappearance of all color, white appearance); yellowing (chlorosis and dominance of yellow pigment); reddening (abnormal anthocyanin formation); browning and blackening (production of dark melanin-like substances); and bronzing (necrosis and collapse of epidermal cells covering apparently healthy mesophyll that is still green).

However, one must exercise caution in diagnosing symptoms. Chlorosis, yellowing, and reddening may also be caused by mineral deficiencies and bronzing, by mites.

The discoloration may also be irregularly distributed. Examples are mosaic (pale green, yellow, or chlorotic areas sharply bordered by small veins that are often angular in appearance); mottle (discolored areas of various rounded shapes, often diffusely bordered); local lesions (ranging in size from small pinpoints of chlorotic or necrotic areas to large irregular patches); ring spots (single or concentric rings of chlorotic or necrotic tissues separated by normal green tissue); and streaking (elongated, sharply defined chlorotic or necrotic patches).

Certain leaf parts can be uniformly discolored. Examples are vein yellowing (yellow discoloration of the veins due to lack of chlorophyll, accented color of carotenes and xanthophylls): vein clearing (translucent rather than chlorotic or yellow veins); vein banding (discolored areas along the veins); and vein necrosis (death of vascular tissues resulting in browning).

Flowers. Flowers may show symptoms of virus infection in the form of color variegation or "breaking" (Caution: This symptom may be confused with a nonvirus-induced genetic variegation). Phyllody (floral parts developing like foliage) and virescence (general greening of the petals) can also result from virus infection. (The latter two symptoms can also be caused by other plant pathogens, such as mycoplasma-like organisms).

Fruits. Discoloration may occur on the whole fruit or parts of the fruit (marbling, mottling, spotting).

Roots. Root lesions and necrosis are examples of virus-induced color deviations in the roots.

Malformation

Leaves may be distorted (crinkling curling, twisting), may show epinasty (curling downwards); narrowing (reduction of laminar tissue, vein growth remains almost normal); reduction in size; thickening in all or part of the lamina and of the veins. Enations are outgrowths of the leaf blade, often resulting in curling of leaves.

Flowers also react with various kinds of distortions and abnormal flower parts. Fruits may be smaller, deformed, or irregular in shape with tumorous swellings, and contain abortive seeds. Fruits can also become woody as a result of virus infection. Stems may be distorted and have shortened internodes. Root decay and dieback also result.

Other Symptoms

Other symptoms include wilting, defoliation, premature leaf drop, premature or delayed flowering, deviation in flower number, abnormal fruit flavor, abnormal secretion, gummosis, bark scaling, wood pitting, shoot swelling, and graft incompatibility.

However, genetic abnormalities, nutritional deficiencies, herbicide toxemia, insect or mite-feeding damage, and air pollution can cause symptoms that resemble those of virus infection. Symptoms caused by these agents are neither sap-nor graft-transmissible, like those of viruses; and recovery is common (except for genetic abnormalities).

Transmission of Viruses in Nature

Plant viruses cannot enter their hosts by themselves. The only way they can enter host tissue is through wounds or through organisms which have acquired the virus from an infected plant. An organism carrying the virus is called a ***vector.***

Insect-Transmitted Viruses

The major characteristics of the individual insect groups are described below, with special emphasis on their relationship to viruses.

Aphid-Transmitted Viruses

More than 190 aphid species are known to transmit more than 160 different viruses. The most common vector species are *Aphis* sp., *Myzus* sp., *Brevicoryne* sp., *Rhopalosiphum* sp., *Macrosiphum* sp., and *Toxoptera* sp. Most aphid-transmitted viruses induce mosaic diseases. Some also produce yellow-type diseases. Aphid-transmitted viruses are rarely transmitted transovarially (i.e., through the egg stage). Thus, newly hatched aphids are nearly always virus-free. Aphid-transmitted viruses can be grouped into nonpersistent, semipersistent, and persistent categories.

Nonpersistent (stylet-borne) viruses. Most aphid-transmitted viruses belong to this group. The virus is acquired by the insect during superficial probing. It is carried on the mouthparts (stylet) of the insect, is usually retained for less than one hour, and is not ingested. The virus is acquired by the insect after a short feeding (few seconds to a few minutes). There is no latent period and the virus can be transmitted after acquisition. Fasting of the aphid prior to acquisition can increase transmission efficiency.

Nonpersistent viruses are sap-transmissible and generally have a wide host range and a low host specificity. The viruses are of considerable economic importance.

Examples of nonpersistent viruses are alfalfa mosaic virus, bean common mosaic virus, bean yellow mosaic virus, cowpea aphid-borne mosaic virus, cucumber mosaic virus, lettuce mosaic virus, onion yellow dwarf virus, papaya ring spot virus, peanut mottle virus, peanut stripe virus, pepper mottle virus, potato virus Y, soybean mosaic virus, sugarcane mosaic virus, tobacco etch virus, turnip mosaic virus, and watermelon mosaic virus.

Semipersistent viruses. Semipersistent viruses are ingested into the alimentary canal of the insect. Retention in the insect is longer than for nonpersistent viruses (12-24 hours and sometimes several days). The acquisition access feeding time is somewhat longer than for nonpersistent virus, but shorter than for persistent virus. There is no latent period in the vector.

The viruses can be sap-transmitted only with great difficulty. Examples of semipersistent viruses are beet yellows virus and clover yellows virus.

Persistent (circulative) viruses. Persistent viruses are carried in the haemolymph and in the salivary and alimentary ducts of the insect. Some persistent viruses multiply in the vector. Acquisition time varies from 30 minutes to several hours. There is a delay (latent period) before aphids can transmit the virus. Retention is long, frequently for life. The viruses are retained through molting. Fasting has no effect on virus transmission. The viruses are generally phloem-associated. With the exception of pea enation mosaic virus, persistent viruses cannot generally be sap-transmitted.

Examples of persistent viruses are beet western yellows virus, carrot mottle virus, lettuce necrotic yellow virus, maize mosaic virus, pea enation mosaic virus, potato leaf roll virus, potato yellow dwarf virus, and rice transitory yellowing virus, striate mosaic virus.

Bimodally transmitted viruses. These viruses are acquired after short and long acquisition feedings, but are not easily acquired during the interval between these two phases. Examples of bimodally transmitted viruses are broad bean wilt virus, citrus tristeza virus, cauliflower mosaic virus, pea seed-borne mosaic virus, and pea streak virus.

Whitefly-Transmitted Viruses

Virus diseases transmitted by whiteflies are of considerable economic importance in tropical and subtropical regions. They generally cause yellowing, leaf curling, and some mosaic diseases. The viruses (except the cucumber vein yellowing virus and cowpea mild mottle virus) are persistent in the vector.

Bemisia tabaci is the most important and widespread whitefly vector. Whiteflies are carried by wind and hence can spread viruses over great distances.

The virus is carried in the haemolymph. An acquisition feeding period of 24-28 hours on a diseased plant is generally enough to make whiteflies infective. The viruses have a variable latent period in the whitefly of 4-20 hours. The whitefly remains infective anywhere from a few days to 35 days or longer. Whiteflies are phloem-feeders and other whitefly-transmitted viruses are generally found in the phloem.

Whitefly-transmitted viruses are not usually sap-transmitted by mechanical means. The exceptions are bean golden mosaic virus, tomato golden yellow mosaic virus, and cowpea mild mottle virus. Exposure to the viruliferous whitefly vector is considered the most reliable method of screening for resistance to whitefly-transmitted viruses.

Examples of whitefly-transmitted viruses are the bean golden mosaic virus; bottle gourd mosaic virus, cassava mosaic virus, cowpea mild mottle virus, cowpea chlorotic mottle virus, chili leaf curl virus, cotton leaf curl virus, cucumber vein yellowing virus, mungbean yellow mosaic virus, sweet potato mild mottle virus, tobacco leaf curl virus, and tomato yellow leaf curl virus.

Leafhopper- and Planthopper-Transmitted Viruses

The most common virus-transmitting leafhopper species are *Agallia* sp., *Circulifer* sp., *Graminella* sp., and *Macrosteles* sp. *Nephotettix* sp., *Peregrinus* sp., and *Laodelphax* sp. are some of the virus-transmitting planthoppers. Leafhoppers and planthoppers are phloem-feeders and most viruses they transmit are phloem-associated viruses.

The viruses are generally transmitted in a circulative manner with acquisition times ranging from 30 minutes to several hours, and a latent period in the vector.

The viruses have a high vector specificity and a limited host range. Only a few are sap-transmissible, such as potato yellow dwarf virus.

Viruses transmitted by leafhoppers and planthoppers mainly cause yellowing, leaf rolling, and witches' broom diseases. Examples of leafhopper-transmitted viruses are beet curly top virus, maize chlorotic dwarf virus, maize streak virus, maize stripe virus, potato yellow dwarf virus, rice tungro virus, rice dwarf virus, rice transitory yellowing virus, rice bunchy top virus, and soybean rosette virus.

Examples of planthopper-transmitted viruses are maize mosaic virus, maize rough dwarf virus, pangola stunt virus, rice black-streaked dwarf virus, rice grassy stunt virus, rice hoja blanca virus, and rice stripe virus.

Beetle-Transmitted Viruses

The most widespread and important vectors are in the family Chrysomelidae. These leaf and flea beetles usually have a very narrow range of hosts on which they feed. In the family Coccinellidae only members of one genus, *Epilachna*, are known to transmit viruses. Certain weevils in the family Curculionidae are also efficient virus vectors. Beetles acquire viruses within 24 hours or less. They may acquire the virus after a single bite, although efficiency increases with more intensive feedings.

There is no latent period. After feeding on infected plants the beetle remains infective for at least one day, often longer. Beetle-transmitted viruses are generally easily transmitted mechanically. There is no evidence of transovarial or transladial transmission.

Transmission is also possible by macerating infected beetles.

About 45 viruses belonging to four major groups of viruses (the bromoviruses, comoviruses, tymoviruses and members of the southern bean mosaic virus) are transmitted by beetles.

Many of these viruses, particularly cowpea mosaic virus, are widely distributed and infect economically important crops such as bean, cowpea, and soybean in many tropical countries.

Examples of beetle-transmitted viruses are Andean potato latent virus, bean pod mottle virus, bean rugose mosaic virus, belladonna mottle virus, broad bean mottle virus, broad bean stain virus, broad bean true mosaic virus, brome mosaic virus, cocoa yellow mosaic virus, cowpea chlorotic mottle virus, cowpea mosaic virus, cowpea severe mosaic virus, eggplant mosaic virus, okra mosaic virus, radish mosaic virus, rice yellow mottle virus, southern bean mosaic virus, squash mosaic virus, turnip crinkle virus, turnip rosette mosaic virus, turnip yellow mosaic virus (also transmitted by grasshoppers and earwigs), and wild cucumber mosaic virus.

Thrips-Transmitted Viruses

Thrips are difficult to handle and require special culturing techniques. Thrips usually feed on very young tissues. There are only two species of virus-transmitting thrips: *Thrips* sp. and *Frankliniella* sp.

Tomato spotted wilt virus (TSWV) is the only thrips-transmitted virus. It must be acquired by the nymphs and only the adult can transmit the virus. TSWV is persistent in the vector. The virus has a wide host range and infects at least 166 species of dicots and monocots from 36 families. Although the virus is very versatile in peanut sap, it is readily sap- transmissible.

Mite-Transmitted Viruses

The most common virus-transmitting mite species are *Aceria* sp., *Brevipalpus* sp., and *Eryophyes* sp. Mites are difficult to rear and handle because they are delicate and easily desiccated. Because of their small size (0.25 mm in length) a hand lens is required to observe them. They must be handled with a single hair; and tafetta, a very fine meshed material, must be used for caging. Mites prefer to feed on very young plant tissues. Extreme care must be taken to avoid confusion between symptoms due to mite feeding (phytotoxemia) and those due to virus infection.

The viruses that they transmit are carried in the alimentary tract and are carried over in molting. They are, however, not passed transovarially to the offsprings. Transmission improves with longer acquisition feeding.

Examples of mite-transmitted viruses are agropyron mosaic virus, citrus leprosis virus, coffee ringspot virus, fig mosaic virus, hardeum mosaic virus, peach mosaic virus, prunus ringspot virus, ryegrass mosaic virus, and wheat streak mosaic virus.

Nematode-Transmitted Viruses

The three main genera of nematodes known to transmit viruses are *Trichodorus* sp., *Xiphenema* sp., and *Longidorus* sp.

Nematode-transmitted viruses are sap-transmissible, host-specific, and lost in molting. The viruses are retained in nematodes from a few weeks to several months. In *Trichodorus* sp. and *Longidorus* sp., the viruses persist for about two weeks and in *Xiphenema* sp., for about eight months.

Nematode-borne virus diseases often occur in slowly spreading patches in the farmer's field.

Examples of nematode-transmitted viruses are pea early browning virus and tobacco rattle virus transmitted by *Trichodorus* sp., and tomato black ring virus transmitted by *Longidorus* sp. Persistence of these viruses in the vector is about two weeks.

Tobacco ringspot virus and tomato ringspot virus are transmitted by *Xiphenema* sp. Persistence of these viruses in the vector is about eight months.

Fungus-Transmitted Viruses

Soil-inhabiting fungi belonging to the *Olpidium* sp., *Polymyxa* sp. and *Spongospora* sp. are also vectors of viruses. These fungi are obligate parasites commonly infecting roots of crop plants. The viruses they transmit are spread by soil movement, root debris, and drainage water. Long-distance spread occurs by transplanting infected plant materials and by the movement of soil particles in the wind.

Examples of fungus-transmitted viruses are cucumber necrosis virus, satellite virus potato mop top virus, and potato virus X.

Seed-Transmitted Viruses

Seed infection is critical to the transmission and survival of many plant viruses. Seed transmission is often responsible for the establishment of a virus disease in the field. Evidence of seed transmission is the scattered infection of plants within a planting area and the infection of young seedlings. Seed transmission provides the virus with a means to survive in the absence of a crop. Weed seeds also frequently harbor important crop viruses. More than 60 viruses are seed-transmitted.

Seed transmission depends on the host species, the strain of the virus, and the temperature at which the plant is grown. Examples of common seed-transmitted viruses are tobacco mosaic virus, alfalfa mosaic virus, bean common mosaic virus, cowpea mild mottle virus, cucumber green mottle mosaic, squash mosaic virus, peanut stripe virus, soybean mosaic virus.

Virus Transmission by Contact

Many viruses can be transmitted by contact between healthy and infected plants, provided that the contact damages the cuticle sufficiently to allow the virus particles to enter the healthy host. Contact transmission can be accomplished through contaminated tools and other implements (used for pruning, weeding, hoeing, etc.) and also by animals and man.

This type of transmission is very rare and only occurs with very stable viruses that are present in high concentrations within the plant tissue such as potato virus X, tobacco mosaic virus, and tomato mosaic virus.

Transmission of Viruses in the Laboratory

Transmission of viruses in the laboratory is necessary to isolate viruses from diseased field plants, identify viruses and sometimes separate viruses from mixed infected plants.

Sap Transmission

Sap transmission, also called ***mechanical inoculation***, is the application of virus-containing plant extract (i.e. inoculum) on the leaf surface of healthy plants. In order for the virus particles to penetrate the cuticle and epidermis of a healthy leaf, the surfaces must be artificially wounded. Once introduced into the host cell, a virus may spread systematically to other areas of the host. Most plant virus diseases are characterized by systematic symptoms, that is, symptoms which result from movement of the virus throughout the plant.

In some plant virus combinations, virus movement is restricted and symptoms appear as local lesions (small chlorotic or necrotic spots). Some viruses cause both local lesions and systematic symptoms on the same host. In some cases, there are no symptoms because the virus, although it has entered the plant does not multiply and invade other parts of the plant. This type of reaction is referred to as highly resistant or hypersensitivity. Absence of symptoms may also be due to a tolerant reaction of the plant to virus infection. In this case, the virus multiplies but the host is not reacting visibly. When the virus has not entered the plant, the plant is referred to as immune to the virus.

The aphids generally transmit nonpersistent viruses through the sap. However, most of the aphid-transmitted semipersistent and persistent viruses, as well as the leafhopper and whitefly-transmitted viruses are not.

Selection of indicator hosts. Indicator hosts react diagnostically to certain viruses. They can be used to distinguish between these viruses, usually by their immunity to one and susceptibility to the other, and also by symptom types. The most commonly used indicator plants are *Chenopodium amaranticolor* (susceptible to more than 40 different viruses), *Chenopodium quinoa, Cucumis sativus, Datura stramonium, Gomphrena globosa, Nicotiana benthamiana, Nicotiana glutinosa, Nicotiana tabacum 'Xanthi', Nicotiana tabacum 'samsun', Phaseolus vulgaris 'Pinto', Vicia faba,* and *Vigna unguiculata.* Seeds of indicator plants can be obtained from:

Plant Introduction
Germplasm Resources Laboratory
Agricultural Research Center
Beltsville, MD .20705
USA

Initially obtain a small number of seeds. Propagate these seeds in an insect-proof greenhouse.

Steam-sterilize the soil in which the indicator plants are grown at 100°C for 30 minutes, to inactivate microbial pathogens, soil-inhabiting viruses and virus vectors. Keep the indicator plants in an insect-free greenhouse or screenhouse, isolated preferably in a separate room from inoculated plants. To avoid build-up of insects, regularly spray the greenhouse with an insecticide. Use insecticides of varying nature to avoid build up of the insect's resistance to insecticides. The use of biological control agents including predators or sticky traps has also become popular. Biological control agents against thrips, whiteflies, and aphids are now commercially available.

Preparation of inoculum and inoculation. Inoculum is the sap extracted from diseased plants. This is used in transmitting the virus. The following three points should be kept in mind when choosing virus-infected tissue for inoculum preparation:

- The virus content often, but not always correlates with the severity of the symptoms.
- The highest virus content is often found in young tissues.
- Some viruses can only be transmitted at certain times of the year.

For the maceration of virus-infected tissue, ground one part of infected tissue in a small sterilized (autoclaved for 30 minutes at 120°C, or boiled in water for three hours) mortar with 2 to 5 parts buffer, generally 0.01 M phosphate buffer, pH 7.0. Prepare the buffer by mixing 49 ml of solution A (1.36 g KH_2PO_4 in 1000 ml H_2O) with 51 ml solution B (1.78 g Na_2HPO_4 x 2 H_2O) in 1000 ml H_2O. Keep the inoculum cool and use immediately.

Stabilizing compounds are often added to the inoculum, particularly in the case of unstable viruses. Furthermore, many plants contain inhibitors that may inactivate the virus, decrease or inhibit its infectivity, or interfere with its transmission. The following compounds, when added to the inoculum, are known to have a stabilizing effect on viruses in plant extracts containing inhibitors, such as 1) ethylenediaminetetraacetic acid-disodium salt (EDTA) (0.0005-0.1 M), 2) sodium diethyldithiocarbamate (NaDIECA) (0.01-0.1 M), 3) thioglycollic acid (TGA) (0.1%-0.5%), 4) 2-mercaptoethanol (ME) (0.2%-1%), 5) ascorbic acid (Vitamin C) (0.1%-0.3%), 6) sodium sulfite (Na_2SO_3) (0.1%-0.3%), 7) bovine serum albumine (0.01%). Any of these compounds can be added to the inoculum in the concentration range listed. The selection of the compound and its concentration depend on the particular virus/host plant system.

Abrasives are necessary for successful inoculation. The use of abrasives increases infection by providing wounds for the entry of virus particles. The most commonly used are carborundum (silicon carbide,400-600 mesh) and celite (diatomaceous earth). The abrasive is either finely dusted over the leaf surface before inoculation or suspended in the inoculum (0.5%-1% w/v).

Gently apply the inoculum on the leaf surface with a cotton swab, a pad of cheesecloth, or a glass rod with a flattened end, or with the forefinger. Rinse the inoculated leaves with water to remove natural toxins in the inoculum which interfere with infection, and reduce injury from chemicals which have been added to the inoculum. Rinsing also facilitates later observation of symptoms.

Inoculate at least two plants from each indicator plant species. Set aside an uninoculated control plant of each species for later comparison of symptoms. Young plants are generally more susceptible to virus infection than older plants. For peas and beans, inoculate the primary leaves; for cucumber, the cotyledons; for Chenopodium, the fourth to eighth leaf; and for tobacco, any leaf from the three to four leaf stage onward. Datura is generally inoculated when the first or second leaf pair has developed.

Symptoms development and recording. Observe plants daily over several weeks (in some cases for several months, e.g., transmission of viruses from woody plants) and compare them with control plants of the same age. Many host plants will develop local reactions on the inoculated leaves, and/or systematic reaction on the non-inoculated leaves (but other symptoms can also appear). Record the symptoms and their sequence of development.

Some of the common symbols used for recording symptoms are: LL = local lesions; nLL = necrotic local lesions; cLL = chlorotic local lesions; Vc = vein clearing; M = mosaic; Mo = mottle; N = systematic necros; Mal = malformation; E = etching; and RS = ringspot.

Transmission by Grafting

Almost all viruses can be transmitted by grafting. Materials needed for grafting are a sharp razor blade (for soft tissues) or sharp knife (for woody tissues) and plastic tape or parafilm (approximately 2 cm wide). To prevent contamination, the knife or razor blade should be flamed with alcohol before each grafting.

The two standard grafting methods are ***approach grafting*** and ***cleft grafting***. In an approach grafting, cut the sterns of a virus-infected and a virus-free plant lengthwise so that the cambium is exposed. Choose stems of similar thickness. Join the cut portions and wrap the union with plastic tape. Cut back the growing tip of the healthy plant to promote the development of lateral buds. Virus symptoms are observed on the previously healthy plant.

Top cleft grafting, also called wedge grafting, is widely used with both herbaceous and woody plants. Cut off the top of the diseased plant and cut a slit axially through the middle of its stem. After its end has been cut into a wedge shape, insert the top scion from a healthy plant tightly into this slit, and wrap the joint with plastic tape. Observe symptoms of systematic infection in the new growth of the originally healthy plant parts. The growing tip of the plants may need to be cut back to promote lateral buds with obvious virus symptoms.

For side cleft grafting, make a cleft tangentially in the main stem near one of the leaf nodes. Insert the virus-infected scion into the slit as described above.

Transmission by Dodder

Dodder (*Cuscuta* sp.) is a semiparasitic plant which attaches itself to other plants and draws nutrients from them by means of root-like haustoria. Several species of *Cuscuta* are known to transmit viruses. The most common ones are *C. campestris* and *C. subinclusa*. Dodder plants used for transmission studies must be grown from seed so that they will be virus-free.

Place the virus-free dodder plant in close contact with the virus-infected plant. The dodder will wrap itself around the stems and leaves of the virus-infected plant and send out haustoria to form unions with the virus-infected plant. After the dodder has become well established on the diseased plant, train its stems towards the healthy plant. If the virus is transmissible by dodder, virus symptoms will eventually appear on the healthy part.

Transmission by Insects

Insect and mite transmission experiments are used to determine the vector of a plant virus, assay viruses which are not mechanically transmitted, and obtain information about the mode of transmission in nature.

Insect cages and insect handling. The materials needed for insect transmission studies are cages, insect handling tools, and test plants. Several types of cages can be used, such as a wooden plant cage of approximately 35 x 35 x 50 cm. The sides are covered either with fine wire or plastic netting or a saran screen. The top and front door of the cage may be covered with a glass plate. For whiteflies, use a cage with two wooden side walls. Each wall should have a round access hole of approximately 18 cm in diameter, just large enough for a hand to pass through. Prevent the whiteflies from escaping during handling by attaching black bloth tubes to the holes on one end and held close by rubber bands on the other.

Another type of plant cage is a plastic cylinder of about 20 cm diameter. The top is covered with cheesecloth, and the bottom is pressed into the soil of the pot. Instead of a potted plant, place fresh leaves in a water-filled test tube in the plastic cylinder. Use cellulose nitrate plastic cylinders or butyrate plastic as certain kinds (cellulose acetate with diethyl phtalate) are toxic to plants and insects.

Use a plastic cylinder leaf cage for transmission tests which utilize a small number of insects. It is made from sections of plastic tubing approximately 3 cm wide and 1.5 cm long, covered on one side with a screen made from a nylon stocking or any other fine meshed material. Transfer the insects through a small hole in the wall of the tube which is then closed with a cork. Attach the cages to the leaves with the aid of hairclips. The hairclips are attached by heating them and pushing them through the wall of the plastic tube.

Use plastic or glass containers to transport insects collected in the field. They should have a screen cover and should be large enough to allow ample space and ventilation.

Handle insects using fine paint brushes, aspirators, or a single hair. Use a pointed artist's brush for aphids. Moisten the tip to make the insect adhere to the brush. Use the aspirator for more active insects (e.g., leafhoppers and whiteflies). It consists of a small glass bottle closed with a two-hole rubber stopper. Through one of the holes, insert a short straight glass tube whose outer end is connected to a piece of rubber tubing which serves as a mouthpiece, and the inner end is covered with a small piece of screen. Insert a slightly longer glass tube which has been bent to the desired shape through the other hole. Insects are sucked into the bottle through this tube.

Use a single hair fastened to a toothpick or a thin wooden stick for mites and very small insects, such as thrips. For easier handling, immobilize insects using a small amount of carbon dioxide.

Collect insects in the field by sweeping or brushing over low vegetation with a net, beating the plant and collecting the fallen insects on a dark sheet spread below, collecting individual insects with an artist's brush and collecting plant material on which the insect is present.

Trap insects in the field by color traps (yellow pans filled with water are used to catch aphids and whiteflies) or by light traps (most insects are attracted to blue-ultraviolet light). Suction traps suck in insects by a stream of air. Sticky surfaces trap insects. Paint the surfaces with colors attractive to insects.

Maintenance of insects. The same plant species from which the insects were collected in the field are generally used as host plants. In general, conditions which favor the growth of host plants also favor the development of vectors. Most vectors can be reared on their host plants or on detached leaves of the same plant. Insects should be maintained on host plants which are not susceptible to the virus being studied. Certain insects can be maintained on artificial diets.

When insects collected in the field are used for transmission studies, transfer them to virus indicator plants to determine whether the insects are virus free. If the virus is not carried in the vector's eggs (transovarially), use the eggs to start a virus-free insect culture. Place the eggs on wet blotting paper until they hatch. Transfer the nymphs to healthy plants. Keep plants on which the insects are reared or placed for acquisition or inoculation feeding absolutely free from insecticide.

Inoculation of plants. Place virus-free insects on a virus-infected test plant to feed and acquire the virus (acquisition-feeding). Depending on the virus, it may take from a few seconds up to a few days for the insects to become infective. The optimal acquisition period varies with the insect, the virus, and the host plant. After the insects have acquired the virus they are usually immediately transferred to a virus-free test plant for transmission feeding (inoculation feeding). Some insects can transmit the virus immediately, but others can do so only after a latent period, which may vary from a few hours to several weeks. This latent period, i.e., the time between acquisition and transmission, can be determined by successive transfers of the insects to virus-free test plants at hourly/daily intervals after the acquisition feeding.

Some insects, such as certain aphids which carry the virus on their stylets, retain it for as little as 30 minutes. Most leafhoppers (and certain aphids which carry the virus in their guts) are able to transmit the virus throughout their lifetime, even after molting.

These insects are usually destroyed after the inoculation feeding with the aid of insecticides or fumigants, and observe the inoculated plants for the development of typical virus symptoms. Observe plants for one to three months.

To check the possibility of the insect culture being infected with virus and to detect virus-like symptoms caused by insect feeding only, transfer some insects from the culture plants directly to test plants without feeding on a virus source. Place non-inoculated plants in a greenhouse to detect accidental spread and ensure that the test plants were not infected before inoculation.

Identification of Viruses

Determination of Host Range

Ground one part of infected plant tissue with five parts buffer, using mortar and pestle. Inoculate the homogenate directly to various test plants or after passing through two layers of cheesecloth.

Determination of Insect Vectors

Place insects on infected plants for virus acquisition feeding. After feeding, place the insects on healthy plants for transmission feeding, and observe the plants for symptom development.

Determination of Virus Identity by Serological Methods

Serological tests are the most important and decisive tests for identifying viruses. The reaction between antigen (the virus) and antibody (antiserum) is highly specific and here lies the main advantage of using these tests. Serology is also useful to determine the relationships among isolates of the same virus. Most serological methods are based on the precipitation produced when antibodies and antigens combine. The specificity of the reaction is based on the nature, size, and number of certain determinate groups found on the surface of the antigen. The counterpart of these groups is located on the surface of the antibody molecule. Antisera must be prepared in rabbits or mice from purified or semi-purified virus preparations. To be effective, the antiserum used for the identification of viruses must be free from antibodies that will react with healthy plant proteins and also free from antibodies that will react with other viruses. Some antisera can be obtained from virologists working on the particular virus(es) or can be ordered from:

ATCC (American Type Culture Collection)
12301 Parklawn Drive
Rockville
Maryland 20852
USA

The serological tests commonly used are the microprecipitation test, the agar-gel double diffusion test, immunosorbent electron microscopy (ISEM), and the enzyme-linked immunosorbent assay (ELISA).

Ouchterlony Agar-Gel Double Diffusion Test. This is the most common serological test. It is performed in a petridish, filled to a depth of 5 mm with agar (approx. 15 ml agar per petridish). Cut wells in the agar using a cork borer or hollow steel tubes in a pattern such that a center well is surrounded by six peripheral wells. Wells of 1 cm diameter are commonly used with a distance of 8 mm between the edge of the center well and the closest edge of the surrounding well. Add antiserum to the center well and add the known viruses, the unknown viruses, and the healthy plant sap to the surrounding wells. Both the viruses and the antisera diffuse outward from their wells into the agar. Where the virus and antibodies meet in optimal proportions, a visible precipitin band forms between compatible antigen (=virus) and antiserum wells. This test works best with spherical viruses. Most elongated virus particles do not diffuse readily through the agar medium. Sodiumdodecylsulfate (SDS) may have to be added to the agar and/or the virus containing sap. SDS causes the elongated virus particles to break down into smaller subunits which can diffuse more readily in the agar.

Immunosorbent Electron Microscopy (ISEM). In ISEM, serology is combined with electron microscopy. With this method, the coating of virus particles with specific antibodies can be seen in the electron microscope.

Enzyme Linked Immosorbent Assay (ELISA). The ELISA test is particularly useful for testing large numbers of samples, such as for virus surveys or for resistance screening of large populations or accessions. The double antibody sandwich method (DAS ELISA) is commonly used. The basic materials needed for this test are polystyrene plates and various chemicals including those for the preparation of buffers, gamma globulins, the gamma globulin enzyme conjugate, and the enzyme substrate.

The test procedure is as follows: Coat wells of the polystyrene plates with gamma-globulins, purified from the virus specific antiserum; add test samples to the well. During the following incubation, any virus particle recognized by the gamma globulin is bound to it. Remove plant sap and non-bound virus particles by washing. Add an enzyme-labelled virus specific gamma globulin which will attach to the trapped virus and will react with a color change when an enzyme specific substrate is added. A number of different enzyme/substrate systems are used; the most commonly used is alkaline phosphatase and its substrate p-nitrophenyl phosphate.

These tests are applicable to virus identification from crude sap, clarified sap, and purified preparations. They require special training, and, in the case of ISEM and ELISA, special equipment is needed which may not be commonly available.

Control of Virus Diseases

Unlike fungi and bacteria, viruses cannot be controlled so far by chemicals. Some antiviral compounds are known, but they are still under development . High costs, phytotoxicity, and regulatory considerations have so far prevented them from being used on a large scale. Indirect control measures remain the only practical method of controlling viruses. To achieve this, the virus has to be correctly identified and its epidemiology and ecology must be understood. Some of the methods most commonly used to control viruses are described below:

Control of the Vector

Chemical control. Insecticides effectively control persistent aphid-, leafhopper-, and whitefly-transmitted viruses. They will not however control viruses, such as CMV and

PVY, which are transmitted in a nonpersistent manner. These viruses can be transmitted within seconds after the insect has started to feed. Thus, the insects are able to transmit the virus before they are killed by the insecticide. For persistent viruses, in which the vector requires several hours or days to acquire and transmit the virus, insecticides can be very effective.

It is also advisable to use insecticides on the weeds surrounding the plant, since these weeds may be alternative hosts of the virus. For nematode-transmitted viruses, nematicides and fumigants have provided effective control.

Nonchemical control. Barrier crops are reportedly useful in controlling aphid-borne viruses. For example, when corn was cropped around papaya seedlings, the incidence of papaya ring spot virus could be reduced significantly in Taiwan. The aphids landed first on the taller, more attractive corn on which they probed briefly, and consequently lost any of the nonpersistently transmitted papaya ring spot virus they might have carried.

Insect traps are also effective in reducing vector population. Color traps, light traps, suction traps, and hormone (pheromone) traps are the most commonly used. Aphids are attracted to the color yellow. Yellow sticky polythene sheets erected on the windward side of pepper fields have become a standard practice in Israel to reduce the incidence of PVY and CMV.

Reflective mulches laid on top of planting beds have recently become popular among farmers. They are highly effective in controlling CMV and PVY in pepper fields and watermelon mosaic virus in squash plantings. The mulches act as a repellent by reflecting UV light and thus confusing the aphids in their landing attempt.

Mineral oil sprays prevent the transmission and spread of viruses when sprayed on the plant surfaces. To be most effective, the oil has to be applied as a very fine spray and maintained as a continual cover over the whole plant surface. An appropriate dilution of the oil has to be determined for each crop species because of its reported phytotoxicity. The exact mode of action of mineral oils is not known, but it is believed to interfere with virus transmission as the stylets of the vectors probe the leaf.

A commercial oil formulation is successfully used in Florida to reduce the nonpersistently transmitted pepper viruses, such as PVY, CMV, TEV, PeMV. In India oil sprays have been applied to reduce the incidence of tomato leaf curl virus.

The biological control of virus vectors, such as whiteflies and thrips, by means of predators is now widely practiced in Europe on a number of economically important crops such as tomatoes, peppers, and cucurbits grown in the greenhouse and under protective cover. The effectiveness of this practice on field-grown crops has not yet been established.

Avoiding Vectors

Areas without or with frequently occurring vector are not easily found in the tropics or subtropics. The safest way to avoid virus vectors, therefore, is to grow the crop in an insect-free glass or net house. This measure, however, is expensive and is usually practiced only on very valuable crops.

Another way to avoid the vectors is to adjust the sowing time of the crop, so that it does not coincide with high insect population because young plants are particularly susceptible to virus infection.

Eliminating Source of Infection

Removal of infected plants. The removal of visibly virus-infected plants is very effective in limiting the spread of a virus within a crop when the plants are still young, because plants do not serve as a source of infection for secondary virus spread. Volunteer plants emerging at the edges of a planting area or within a field should also be removed, since they may be potential virus carriers.

Eradication of weeds and alternative hosts. Weeds are potential reservoirs of viruses and should be eradicated from within and around the crop. For example, CMV and PVY have a very wide host range and infect many weed species commonly found near the crop.

The removal of alternative hosts is difficult to practice in the tropics where mixed cropping and intercropping are widely practiced. For example, when hot or sweet peppers are planted in the vicinity of a tomato crop, the chances are high that aphids will introduce the viruses from the tomato to the pepper plants.

Modification of cultural techniques. Continuous cropping may lead to a virus or vector build-up or both. A crop-free period or the planting of a resistant or nonsusceptible crop can break this cycle.

In Southern California, celery mosaic virus became severe because the growing of celery crops overlapped. The enforcement of celery-free periods of three to five months subsequently suppressed the virus.

Growing a crop away from the source of inoculum is another useful technique for raising a virus-free crop. This measure is frequently used in the production of virus-free *Brassica* seed plants and "seed" potato tubers.

Our studies showed that TMV was still found in soils eight months after the harvest of the tomato crop, regardless of the crop grown afterwards. The virus was found in the soil even when irrigated rice followed the tomato crop. The continuous planting of tomato or any TMV-susceptible crop will thus lead to a high virus incidence.

Crop hygiene. Hygiene significantly reduces the spread of stable viruses, such as TMV and PVX, which are easily transmitted by contact and which remain infectious for long periods. The plants should be handled as little as possible. The use of clean tools for cutting and pruning is necessary. A 10% trisodium phosphate (Na_3PO_4) solution may be used to disinfect these tools.

Use of healthy planting materials. Virus-carrying seeds are an important source of infection, particularly when the virus is also aphid-transmitted. In this case, even a low seed transmission rate can result in scattered initial infection within the crop and a subsequent rapid secondary spread by aphids. Many legume viruses, including bean common mosaic virus (BCMV) and soybean mosaic virus (SMV), are seed-borne. Since it is not possible to visually recognize virus-infected seeds and separate them from healthy ones after harvest, seeds should be selected only from virus-free plants.

Exposure of seeds to high temperature can sometimes eliminate viruses inside the embryo. It is important, however, for the seeds to have a low moisture content beforehand. Tomato seeds, for example, can be freed of internally carried ToMV by first drying them to a moisture content of approximately 4%-8% and then heating them to 78°C (dry heat) for two to three days. The treatment does not appear to affect germination.

In cases where the virus is carried on the outside of the seed, as in the case of TMV on tomato or pepper, it can be eliminated by treating the seed with trisodium phosphate or sodium hypochlorite solution. The literature must be consulted for the exact timing of these treatments and the preconditioning of the seeds prior to these treatments, so as not to effect seed germination.

In vegetatively propagated crops, all progenies originating from a virus-infected clone will be diseased. Infected plant material is a source of virus infection and a means of spreading the virus widely. Vegetatively propagated crops such as sweet potato can be freed of virus by meristem-tip culture, heat therapy, or a combination of both. Usually these treatments are followed by a virus assay (indexing) through grafting on susceptible indicator plants or through serological tests to assure that plants produced by such methods are indeed virus-free.

A significantly higher yield has been achieved with meristem-derived sweet potato plants than from field-propagated and possibly virus-infected plants. At AVRDC all sweet potato breeding lines destined for international testing have undergone this procedure. Similar approaches are widely used for the production of virus-free seed potato, cassava, and fruit trees.

Cross Protection

Cross protection is based on the theory that a plant infected with one strain of a virus is often protected from infection by other related strains. Prior to the development of resistant varieties, it had been utilized in greenhouse tomato production to reduce yield losses due to tomato mosaic virus (ToMV). When artificially inoculated at the seedling stage with experimentally produced mild strains (attenuated strains) of ToMV, tomato plants were less severely damaged than noninoculated plants, when subsequently infected with naturally occurring ToMV strains. Similar protection is also reportedly obtained by inoculating tomato crops with mild strains of CMV in Japan.

Attenuated strains of viruses can be produced by treating naturally occurring strains with heat or with chemical mutagens, such as nitrous acid. They can also appear after repeated passage of a virus through a certain host plant.

Resistance

It must be recognized that the virus-control methods described above are only partially effective. The difficulties in controlling viral diseases by preventive or curative measures make it logical to look to crop resistance as the ultimate solution.

The principal aim is to produce cultivars able to withstand losses from serious virus diseases and at the same time possess acceptable horticultural characteristics. Ideally resistance should prevent entry, multiplication, and movement of the virus in the host and should be effective against all virus strains. In reality, there are several types of resistance to infection and they differ in their ability to control these viruses (Table 10.4).

Quarantine

It is highly important to control the spread of virus diseases on a worldwide basis and prevent the introduction of viruses not known to be widely established in a country. Because of rapid interregional and intercontinental travel and the increased international trade in seeds, planting materials, and ornamentals, the geographic distribution of many

Table 10.4. Types of resistance to virus diseases.

Resistance Type	Reaction of Virus in the Host[a] Entrance	Multiplication	Movement	Virus Conc.	Symptom	Yield Reduction
Immunity	-	-	-	-	-	-
Extreme resistance	+	-	-	-	-	-
Resistance to spread (hypersensitivity)	+	+ or +/-	-	+/-	+ local	- or +/-
Resistance to multiplication	+	-	- or +/-	+/-	+/-	- or +/-
Symptomless carrier (latency)	+	+	+	++	-	+
Tolerance	+	+	+	++	++ (systemic)	+/- or -
	+	+	+	++	+/- or	+/- or -
Susceptibility	+	++	+	++	++ (systemic)	++

[a]+ = present; - = absent; +/- = present, but not much; ++ = present, very strong.

localized pathogens has expanded and is likely to continue. The probability of virus introductions is greater than ever before. Most countries have import and quarantine regulations aimed at preventing the entry of specific virus diseases.

To maximize the efficiency of quarantine regulations, they must be rational and focused only on viruses likely to cause serious damage. It is, therefore, paramount that the viruses, their epidemiology, effect on yield, and geographic distribution be first known. The African cassava mosaic virus is an example of a threatening virus that has so far only been reported in Africa and which should be prevented from entering other geographic areas where the crop is grown and where the whitefly vector is also present.

Viruses of AVRDC's Principal Crops

The viruses of the AVRDC's principal crops and their characteristics are listed in Tables 10.5-10.10.

Table 10.5 Viruses of peppers.

Virus	Particle Size (nm)	Vector[a]	Host Range	Geographic Distribution
Isometric (Spherical) Viruses				
Belladonna mottle (BMV)	27	B	Solanaceae	Europe, USA
Cucumber mosaic (CMV)	28	A	Wide Monocotyledonae	Worldwide
Tomato aspermy (TAV)	30	A	Wide Dicotyledonae Monocotyledonae	USA, Europe
Tobacco ringspot (TobRV)	28	N	Solanaceae, herbaceous	Canada, USA

Table 10.5. Continued.

Virus	Particle Size (nm)	Vector[a]	Host Range	Geographic Distribution
Tomato ringspot (TomRV)	28	N	Ornamentals, woody, herbaceous herbaceous	Japan, Europe, Chile
Tomato black rir.g (TBRV)	30	N	Wide	Europe
Tobacco streak (TSV)	27-35	T	Monocotyledonae Dicotyledonae	America, New Zealand, Argentina, Europe, Japan
Tomato bushy stunt (TBSV)	30	S	*Capsicum* spp., *Lycopersicon Lycopersicum*	USA, Europe, North Africa
Petunia asteroid mosaic (PeAMV)	30	S	*Capsicum* spp. hop, grape	Europe, North
Tomato spotted wilt (TSWV)	70-90	T	Wide	Possibly worldwide (temperate/ subtropical regions)
Tobacco necrosis (TNV)	26 and 17	F	Wide Monocotyledonae Dicotyledonae	Worldwide
Broad bean wilt (BBWV)	25	A	Dicotyledonae	Argentina, Egypt, Europe, Japan, Morocco
Beet western yellows (BWYV)	26	A	Wide, mainly	Europe, USA Dicotyledonae
Filamentous Viruses				
Chilli veinal mottle (CVMV)	750	A	*Capsicum* spp.	Malaysia
Pepper mild mosaic	714	A	Solanaceae	Venezuela
Pepper mottle (PeMV)	737	A	Solanaceae	El Salvador, USA, India, Thailand
Pepper severe mosaic	761	A	Solanaceae	Argentina
Pepper veinal mottle (PVMV)	770 850	A	Solanaceae	West Africa (Ghana, Ivory Coast, Nigeria), India
Peru tomato virus (PTV)	775	A	Solanaceae	Per ı
Potato virus Y (PVY)	730	A	Mainly Solanaceae	Worldwide
Tobacco etch (TEV)	730	A	Dicotyledonae mainly Solanaceae	USA, Mexico, Sudan, Nigeria, Venezuela

Table 10.5. Continued.

Virus	Particle Size (nm)	Vector[a]	Host Range	Geographic Distribution
Potato virus M (PVM)	650	A	Solanaceae	USSR, India
Potato virus S (PVS)	650	A	Solanaceae	USSR, India
Rod-Shaped Viruses				
Pepper mild mottle (PMMV)	312	C	*Capsicum* sp.	Italy, Germany, Spain, England, Australia
Tobacco mosaic (TMV)	300	C	Solanaceae	Worldwide
Tomato mosaic (ToMV)	300	C	Solanaceae	Worldwide
Bell pepper mottle (BePMV)	300	C	Solanaceae	Argentina
Tobacco mild green mosaic (TMGMV)	310	C	Solanaceae	Germany, Italy, USA
Potato aucuba mosaic	580	C	Solanaceae	Worldwide
Potato virus X (PVX)	515	C	Solanaceae	Worldwide
Tobacco rattle (TRV)	2 components: 21-23x46-117 21-23x185-197	N	Wide (Monocotyledonae)	USA, Europe Brazil, Japan
Bacilliform Viruses				
Alfalfa mosaic (AMV)	5 components: 18 x 18 18 x 29 18 x 38 18 x 49 18 x 58	A	Wide (Dicotyledonae)	Worldwide
Gemini Viruses				
Curly top (CTV)	18-20	L	Wide Dicotyledonae	USA, Canada, Mexico, Europe, Turkey
Tobacco leaf curl (TLCV)	15-20 x 25-30	W	Solanaceae (Compositae)? (Caprifoliae)?	Japan
Other Viruses (not yet characterized)				
Brinjal mosaic		A	*Capsicum* spp.	India
Green vein banding		A	*Capsicum* spp.	Cuba
Pepper vein	679	A	*Capsicum* spp.	India

Table 10.5. Continued.

Virus	Particle Size (nm)	Vector[a]	Host Range	Geographic Distribution
banding				
Launaea mosaic		A	*Capsicum* spp.,	India
L. lycopersicum			*L. lycopersicum*	
Marigold mottle		N	*Capsicum* spp.	India
Chilli leaf curl		W	Solanaceae	Sri Lanka
Pepper yellow vein		F	*Capsicum* spp.	England
Bell pepper dwarf mosaic		?	Solanaceae	India

[a]A = aphid; C = contact; F = fungus; L = leaf hopper; N = nematode; S = soil; T = thrips; W = whitefly; ? = not known.

Table 10.6. Major viruses of tomato.

Virus	Particle Size (nm)	Transmission			Host Range	Geographic Distribution
		Vector[a]	Mech[b]	Seed		
Isometric (Spherical) Viruses						
Cucumber mosaic (CMV)	35	A, np	+	+	Wide	Worldwide
Tobacco spotted wilt (TSWV)	70-90	T	+	+	Wide	Worldwide
Tomato aspermy (TAV)	30	A, np	+	-	Wide	Europe, USA
Tobacco ringspot (TobRV)	28	N	+	?	Solanaceae	Canada
Tobacco streak (TSV)	27-35	T	+	?	Wide	USA, Argentina Europe, Japan, New Zealand
Tomato bushy stunt virus (TBSV)	30	?[c]	+	+	Solanaceae	England, Argentina, Morocco, Mexico
Filamentous Viruses						
Peru tomato virus (TPMV)	775	A, np	+	-	Solanaceae Chenopodiaceae	Peru
Potato virus Y (PVY)	730	A, np	+	?	Wide	Worldwide
Tobacco etch (TEV)	730	A, np	+	-	Wide	North & South America
Rod-Shaped Viruses						
Tobacco mosaic (TMV)	300	-[d]	+	+	Wide	Worldwide
Tomato mosaic (ToMV)	300	-[d]	+	+	Wide	Worldwide
Potato virus X (PVX)	515	-[d]	+	-	Solanaceae	Worldwide
Tobacco rattle (TRV)	2 components 21-23x46-117 21-23x185-197	N	+	?	Wide	USA, Europe, Brazil, Japan

Table 10.6. Continued

Virus	Particle Size (nm)	Transmission			Host Range	Geographic Distribution
		Vector[a]	Mech[b]	Seed		
Gemini Viruses						
Tomato yellow leaf curl (TYLCV)	18-20	W	-	-	Mainly Solanaceae	Israel, North Africa, India, Thailand (?), Taiwan
Tomato yellow dwarf	18-20	W	-	-	Intermediate	Japan
Curly top (CTV)	18-20	L, p	-	?	Wide	USA

[a]A = aphid, N = nematode, T = thrips, W = whitefly, np = nonpersistent, L = leafhopper, p = persistent.
[b]Mechanical transmission is possible = +; mechanical transmission is not possible = -.
[c]The virus is soil-borne.
[d]The virus is transmitted by contact.

Table 10.7. Common viruses of Chinese cabbage.

Virus	Particle Size (nm)	Transmission			Host Range	Geographic Distribution
		Insect[a]	Sap[b]	Seed[c]		
Isometric (Spherical) Viruses						
Turnip yellow mosaic virus (TYMV)	28	FB	+	-	Cruciferae	Western Europe
Cauliflower mosaic virus (CaMV)	50	A, np sp	+	-	Cruciferae	Worldwide
Turnip crinkle virus (TCV)	30	FB	+	?	Wide	Europe
Radish mosaic virus (RaMV)	25-30	B	+	?	Narrow (Cruciferae)	Europe, USA, Japan
Cucumber mosaic (CMV)	28	A, np	+	?	Wide	Worldwide
Beet western yellows (BWYV)	25	A,np	-	-	Wide	Worldwide
Filamentous Viruses						
Turnip mosaic virus (TuMV)	720	A, np	+	-	Wide	Worldwide

[a]A = aphid; B = beetle; FB = flea beetle; np = nonpersistent; p = persistent; sp = semipersistent.
[b]+ = can be transmitted mechanically; - = cannot be transmitted mechanically.
[c]- = the virus is generally not seed-transmitted.

Table 10.8. Major viruses of sweet potato.

Virus	Particle Size	Transmission		Host Range	Geographic Distribution
		Insect[a]	Mech[b]		
Isometric (Spherical) Viruses					
Cucumber mosaic virus (CMV)	28	A, np	+	Wide	Ghana, Israel, USA
Caulimovirus	50	?	?	?	Puerto Rico, Pacific Islands
Gemini Viruses					
Sweet potato leaf curl disease	?	WF	-	*Ipomoea* sp.	Taiwan
Filamentous Viruses					
Sweet potato feathery mottle virus (SPFMV)	850	A, np	+	*Ipomoea* sp., *Nicotiana benthamiana*, *Chenopodium amaranticolor*, *C. quinoa*	Worldwide
Sweet potato vein mosaic virus (SPVMV)	761	A, np	?	Convolvulaceae	Argentina
Sweet potato latent virus (SPLV)	700-750	?	+	Convolvulaceae, *Chenopodium* sp., *N. benthamiana*	Taiwan
Sweet potato mild mottle virus (SPMMV)	800-950	WF	+	Wide, (45 species, 14 plant families)	East Africa
Sweet potato yellow dwarf virus SPYDV)	750	WF	+	Convolvulaceae, *Chenopodium* sp., *Gomphrena globosa*, *Sesamum orientale*, *Datura stramonium*, *Cassia occidentalis*	Taiwan
Others					
Sweet potato virus disease[c]				*Ipomoea* sp.	Nigeria

[a]A = aphid, W = whitefly, np = nonpersistent.
[b]+ = mechanical transmission is possible; ? = not known.
[c]A disease due to synergistic action of two viruses, a strain of FMV and an unidentified whitefly-transmitted agent. Symptoms caused by either agent alone are relatively mild or nonexistent in sweet potato.

Table 10.9. Major viruses of soybean.

Virus	Particle Size (nm)	Transmission			Host Range[d]
		Insect[a]	Sap[b]	Seed[c]	
Isometric (Spherical) Viruses					
Peanut stunt	30	A, np	+	+	(Low) Wide
Soybean stunt (SSV)	25-28	A, np	+	+	Intermediate
Soybean dwarf (Japan) (SDV)	25	A, np	-	-	Narrow
Tobacco ringspot (TRSV)	28-30	T, N	+	+	Wide
Tobacco streak (TSV)	25-30	?	+	+	Wide
Bean pod mottle (BPMV)	28	B	+	+ (very low)	Narrow (Leguminosae)
Cucumber mosaic (CMV)	29	A, np	+	+	Wide
Cowpea chlorotic mottle (CCMV)	26	B	+	-	Intermediate (Leguminosae) Cucurbitaceae Solanaceae
Cowpea mottle	30	B	+	+	intermediate (Leguminosae)
Cowpea mosaic (CpMV)	20-24	B	+	+ (low)	Intermediate (Leguminosae)
Cowpea severe mosaic (CSMV)	25	B	+	+ (not in soybean)	Intermediate (Leguminosae)
Black gram mottle (BGMV)	28	B	+	+	Narrow
Indonesian soybean dwarf (ISDV)	25-30	A, np	-	-	?
Broad bean mottle (BBMV)	26	B	+	-	Intermediate
Soybean chlorotic mottle	25	?	+	-	Narrow
Subterranean clover red leaf	27, 30	A, p	-	-	Intermediate
Soybean mild mosaic	26	A, np	+	+ high	Intermediate
Pea leafroll		A, np	-	-	Narrow
Broad bean wilt (BBWV)	25	A, np	+	-	Wide
Southern bean mosaic (SBMV)	28	B	+	+ (low)	Narrow (Leguminosae)
Tomato spotted wilt virus (TSWV)	85	T	+	-	Wide

Table 10.9. Continued.

Virus	Particle Size (nm)	Transmission			Host Range[d]
		Insect[a]	Sap[b]	Seed[c]	
Filamentous Viruses					
Soybean mosaic (SMV)	750	A, np	+	+	Narrow
Bean common mosaic (BCMV)	750	A, np	+	+	Intermediate
Bean yellow mosaic (BYMV)	750	A, np	+	+ (low) (not in soybean)	Wide
Peanut mottle (PMV)	750	A, np	+	+ (not in soybean)	Narrow (Leguminosae)
Cowpea aphid borne mosaic	750	A, np	+	+	Intermediate (Leguminosae)
Cowpea mild mottle (CMMV)	650-700	W, sp	+	+	Intermediate (Leguminosae) Solanaceae
Peanut stripe (PStV)	750	A, np	+	+	Leguminosae
Blackeye cowpea mosaic (BlCMV)	753	A, np	+	+	Intermediate
Adzuki bean mosaic (AZMV)	750	A, np	+	+	Narrow (Leguminosae)
Cowpea mild mottle	650	B, sp	+	+	Intermediate
Rod Shaped Viruses					
Peanut clump (PCV)	245,160,190	F	+	+	Intermediate
Tobacco rattle (TRV)	2 components: 46-117 185-197	N	+	?	Wide
Bacilliform Viruses					
Alfalfa mosaic (AMV)	5 components 18 18 x 29 18 x 38 18 x 49 18 x 58	A, np	+	+	Wide
Gemini Viruses					
Bean golden mosaic (BGMV)	30	W	+	-	Narrow
Soybean crinkle leaf	30	W	-	-	Wide

Table 10.9. Continued.

Virus	Particle Size (nm)	Transmission			Host Range[d]
		Insect[a]	Sap[b]	Seed[c]	
Mungbean yellow mosaic (MYMV)	30	W	+/-	-	Narrow (Leguminosae)
Others					
Groundnut rosette	?	A[e]	+	?	Narrow
Mungbean mosaic	?	?	+	+	Narrow

[a]A = Aphid; F = Fungus; W= Whitefly; T = Thrips; N = Nematode; B = Beetle; np = nonpersistent; p = persistent; sp = semipersistent.
[b]+ = can be transmitted mechanically; - = cannot be transmitted mechanically;+/- = can be transmitted with difficulty.
[c]+ = the virus is generally seed-transmitted but not necessarily in soybean; - = the virus is generally not seed-transmitted.
[d]Narrow host range = 1-3 families; intermediate host range = 3-10 families; wide = more than 10 families.
[e]Helper virus required.

Table 10.10. Major viruses of mungbean.

Virus	Particle Size (nm)	Transmission			Host Range[d]
		Insect[a]	Sap[b]	Seed[c]	
Spherical (Isometric) Viruses					
Tobacco ringspot (TRSV)	28-30	T, N	+	+	Wide
Cucumber mosaic (CMV)	29	A, np	+	+	Wide
Cowpea chlorotic mottle (CCMV)	26	B	+	-	Intermediate (Leguminosae) Cucurbitaceae Solanaceae
Cowpea mottle	30	B	+	+	Intermediate (Leguminosae)
Cowpea mosaic (CpMV)	20-24	B	+	+ (low)	Intermediate (Leguminosae)
Southern bean mosaic (SBMV)	28	B	+	+ (low)	Narrow (Leguminosae)
Filamentous Viruses					
Bean common mosaic (BCMV)[e]	750	A, np	+	+	Intermediate
Bean yellow mosaic	750	A, np	+	+ (low) (not in soybean)	Wide

Table 10.10. Continued.

Virus	Particle Size (nm)	Transmission			Host Range[d]
		Insect[a]	Sap[b]	Seed[c]	
Peanut mottle (PMV)	750	A, np	+	+ (not in soybean)	Narrow (Leguminosae)
Cowpea aphid borne mosaic	750	A, np	+	+	Intermediate (Leguminosae)
Cowpea mild mottle	650	B, sp	+	+	Intermediate
Blackeye cowpea mosaic (BlCMV)	753	A, np	+	+	Intermediate
Adzuki bean mosaic (AZMV)	750	A, np	+	+	Narrow Leguminosae)
Bacilliform Viruses					
Alfalfa mosaic (AMV)	5 components 18 18 x 29 18 x 38 18 x 49 18 x 58	A, np	+	+	Wide
Gemini Viruses					
Mungbean yellow mosaic (MYMV)	18 x 30	W	+/-	-	Narrow (Leguminosae) Compositae? Graminaceae?
Others					
Mungbean mosaic	700-750	A, np	+	+	Narrow (Leguminosae)
Mungbean leaf crinkle	?	A, np	+	+	*Vigna aureus* *Vigna unguiculata* *Phaseolus aconitifolius*

[a]A = Aphid; W = Whitefly; T = Thrips; N = Nematode; B = Beetle; np = non-persistent; p = persistent.
[b]+ = can be transmitted mechanically; - = cannot be transmitted mechanically;
+/- = can be mechanically transmitted with difficulty.
[c]+ = the virus is generally seed-transmitted but not necessarily in mungbean;
- = the virus is generally not seed-transmitted.
[d]Narrow host range = 1-3 families; intermediate host range = 3-10 families;
wide host range = more than 10 families.
[e]Sometimes referred to as the mungbean strain of BCMV (M-BCMV).

Part III - Weeds

Weeds are commonly defined as plants that are not desired and grow out of place. They can be a problem in vegetable production because they compete with the crops for nutrients, light, and water. This competition reduces yield, as well as vegetable quality.

Some weeds also harbor insects and plant pathogens that damage crops. For instance, the common purslane and tropic ageratum are hosts of root-knot nematodes; horse purslane and spiny amaranth are hosts of the tobacco mosaic virus. Weeds also interfere with farm operations, such as water management and harvesting; and they may impair the health of man and his animals.

Weeds are generally more competitive than many of the cultivated crops. They are persistent, and they possess survival mechanisms and adaptations that enable them to exist under unfavorable conditions. Some examples are the prolific production of seeds, production of numerous vegetative propagation organs (rhizomes, tubers, runners), effective means of dissemination, and dormancy of seeds and vegetative propagules.

Classification of Weeds

Weeds are classified in many ways. Some common and practical ways of classification are as follows:

Based on life duration. Annuals are weeds that complete their life cycle within one year or less. They germinate, undergo vegetative growth, and reproduce within this period.

Biennials complete their life cycle in more than a year. In the first year, the stems, leaves, and stored food are established; in the second year, the fruits and seeds are produced.

Perennials are the weeds that continue to live every year. Their food supply comes from the vegetative organs which store food.

Based on habitat. Terrestial weeds grow normally on land; aquatic weeds grow in areas under water.

Based on plant groups. Broadleaves are dicotyledonous or monocotyledonous plants with expanded leaf blades.

Grasses are plants belonging to the family Graminae or Poaceae. They have stems (culms) with swellings (nodes) at regular intervals from which leaves arise alternately. The leaves are characterized by a sheath which clasps the stem, and the upper blade which is thin, narrow, and linear with parallel veins.

Sedges are monocotyledonous plants belonging to the Cyperaceae family. Many have triangular stems which are enclosed by the fused leaf sheaths. The thin, narrow leaves are in a rosette form. Basal leaves are present in many of the sedges.

Some common weeds of vegetables are listed in Table 10.11. Pictures of some weeds are shown in Figs. 10.37a-h, See p. 321-322).

Occurrence and Dissemination

The weed vegetation of a particular area depends on climatic, soil, and biological factors. Weeds in temperate localities differ from those in tropical countries. Even within

Table 10.11. Some common weeds of vegetables in the tropics.

Scientific Name	English Name
Broadleaves	
Celosia argentea L. (Fig. 10.37a)	Celosia
Portulaca oleracea L. (Fig. 10.37b)	common purslane
Commelina benghalensis L.	spreading dayflower
Eclipta prostrata L.	Eclipta
Euphorbia hirta (L) L.	garden spurge
Bidens pilosa L. (Fig. 10.37c)	hairy beggarticks
Trianthema portulacastrum L.	horse purslane
Heliotropium indicum L. (Fig. 10.37d)	Indian helioptrope
Peperomia pellucida (L) H.B & K (Fig. 10.37e)	peperomia
Amaranthus viridis L. (Fig. 10.37f)	slender amaranth
Cleome rutidosperma D.C.	spindletop
Amaranthus spinosus L.	spiny amaranth
Ipomoea triloba L.	three-lobe morning glory
Ageratum conyzoides L. (Fig. 10.37g)	tropic ageratum
Grasses	
Dactyloctenium aegyptum (L) Beauv.	crowfoot grass
Eleusine indica (L.) Gaertn. (Fig. 10.37h)	goosegrass
Rottboellia exaltata L.f.	itchgrass
Echinochloa colona (L) Link	jungle rice
Digitaria sanguinalis	large crabgrass
Sedge	
Cyperus rotundus L.	purple nutsedge

tropical areas, weeds in the higher altitudes differ from those in the lower areas. In a climatic zone the distribution of weeds is influenced by soil and biotic factors. Soil moisture, pH, temperature, and nutrient status greatly affect weed occurrence. Biotic factors include man, animals, other plants, insects, and soil organisms.

Weeds are disseminated in many ways. Weed seeds contaminate or mix with crop seeds, feed grains, or straw. Other weeds have structures that make them easily carried by wind. Still others are carried by water in streams and rivers or in irrigation and drainage canals. Man and animals also help carry weed seeds on their feet, on their fur or clothes, or as ingested seeds. Some of these seeds have barbs, hooks, and spines.

Crop-Weed Competition

Growers erroneously assume that removing weed competition any time during the growing season solves the weed problem. Substantial evidence indicates that the time of weed removal is as important as the removal itself. Usually the sooner the weeds are removed, the better. It is good to have the plot without weeds all the time, but this may not be economical.

Fig. 10.37a. *Celosia argentea* L.

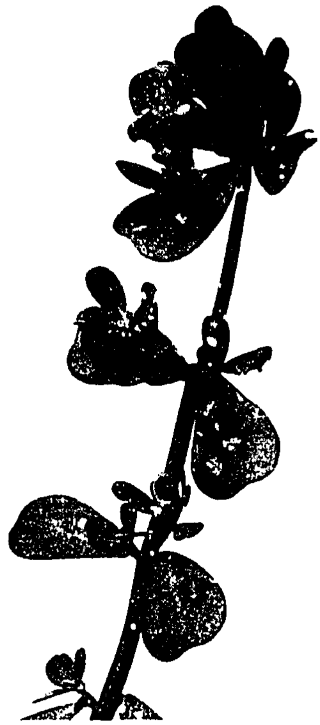

Fig. 10.37b. *Portulaca olenacea* L.

Fig. 37c. *Bidens pilosa* L.

Fig. 37d. *Heliotropium indicum* L.

Fig. 10.37e.
Peperonia pellucida (L.).

Fig. 10.37f.
Amaranthus viridis L.

Fig. 10.37g. *Ageratum coryzoides* L.

Fig. 37h. *Eleusine indica* (L.) Gaertn.

Economic advantage is the idea behind the concept of "critical period of weed competition". Undoubtedly, the longer the weeds compete with the crop, the greater their effect will be. However, this effect is negligible until the environmental resources (air, water, nutrients) cease to meet the needs of both the crop and the weed. Control is needed at the critical period when the demands of both types of plants cannot be met. Generally, the term "critical period" refers to the maximum period weeds can be tolerated without affecting crop yield.

Studies on yield reduction of some vegetables showed the following results:

- Carrot — If a 15% weed stand was allowed to grow for the first 5 1/2 weeks before removing it, carrot yield was reduced by 78%; on a 50% weed stand, reduction was 91%.
- Onion — If a 15% stand of weeds was allowed to grow for the first six weeks before removal, bulb weight was reduced by 36%; on a 50% weed stand, reduction was 91%.
- White potato — Yield reduction ranged from 10%-72%.
- Tomato — Yield reduction ranged from 39%-87%.
- Transplanted cabbage — Yield reduction ranged from 52%-90%.

The critical weed-competition period for most vegetable crops is at the first third of the crop life cycle. Onion is, however, susceptible to weed competition and requires a weed-free condition for more than half of its life cycle. To reduce the critical weed-free period, vegetables are transplanted to give them an advantage over the weeds.

Weed Control Approaches

Principles of weed control. To successfully implement a system of controlling weeds in a farm, some important guiding principles must be followed:

1. A weed control program does not aim to eradicate weeds, but rather to reduce weed population to the minimum that would allow optimum crop yield.

2. Weed control should be done early in the growing period and sustained until the vegetable crop is able to compete effectively with weeds.

3. The organs of reproduction and of dispersal must be the main target against weeds.

4. The weeds should be controlled before flowering.

5. Prevent the introduction of weed seeds by using vegetable planting materials which are free from weed seeds, by cleaning weeding implements before transferring them from one field to the other, and by reducing spread of weed seeds through irrigation canals.

Specific weed control methods. Several methods which vary in their efficiency to control weeds are used. The advantages and limitations of the different methods are briefly discussed below:

1. Physical/mechanical methods — These methods are quite common in small vegetable farms.

a. Hand pulling — This is the method most suited for home or backyard gardens where a variety of vegetables are grown. It is very effective but time-consuming.

b. Use of tools (hoe) — These are faster than hand pulling weeds between rows of plants and are commonly used in small farms.

c. Cultivation — This makes use of implements which disturb the root system or physically damage the weeds. They may be animal- or tractor-drawn. The tractor is quite convenient and less time-consuming for bigger areas.

It has two main operations: off-barring which cultivates the soil away from the rows, and hilling-up which throws the soil towards the base of the plants. If these operations are done at the right time, the weeds within the rows can also be controlled. However, for this method to be effective, the soil must not be too wet.

d. Mulching — This is very effective in controlling weeds. If natural organic mulches are used, they help conserve moisture, reduce the incidence of fruit rot in some vegetables, and add organic matter to the soil when they decay. The limitation of this method is the unavailability of mulching materials for large farms.

2. Cultural method — This involves the judicious use of management practices which render the environment unfavorable to weeds. Examples of this method are the use of competitive vegetable species and cultivars, closer spacing, thorough land preparation, and multiple cropping.

3. Chemical control — This control method has developed rapidly since the 1940s. The chemicals used for killing the weeds are called ***herbicides.*** Herbicides have gained importance in vegetable production because of their selective properties; that is, they kill some plants but do not harm others.

The chemical method does not require much labor, and it can be done to control weeds within the plant rows, even when the soil is too wet for the mechanical method to be used. This method is also popular in places where labor is very expensive or not readily available.

4. Management approach — This combines the different weed control methods during the whole cropping period. A suggested integrated approach follows:

- Preventive: the practice of sanitation is one example.
- Proper and thorough land preparation
- Application of preemergence herbicide
- Hand weeding or mechanical weeding at 30 days after sowing or transplanting; application of postemergence herbicide when available
- Cultivation - off-barring followed by hilling-up, with timing depending on weed growth
- Hand weeding within the rows of the crop

Chemical Weed Control

The life processes of plants are many and varied. They are complex and delicately balanced. Disturb one even slightly, and a chain of events that will cause major changes in the plant metabolism may be set off. Herbicides work on these very factors which may be based on the following differences: (1) morphological, (2) absorption, (3) translocation, or (4) physiological.

Morphological differences. These may be differences in the location of the meristematic region. The growing point of dicotyledons (broadleaf plants) is at the apex in the terminal portion of the stem; the growing point of monocotyledons (grasses) is at the node which is protected by the leaf sheath. Other differences are in the waxiness, hairiness, and pubescense of the plant which may present spray droplets from adhering to the leaf. Another factor may be the leaf angle or leaf orientation.

Absorption. Absorption of chemicals may depend on the plant species and the types of chemicals. Therefore, differential or selective absorption may account for differences in plant responses. In essence some plants absorb chemicals quicker than others through the leaves, cuticles, cell walls, root,and the stem.

Some herbicides or formulations referred to as "nonpolar" penetrate the leaf surfaces faster than polar ones. Wetting agents are used to increase the absorption and hence the activity of herbicides in the plants. The addition of wetting agents tends to equalize foliar herbicide absorption in all plants. Therefore, it may reduce the selectivity of the herbicide. Temperature also increases the absorption of chemicals.

Translocation. Chemicals are translocated through plants in a number of ways: through the phloem and xylem, and between the cells (intercellular). Phloem translocation generally moves from the leaves toward the roots. The phloem tissues are composed of living cells. Extremely toxic chemicals quickly kill the cells and stop translocation. For example, 2, 4-D is translocated at a rate of 100 cm/hour in some plants. The translocation parallels the movement of food from the leaf to other plant parts.

Of course, these rates and spraying times vary with the plant species. Xylem translocation moves herbicides from the soil, through the roots, and upward along with the transpiration stream of water and nutrient. Leaf-sprayed herbicide may first be translocated through the phloem downward and then through the xylem upward.

Physiological differences. These differences are only slightly understood. They may be differences in the enzyme systems, in the response to pH changes, in cell metabolism, in cell permeability, and in chemical constituents. A change in one or more of these may block or stimulate certain biochemical processes. Photosynthesis (starvation) and respiration (energy) are two major physiological processes involved.

Types of Herbicides

Contact herbicides kill plant parts which are covered by the chemical. The chemical used must be toxic to living cells. There is little or no translocation through the living cells, such as in the phloem. However, the chemicals may move upward in transpiration through the xylem (nonliving) cells.

Generally, the effect is acute and the plants die quickly after treatment. These chemicals are effective against annual weeds, but they only burn off the tops of perennials weeds. Contact herbicides are rarely selective. A nonselective herbicide is toxic to all plants. Living plant tissue has little or no resistance to this type of herbicide.

Growth regulators are usually growth substances which are translocated herbicides and systemic herbicides. They can be absorbed by either root or aboveground plant parts and moved (by translocation) through the plant system. The chemicals unbalance plant growth and metabolic processes. It is believed that they normally affect the plant's enzyme system. They may have a chronic effect, that is, the full effect may not show up until a week to a month or more after the treatment.

These chemicals are absorbed by the leaf and move from there through the phloem. An overdose on the leaves may kill the immediate cells quickly and thus prevents effective translocation. Therefore, in killing the underground parts by leaf treatment, it is desirable to apply the chemical at a low rate and repeat as needed. Growth regulators are usually selective, but overdoses will kill all plants. Examples of growth regulator herbicides are 2,4-D; 2,4,5-T; MCPA; and 2,4,5-TP.

A soil sterilant is any chemical in the soil which prevents the growth of green plants.

Timing of Chemical Treatment

The timing of herbicide application may vary with respect to the crop or to the weed. "Preplant" applications are those made before the crop is planted. "Preemergence" herbicides are those applied prior to the emergence of a specified crop or weed or both.

Types of Application

Herbicides may be applied in the following ways:

1. Broadcast treatment — a blanket application uniformly placed on an entire area.

2. Band treatment — treatment in a narrow band or strip directly over or in the crop row. The space between the rows is not treated. This method saves chemicals and money.

3. Directed treatment — applied to a particular part of the plant. Precise application enables the treatment to specific areas of the weed, row, bed, leaves, or stems.

4. Spot treatment — a treatment to a restricted area, usually to control an infestation of a weed species requiring special treatment. Soil sterilants are often used to control a serious growth of perennial weeds in a small area.

Herbicides and the Soil

Many factors influence the effectiveness of an herbicide. Herbicides applied in the soil are affected by certain soil characteristics; whereas those applied through foliar application are not. The length of time that a herbicide remains active in the soil is extremely important, as it relates to the length of time that weed control can be expected.

Also there may be a problem of residual toxicity to the succeeding crops. Herbicides may be lost faster in the soil with large amounts of water through heavy leaching and with repeated cultivation or mixing of the soil. The factors which affect their persistence in the soil are (1) microorganisms, (2) chemicals, (3) absorption of soil colloids, (4) leaching, (5) volatility, and (6) photo-decomposition.

Fungi, actinomyces, and bacteria might use organic herbicides as a carbon source which results in the microbial decomposition of the herbicide. The larger the number of microbes, the faster is the decomposition. Thus warm, moist, well-aerated, and fertile soils are most favorable for microbialactivity. Medium soil pH is favorable to the activity of many microbes, while a pH below 5.5 reduces it.

For most herbicides applied at the recommended rates for cultivated crops, the residues last shorter than six months; rarely do residues persist longer than one year. Chemical decomposition such as oxidation, reduction, hydrolysis, and hydration destroy some herbicides.

Application rates for soil-applied herbicides may be increased in soils with high organic matter or high clay content. This may be due to the fact that only small amounts of herbicides are readily available in these soils.

Preemergence herbicides are frequently applied to the soil surface. Rain leaches the chemical into the upper soil layers where it remains near the soil surface. The extent of leaching is determined by the solubility of the herbicide in water, the amount of carrying water, and the absorption capacity of soil colloids.

Volatile herbicides may be toxic to untargeted plants. Generally, temperature increases volatility while rain and moisture decrease it.

Light results in the photo-decomposition of herbicides. Sunlight directly decomposes herbicides. Indirectly, raised temperatures caused by sunlight increase microbe population that decomposes the herbicides.

Types of Herbicide Formulations

The major types of herbicide formulations are emulsions, wettable powder, and granules. An emulsion is one liquid dispersed in another liquid, each maintaining its original identity. Without agitation the liquids may separate. Once the emulsions are thoroughly mixed, they require little agitation to prevent separation. Oil-soluble herbicides are often formulated for mixture with water as an emulsion. Emulsions often appear milky and are easy to spray.

A wettable powder is a suspension which consists of finely divided solid particles dispersed in liquid. Some herbicides are nearly insoluble in both water and oil-like substances. Therefore, they are finely ground and the powder is mixed in water or oil carriers. Most suspensions require agitation to prevent the settling of the solid particles. The smaller the size of the particles, the slower the rate of separation. Similar densities of solid particles and liquid also slow down the rate of separation.

Carriers such as sand, clay, and finely ground plant parts can be used. The advantage of carriers is that water and spray equipment are not needed; and the granules fall off the leaf easily. The major disadvantages of granules are that they are bulky and are seldom applied uniformly.

Some herbicides used in vegetables are indicated in Table 10.12.

Table 10.12. Herbicide recommendations for preemergence control of weeds.

Crop	Herbicide: Common Name	Herbicide: Trade Name	Application: Rate (kg.a.i./ha)	Application: Time	Weeds Controlled
Bush sitao, cowpea, lima beans	Trifluralin	Treflan (4 lb/gal)	1	within 2 days after planting	Annual grasses and a few annual broadleaves
	DCPA or Chlortal	Dachthal (75% WP)	8	same as above	Same as above
	Prometryne	Gesagard	1.5	same as above	Annual grasses and some annual broad-leaves; cannot control *Rottbőellia exaltata*
White potato	Ametryne	Gesapax (80% WP)	1-2	same as above	*Spergular arvensis*, *Galinsoga parviflora*, and other annual grasses and broad-leaves
	Linuron	Afalon,Lorox (50% WP)	1-2	same as above	Same as above
	Prometryne	Gesagard (80% WP)	1-2	same as above	Same as above
	Diphenamid	Dymid, Enide	2-4	same as above	Same as above
Onion (transplanted)	Trifluralin	Treflan	1-2	same as above	Annual grasses like *Echinochloa colonum*, *Eluesine indica*, and annual broadleaves like *Portulaca oleraceae* and *Trianthema portulacastrum*.
	Nitrofen	TOK - E 25 (2 lbs/gal)	1-2	same as above	Same as above
		TOK - 50 W	1-2	same as above	Same as above
	DCPA or Chlortal	Dacthal (75% WP)	8	same as above	Same as above
	Butachlor	Machete (600 g/l)	2	same as above	*E. colonum*
Cabbage or tomato (transplanted)	Napropamide	Devrinol (50% WP)	1.5	Incorporated in the soil before planting	*C. rotundas*
	Butralin	Amex 820 (4 lb/gal)	1.5	same as above	Grasses and few broadleaves
	Napropamide + Butralin		1 + 1	same as above	For a mixed population of *C. rotundas* and grasses

Part IV. Insect Pests

The destructive insects affect the yield of vegetable crops by feeding on the leaves, sucking the cell sap, and in some cases carrying disease-causing organisms which are transferred to other plants. As a result, the area for photosynthesis is reduced, plants are curled, and blemishes such as spotting, fruit discoloration, and perforations on heads and fruits appear. These lead to considerable reduction in yield and quality of vegetables.

Control Methods

There are several ways to control insects satisfactorily, but the first thing to do is to identify which of these insects are beneficial and which are destructive. The following control methods are recommended:

Mechanical and cultural methods. These are the oldest methods of insect control. They are used to (1) directly destroy the insect, (2) interfere with the normal biological processes of the insect, or (3) make the environment unpleasant for the insect. These methods are the following:

1. Sanitation — The main objective of this method is to make the production area clean and free of materials where the insect is likely to live and multiply after harvest of the vegetables. Plant residues, animal manure, and discarded vegetables must be covered with soil.

2. Crop rotation — Vegetables should not always be grown in the same area where infestation has occurred. If this cannot be avoided, the sequencing of the vegetable crops should be varied. Do not plant immediately after plowing to minimize damage as grubs may be prevalent during this stage of land preparation.

3. Cultural practices — These comprise the different field operations in crop protection. To effectively control insects, these operations must promote favorable growth of the vegetables. An example is proper timing of planting to escape the peak of insect infestation. Other practices are transplanting instead of direct seeding and cultivating the soil to injure or kill insects and weeds.

4. Use of physical barriers, traps, handpicking and in some cases use of soap and detergent sprays to injure or kill soft-bodied insects, such as mites, aphids, and thrips.

Biological control. This method makes use of living organisms, such as parasites, predators, microbial insecticide, and even birds to reduce the insect population below the economic level.

The use of resistant cultivars is also a kind of biological control which minimizes undesirable side effects. Once established, these crops are very economical to maintain and more or less permanent. On the other hand, biological control cannot easily be established. It may also reduce the number of beneficial insects, as some predators may feed on them. Moreover, not all insects are susceptible to biological control; and handling of the organisms for transport can be a problem.

Chemical control. This consists mainly of using natural and synthetic materials, otherwise known as insecticides, to kill insects. This is the most common method used at present because insecticides are readily available, easy to apply, and effective. The natural insecticides are manufactured from plants, thus, they are referred to as botanical insecticides. Synthetic insecticides are as toxic as the natural, but are readily degraded so that they have very negligible residual effects on humans.

Insect Pests of Tomato

Tomato Fruit Worm

Tomato fruit worm, *Heliothis armigera* (Huebner) (Lepidoptera: Noctuidae) is one of the most destructive pests of tomato. It attacks a wide range of crop plants including cotton, tobacco, corn, sorghum, sunflower, soybean, okra, pepper, and eggplant.

Biology. The adult female lays eggs singly on the upper leaf surface. Egg incubation lasts for about eight days. The newly-hatched larva feeds on the foliage first and then descends and attacks tomato fruits. The insect feeds while hiding inside the fruit where it undergoes five to six larval instars in 15-35 days. The full-grown larva comes out of the damaged fruit and pupates in the soil for 10-12 days. The adult is yellowish brown with some irregular crosslines on its forewing.

Damage. Foliage-feeding by newly emerged larvae does not cause any significant damage, but fruit boring results in yield loss of up to 70%.

Control. This polyphagous insect has developed resistance to many commonly used chemicals. Therefore, when choosing a chemical spray, its efficacy against the pest should be tested first. In Taiwan, tomato fruit worm has not developed any significant level of resistance to synthetic pyrethroids and deltamethrin. Permethrin, cypermethrin, and fenvalerate sprayed at 50-100 g a.i./ha can control these insects. Planting tomato near cotton or corn plants should also be avoided to reduce heavy insect infestation.

Cotton Aphid

Cotton aphid, *Aphis gossypii* Glover (Homoptera: Aphididae), is a major pest of tomato especially in the cool, dry autumn and winter seasons.

Biology. This pest reproduces without fertilization. A single female produces 20-140 nymphs. Adults measure about 1-2 mm in length.

Damage. The aphids cause injury by sucking the plant sap. Heavily infested plants appear stunted and leaves curl down at the edges. This insect also transmits viruses.

Control. Several species of coccinellid beetles and syrphid prey on aphids. However, these natural enemies are found mostly where the aphid population is high, indicating that the damage is already significant and control may no longer be effective. Dimethoate and prothiophos can adequately control. Pirimicarb, an aphicide, may also be used, but it may cause phytotoxicity in some tomato cultivars.

Insect Pests of Crucifers

Diamondback Moth

Diamondback moth (Fig. 10.38, See p. 340), *Plutella xylostella* (L.) (Lepidoptera: Yponomeutidae), is the most destructive insect pest of all crucifers. It is distributed worldwide and is becoming a serious pest in other areas.

Biology. The brown adult moths are about 8-12 mm long. They bear white spots on the forewings, which appear like diamond patterns when the wings are folded. Adult females lay small yellowish eggs singly on the underside of the leaves. Eggs hatch in two to three days. The newly hatched larva bores into the plant tissue from the underside of leaves and feeds in these tunnels. During the ten-day larval period, the larva constructs a silken cocoon on the leaves for pupation. The adults emerges in four to five days.

Damage. The larvae feed from the underside of leaves, leaving intact a transparent cuticular layer on the upper leaf surface. Damaged leaves are riddled with holes and the produce becomes unfit for human consumption. Yield is lost when infestation occurs in the early growth stage.

Control. In recent years it has become difficult to control this pest by readily available chemical insecticides because the insect has developed resistance to most of them. However, biological control measures may help reduce the population and damage by this pest. Parasitic wasps like *Diadegma eucerophaga, Apanteles plutellae*, and *Hyraeella collaris* are good control agents in areas where they are established. All *Bacillus thuringiensis* formulations can control diamondback moth and other pests such as cabbage looper (*Trichoplusia ni*), imported cabbageworm (*Pieris rapae*), and cutworms (*Spodoptera litura, S. exigua*). Insect growth regulators are also effective against a wide range of caterpillar pests, including diamondback moth, and are safe to parasites.

Cabbage Webworm

Cabbage webworm, *Hellula undalis* F. (Lepidoptera: Pyralidae), is a destructive pest of crucifers which causes serious damage in hot and humid summer months.

Biology. The adult cabbage webworm lays eggs on the foliage of cruciferous seedlings soon after transplanting. The oval pinkish-colored eggs are laid singly or in clusters of two to four eggs on the undersurface of the leaf. The eggs hatch in two to three days. The larva constructs a web on the growing point and feeds inside. It molts four times in 7-12 days. The full-grown caterpillar forms a cocoon on basal leaves in the feeding tunnel. Pupal period lasts for six days and a full cycle is completed in 15-25 days.

Damage. The caterpillar feeds on the growing point of the seedling. If a growing plant survives this attack it forms several small unmarketable heads. Control measures should be adopted soon after transplanting when the growing points of the plants are still open, otherwise, replanting of the crop is necessary. Once head formation begins and the growing point is covered, this pest can no longer cause any significant yield loss.

Control. Seedlings should be covered with nylon net cage to prevent the adult webworm from laying eggs on the foliage. In areas where the pest is endemic, insecticides must be sprayed within a week after transplanting and repeated once a week for four weeks to kill the larvae before they cause damage. Insecticides like EPN, triazophos, and methomyl are recommended.

Striped Flea Beetle

The major hosts of the striped flea beetle (Fig. 10.39, See p. 340), *Phyllotreta striolata* (F) (Coleoptera: Chrysomelidae), are cruciferous vegetables, such as common cabbage, cauliflower, and Chinese cabbage. This occurs mainly during the cool, dry season.

Biology. Female adults lay eggs in the soil near the plant. The larvae live in the soil and feed on the roots and other plant debris. Pupation also takes place in the soil. The adults have yellow stripes on their black elytra (forewings) and jump in a flea-like manner.

Damage. The adults feed on the foliage of young cruciferous plants producing small round holes all over the leaf surface and sometimes cause seedlings to die. Larval feedings rarely cause significant damage, but a large number of larvae feeding on the roots may result in wilting of plant.

Control. The adults can be controlled easily by spraying contact insecticides. In fields where the striped flea beetle is endemic, spot application of carbofuran 3G in transplanting holes before planting will reduce larval population.

Imported Cabbage Worm

The imported cabbage worm (Fig. 10.40, See p. 340), *Pieris rapae* (L) (Lepidoptera: Pieridae), is a widespread pest of crucifers in most subtropical and temperate countries.

Biology. Tiny yellow eggs are laid singly on both sides of the leaf surface and are hatched in about a week's time. The larvae are velvety, green pubescent caterpillars. Larval period lasts for two to three weeks. Pupation takes place on the leaves and lasts for about ten days. The adults are white butterflies, tinged with yellow and with several black spots on the wings.

Damage. The larvae feed on the leaves and may completely skeletonize the foliage, thus reducing quality and quantity of the yield.

Control. This insect can be easily controlled by *Bacillus thuringiensis* spray.

Cabbage Looper

The cabbage looper, *Thrichoplusia ni* (Hubner) (Lepidoptera: Noctuidae), which is not common in the tropics, infests crucifers in the cool, dry autumn and winter months. Alternate hosts are beans, including soybean.

Biology. Female moths lay dome-shaped, pale green eggs on the crucifers. Soon after hatching the larvae start feeding on the foliage. The larva has three prolegs and makes characteristic loops while moving on the plant surface. Larval stage lasts for two to four weeks. Pupation takes place in the soil and the adult emerges in seven to ten days.

Damage. Larvae feed on the foliage of crucifers and skeletonize the leaves. As a result of their feeding, the quality and yield of cabbage are reduced especially when the damage occurs before the heading stage. Once the head is formed, the insect feeds on outer leaves which rarely affects the yield.

Control. This pest, being a surface feeder, can be controlled easily by application of recommended contact insecticides. Formulation of *Bacillus thuringiensis* can also give satisfactory control of cabbage looper in the larval stage. This insect is also susceptible to the nuclear polyhedrosis virus found in the soil. During a virus epidemic practically all larvae are killed.

Aphids

Brevicoryne brassicae (L), *Lipaphis erysimi* Davis, and *Myzus persicae* Sulzer (Homoptera: Aphididae) are three major aphid species that damage cruciferous vegetables in the cool, dry time of the year.

Biology. Aphids produce young ones parthenogenetically (without mating) and viviparously (producing nymphs and not eggs). Each adult produces 50-60 nymphs which develop and reproduce in a short span of time. A life cycle is completed in eight to ten days.

Damage. The nymphs and adults suck plant sap and transmit virus diseases. Heavily infested plants are stunted and yield is reduced. Chinese cabbage may not survive aphid infestation but common cabbage is more tolerant.

Control. Coccinelid adults and syrphid larvae serve as biological control agents when population is high. Pirimicarb, a selective insecticide sprayed at the rate of 0.5 kg a.i./ha, gives excellent control of aphids on crucifers.

Insect Pests of Mungbean

Bean flies in seedling stage, pod borer in podding stage, and bruchids in storage are the major pests that affect mungbean production in tropical and subtropical Asia.

Bean Flies

Three species of bean flies, *Ophiomyia phaseoli* (Tryon), *Ophiomyia centrosematis* (De Meijere), and *Melanagromyza sojae* (Zehntner) (Diptera: Agromyzidae), are very destructive pests of mungbean in tropical to subtropical Asia. The nature of their damage, biology, and control measures are similar to those described for soybean pests.

Pod Borers (Figs. 10.41a and b, See p. 341).

At least five species of insects infest mungbean pods when they are green. The species *Maruca testulalis, Etiella zinckenella, Heliothis armigera, Ostrinia furnacalis,* and *Porthesia taiwana* are polyphagous and mungbean is not a primary host. *H. armigera* and

O. furnacalis are major pests of corn and attack mungbean only when it is planted near corn plants.

P. taiwana is a pest of several vegetables and soybean. It attacks mungbean pods when these crops are not readily available. *E. zinckenella* attacks lima bean primarily and soybean and infests mungbean in their absence. The biology and damage of *E. zinckenella* is described under soybean.

M. testulalis, commonly called bean pod borer, attacks cowpea and mungbean throughout Asia.

Biology. The female lays eggs on leaves, terminal shoots, flowers, or pods. Yellow oval eggs are laid singly or in batches. They hatch in two to three days. The larva can be distinguished by the two pairs of dark spots on each white body segment on the back. Larval period lasts for 12-14 days during which the larva undergoes five instars. Pupation takes place in cocoons inside the pod or in the soil. The adults have light brown forewings with white markings and pearly white hindwings with brown markings at the lateral edge.

Damage. The larva of this pest feeds inside the mungbean pod. It prefers to feed on pods which are stuck together or on pods which are touching the leaves. This pest rarely attacks isolated pods. This peculiar habit can be exploited in the selection of mungbean cultivars which have solitary pods above the leaf canopy.

Bruchids

Among scores of bruchid species (Coleoptera: family Bruchidae) that infest food legumes in the tropics, *Callosobruchus chinensis* (L.), *C. maculatus* (F.), and *C. analis* (F.) are of economic importance. The first two species are native of Asia and Africa. Cowpea and pigeon pea also serve as their principal hosts. *C. analis*, an Asian native, is now found in Africa where it is a pest of cowpea. Although the bruchids, commonly called pulse beetles or cowpea weevils, attack mungbean in the field and storage, it is the infestation of stored grains that results in greatest loss.

Biology. In general the life history of all three species follows that of a typical coleopterous insect and there is very little difference among them. Usually one to three eggs are laid on individual seeds. Eggs are covered with a sticky substance which fastens the eggs to the seed surface. The average incubation period is 3.5, 4, and 5 days, respectively, for the eggs of *C. chinensis*, *C. maculatus*, and *C. analis*.

Soon after hatching, the larva makes a hole in the seed coat, just underneath the spot where the egg is laid, and enters the kernel where it feeds concealed inside the seed. When the eggs are laid on the pods, the larva feeds and pupates inside the developing seed. The combined larval and pupal periods are 18.8, 20, and 23.5 days for *C. chinensis*, *C. maculatus*, and *C. analis*, respectively. Average development period is 22.3 days for *C. chinensis*, 24 days for *C. maculatus*, and 28.5 days for *C. analis*.

Damage. In the field, adult bruchids lay eggs on maturing pods and young larvae immediately after emerging, gnaw through the pod cover, and bores into the developing seeds. As the seeds enlarge, the entry holes are closed, so the seeds appear normal at harvest time. However, at storage time, the adults emerge and lay eggs on the neighboring seeds. This initiates the secondary infestation which is much more damaging.

In storage, three aspects of bruchid damage are of particular importance. First is weight loss which is a direct consequence of bruchid feeding on the seed. It is also the result of accelerated loss of moisture due to perforation of mungbean seeds. Another is the reduction in the nutritional quality of the seeds.

Pulses are important source of dietary proteins and certain vitamins, such as thiamine. However, insect feeding may result in the loss or denaturation of these nutrients. The third damage is loss in seed viability. Even slight feeding damage by these pests on the embryo impairs germination. Feeding on cotyledon will not affect germination but will reduce the vigor of the young seedling.

Control. The nature and extent of bruchid damage described above entail sound control practices in order to protect the harvest from ravages of the bruchids, especially in storage. The use of insecticides on small-scale storage is not advisable since the grains are stored for a short duration and often used for family consumption. For bruchid control, therefore, clean storage facilities coupled with nonchemical control measures are necessary. These measures include drying of seeds before storage, use of nontoxic chemicals such as vegetable oils, neem (*Azadirachta indica*) seed extracts, and sex pheromones. If chemical control is necessary, selective and safe insecticides should be applied. Fumigation is practical only in large-scale storage facilities. The most effective and convenient fumigant to use is phosphine.

Insect Pests of Soybean

Stem Feeders

Agromyzid Flies

Agromyzid flies, commonly called bean flies, are the most destructive stem feeders. In tropical areas of Asia, four species, *Ophiomyia phaseoli* (Tryon), *O. centrosematis* (de Meijere), *Melanagromyza sojae* ((Zehntner), and *M. dolichostigma* (de Meijere), are the most destructive. While the first three species feed on the stems of young seedlings, *M. dolichostigma* feeds on young shoots when the plants are four weeks or older.

Biology. *O. phaseoli* — The adults are tiny black flies usually 2-3 mm long. Oviposition takes place in young leaves or in cotyledons. The eggs hatch in two to four days. The larva mines into the leaves, stems, and cotyledons. Larval stage lasts for 10 days and the pupal stage, for 16-17 days. The puparium remains beneath the epidermis, normally near the base of the stem.

O. centrosematis — Oviposition of this insect takes place in the hypocotyl and stem, not in the leaves. The larva feeds just underneath the epidermis of the stem and part of the tap root. It pupates in the epidermis where it feeds.

M. sojae — Oviposition takes place in the leaves and soft portions of the stem. The larva hatches after two to three days and immediately bores into the nearest vein. It feeds through the petiole into the stem, then bores down to the root and then again upwards until it is full-grown. It pupates deep within the stem. Larval period lasts for 7-11 days and the pupal stage, for 9-10 days. The entire life cycle is completed in 16-26 days.

M. dolichostigma — Eggs are laid on the underside of the leaves. They hatch within two to three days. The larva mines into the leaf tissue and then into the stem. Pupation takes place in the damaged shoots. Usually one maggot is found per damaged shoot. The larval stage lasts for nine days and pupal stage lasts for about six to eight days. The length of the entire life cycle ranges from 17-21 days.

Damage. Adult flies and larvae both feed on soybean plants. However, it is the larval feeding that causes reduction in plant growth and yield. The first three species prefer to feed on young plants from the cotyledon stage up to early trifoliate leaf stage. *M. dolichostigma*, on the other hand, feeds on young growing shoots of three-to-four weeks or older.

Control The critical protection period is confined to the first three to four weeks after germination.

Cultural control — Various cultural practices like ridging of young plants, planting after green manure, crop rotation, fertilization, and rice straw mulching enhance plant growth and induce tolerance to agromyzid damage. Late planting should be avoided to reduce heavy bean fly infestation.

Biological control— Certain hymenopterous parasites parasitize bean flies. However, the hidden mode of egg, larval, and pupal stages of these pests restricts easy access of these mobile stages to attack by predators and parasites.

Chemical control — At present, only preventive and curative insecticide sprays are being used on bean flies in tropical and subtropical Asia. Since bean fly causes significant yield loss only during the seedling stage, insecticide applications can protect the plant within the first four weeks after germination.

Weekly spraying of Monocrotophos, dimethoate, and omethoate, applied at the rate of 0.5 kg a.i./ha during the first four weeks after germination is effective against *O. phaseoli*, *O. centrosematis*, and *M. sojae* on soybean, mungbean, cowpea, and snap bean (AVRDC 1985). Systemic insecticides, like phorate and carbofuran, when banded along the seeds at sowing can give satisfactory control of *O. phaseoli*. Carbofuran or carbosulfan can be coated on seeds before sowing. Such treatment protects plants against bean flies for two to three weeks.

Girdle Beetle

Girdle beetle *Obrea brevis* Swed (Coleoptera: Lamiidae) is a serious soybean pest in Central India. It also attacks cowpea, bitter gourd, chillies, mungbean, and black gram.

Biology. The female lays eggs singly on stems or petioles. They hatch in three to five days. The newly emerged larvae start feeding inside the stem and make them hollow. They overwinter and oversummer in 18-25 mm long pieces of stems cut by the pest. The total life cycle is completed in 40-60 days.

Damage. The infested twigs wither and dry. The yield loss caused by the pest varies with the plant growth stage when the infestation occurs. When the pest attacks at the seedling stage, plant mortality may reach up to 75%. If the pest attacks when the crop is 1.5-2 months old, plant mortality is negligible; but the loss in grain yield may reach up to 66.7%.

Control. At present spraying of insecticide is the only control measure used against this pest. Endosulfan, dimethoate, and methyl demeton sprays are recommended.

Defoliators

Many insects, mainly Lepidoptera and Coleoptera, infest soybean foliage in tropical and subtropical Asia. The following are major foliage feeders that cause significant damage and yield loss.

Spodoptera litura (F) (Lepidoptera: Noctuidae)

The common cutworm (Fig. 10.42, See p. 341), *S. litura,* infests soybean throughout tropical and subtropical Asia. It also attacks cabbage, eggplant, mungbean, maize and tomato.

Biology. Eggs are laid in batches on the undersurface of the leaves. Incubation period ranges from three to seven days. The newly emerged caterpillars feed immediately on the oviposition site and completely skeletonize the leaflet. These larvae later migrate and feed on other parts of the plant including the pods. Larval period lasts for 14-21 days. They pupate in soil or plant refuse and adults merge 7-12 days later. Adult moths are brownish with silvery markings on the forewings.

Spodoptera exigua (Hubner) (Lepidoptera: Noctuidae)

In addition to soybean, this pest also attacks cabbage, cotton, eggplant, maize, mungbean, and tomato.

Biology. *S. exigua* lays eggs in batches on the soybean foliage. The eggs hatch in two to three days. The larvae molt five to seven times during the 17-22 day larval period. High larval population can cause complete defoliation. Pupation takes place in the soil or plant debris and lasts for six to eight days. The entire life cycle is completed in four to five weeks.

Plusia orichae (F) (Lepidoptera: Noctuidae)

This semilooper is an important pest in India and another species, *P. chalcites,* is a pest in Indonesia.

Biology. The eggs are laid singly on the leaves. In three to four days, the pale greenish larvae emerge and feed immediately on tender green foliage. In the case of severe infestation, the plant can be completely defoliated. The larval period lasts for 13-24 days and pupation takes place inside folded leaves. After eight to nine days of pupation, the adults emerge. The entire life cycle is completed in approximately 27 days.

Hedylepta Indicata (F) (Lepidoptera: Pyralidae)

This insect attacks soybean in Japan, Korea, the Philippines, and Taiwan.

Biology. The eggs are laid mainly on the upper leaf surface. The newly hatched larvae feed on the leaves and scrape the leaf laminae, leaving only a membrane coat. While feeding, they roll the leaflet often causing several leaves nearby to stick together.

There are five larval instars during the 14- to 15-day larval period. Pupation takes place in the rolled-up leaves and lasts for 16 days.

Damage. Heavy damage is noticeable from a distance by the presence of silvery to yellow leaf masses. Heavy infestation during early vegetative and mid-pod-filling stages is detrimental to yield.

Lamprosema indicata (F) (Lepidoptera: Pyralidae)

This insect is another defoliator.

Biology. The adult female lays eggs singly or in groups of five on the foliage. Eggs hatch in seven to eight days. The first instar larvae fold leaves around themselves and feed while hiding in the mesophyll tissue, resulting in an intact papery skeleton of folded leaves. There are six larval molts. The pupal period lasts for 5-15 days.

Damage. The nature of damage by this pest is similar to the one caused by *H. indicata.*

Phaedonia inclusa (Stal) (Coleoptera: Chrysomelidae)

This beetle is a serious soybean pest in Java and some parts of Malaysia.

Biology. Adult females lay eggs in clusters of 2-18 on the underside of young foliage. The eggs hatch after four days. The larvae feed on top shoots, flowers, and pods. They go through five instars in eight days. Pupation lasts for one week and takes place in the soil. Adults can survive for a long period of time. In areas where soybean is cultivated, the adults can survive for more than five months on alternate hosts during the off-season.

Damage. Both larvae and adults feed on the foliage; the infested crop is rapidly defoliated and produces little or no yield at all.

Diacrisia obliqua (Waker) (Lepidoptera: Arctiidae)

This polyphagous insect is a major pest of soybean in the Indian subcontinent. It has a wide host range which includes black gram, jute, maize, and mungbean.

Biology. The female moth lays eggs in batches of 400-750 on the leaf surface. Incubation period lasts for three to seven days but is longer during the cool months. Newly emerged larvae are gregarious and feed on the leaf epidermis, skeletonizing the entire foliage. The total larval period ranges from 20-30 days. The pupal stage lasts for 10-15 days. The entire life cycle is completed in five to six weeks, but during cool periods a single generation may take up to 10 weeks.

In addition to the above-described pests which attack soybean in fairly widespread areas in tropical to subtropical Asia, certain pests are endemic only to a small area within a country where it can cause considerable damage. The following examples represent only a few of these pests which are polyphagous and too numerous to discuss here. In Taiwan, for example, two beetle species *Anomala cupripes* Hope and *Anomala expansa* Bates (Coleoptera: Scarabidae) and a tussock moth *Porthesia taiwana* Shiraki (Lepidoptera: Liparidae) at times cause severe defoliation especially in the spring season. In India, *Mocis undata* F and *Stomopterux subsecivella* Zeller can also cause considerable localized damage.

Control. At present insecticides are ordinarily used for defoliator control. However, frequent insecticide use leads to a selection of resistant strains. *S. litura* and *H. armigera*, for example, have become resistant to several of these chemicals.

Female sex pheromones of *H. armigera* and *S. litura* are available commercially. Intensive research on the use of these chemicals to mass-trap the males or confuse them so that they will not mate with females, has been carried out in Japan and Taiwan to control these pests on vegetables, such as tomatoes and crucifers. Although these sex pheromones cannot by themselves obtain effective control of these pests, they can provide a valuable tool for monitoring the pest infestation for immediate and timely control.

***Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae).**

See Insect Pests of Tomato

Pod Feeders

Stink Bugs

Phytophagous stink bugs are an important group of pod-infesting insect pests of soybean and other legumes throughout the world. The following species infest soybeans in tropical and subtropical Asia.

***Nezara viridula* (L) (Heteroptera: Pentatonidae)**

The green soldier bug (Fig. 10.43, See p. 341), *Nezara viridula*, is one of the most important insect pests of legumes. This pod feeder attacks sweet potato, cabbage, tobacco, rice, corn, sugarcane, cotton, okra, and lettuce.

Biology. Eggs are laid in masses. The egg incubation period ranges from four to six days. The insect undergoes five nymphal stages in a period of 18-28 days. Each instar is characterized by distinct shape, size, color pattern, and number of spots found on the dorsal surface of the thorax and abdomen. The adult is a large, green bug. Males can be differentiated from females by the presence of a notch and two brown spots on the ventral surface of the terminal end of the abdomen. These features are absent in females.

***Riptortus clavatus* (Thunberg) (Heteroptera: Coreidae)**

Like *N. viridula* this species is also polyphagous and reportedly injures the seeds of about 30 species belonging to five families: Leguminosae, Gramineae, Convolvulaceae, Rosaceae, and Pedaliaceae. It is confined to Japan, Korea, and Taiwan.

Biology. Adult females lay eggs on foliage, stems, and pods of soybean plants. The eggs are laid singly and are scattered over the plant. They hatch in about six days. The nymphal period lasts for 16-23 days during which the insect passes through five instars. Riptortus linearis (F) (Heteroptera: Coreidae)This species is widespread in tropical and subtropical Southeast Asia and is economically as important as *R. clavatus*. The species

Fig. 10.38.
Diamondback moth.

Fig. 10.39.
Striped flea beetle.

Fig. 10.40.
Imported cabbage worm.

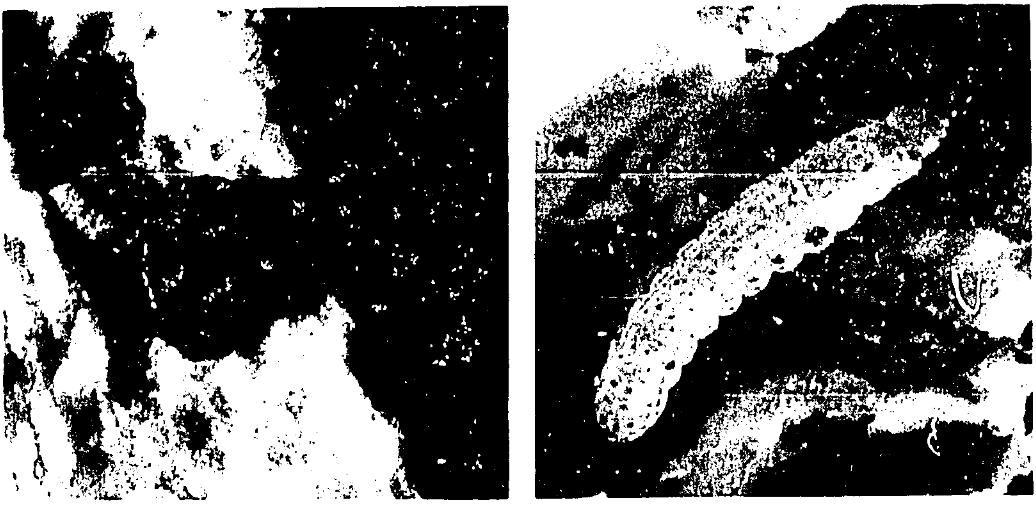

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Fig. 10.41a and b. Pod borers.

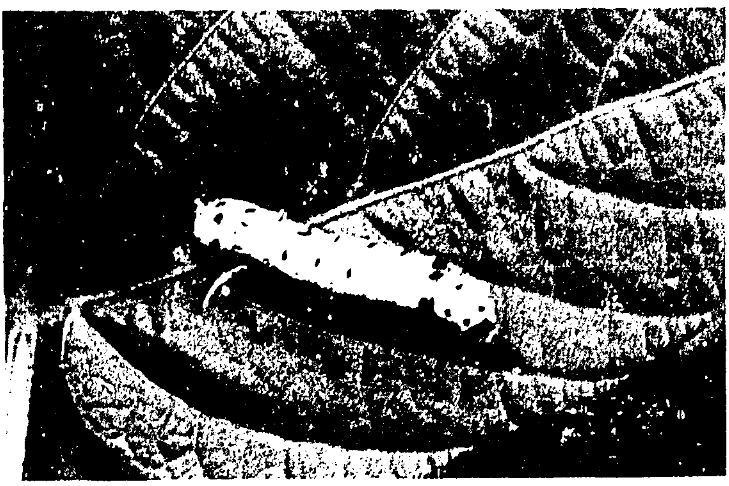

Fig. 10.42.
Common cutworm.

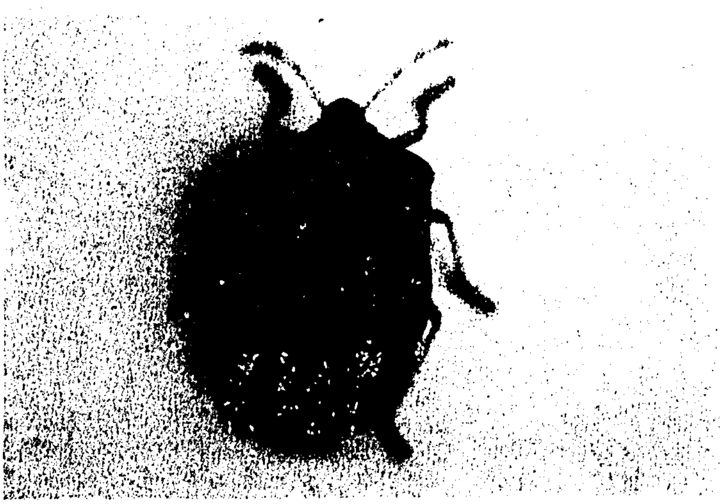

Fig. 10.43.
Green soldier bug.

mainly attacks soybean, but other legumes including wild species of Solanaceae and Convolvulaceae also harbor this pest.

Biology. Eggs are laid in clusters on leaves and pods. The egg stage ranges from six to seven days. The nymphs go through five instars in about three weeks, and the development from egg to adult stage takes 29 days.

Piezodous hybneri (Gmelin) (Heteroptera: Pentatomidae)

This pentatomid damages soybean in Japan, Korea, Taiwan, and Thailand. It is economically less important than the other stink bug species.

Biology. The cylindrical-shaped eggs are laid in double rows on the leaves. Average egg incubation time is four days. The newly hatched nymphs undergo five instars in 14-22 days.

Damage. Both nymphs and adults of stink bugs damage soybean by sucking the juice from the developing seeds. As a result, both yield and quality of soybean are reduced. In certain cases these insects transmit microorganisms which reduce the quality and viability of soybean seeds.

Control. Collection of eggs, nymphs, and adults in the field and application of insecticides are effective ways to control these pests. Several species of parasites and predators have been reported to be important biological agents in regulating stink bug populations. Planting resistant varieties and short-duration cultivars tend to avoid stink bug attack to some extent. In early maturing cultivars, the blooming-to-maturation period (the period at which plants are available for insect feeding) is shortened. Early maturation also allows plants to mature before the stink bug population reaches its peak.

Pod Borers

Leguminivora glycinivorella Matsumura (Lepidoptera: Tortricidae), *Matsumuraeses phaseoli* Matsumura (*Matsumuraeses falcana* (Washingham) (Lepidoptera: Tortricidae), *Etiella zinckenella* (Treitschke), and *E. hobsoni* (Butler) (Lepidoptera: Pyralidae) are the major pod borer species that infest soybean in Asia. The first two species are found only in temperate areas in Japan and Korea.

E. zinckenella is more widespread in the tropics and subtropics and is the most damaging pod borer species in Asia. *E. hobsoni* is found mainly in Indonesia.

E. zinckenella, also known as lima bean pod borer, is a cosmopolitan pest with worldwide distribution. It is known to damage a wide range of cultivated and wild legumes, namely: cowpea, garden pea, lima bean, mungbean, pigeon pea, snap bean, and soybean.

Biology. The white oval eggs (0.6 mm long) are laid singly or in batches of 2-12 on young pods, calyx, or leaf stalks. The egg-incubation period lasts for 3-16 days. The larvae feed on developing seeds. They change color from yellow to green during development, with dark pink stripes just before pupation. The larval development lasts for 20 days. Pupation takes place in the soil and lasts for one to nine weeks depending upon the temperature. *E. zinckenella* moths are brownish grey, with a white stripe along the leading edge of the narrow forewings.

Damage. The larvae cause damage by boring on young pods. Seeds are partially or entirely eaten, which may cause significant yield loss.

Control. *E. zinckenella* has several natural enemies. However, the extent of parasitism and their potential use in biological control of *E. zinckenella* needs to be investigated.

It is possible to obtain satisfactory control of this pest by the use of synthetic insecticides. However, the chemicals should be applied frequently to kill the larvae immediately after hatching before they enter into the pod. The spray should be directed towards pods where most of the eggs are laid. This presents a problem in soybean because its leaf canopy completely covers the pods.

Some insecticides effective against this pest include carbaryl, azinphos-methyl mexacarbate, monocrotophos, triazophos fenvalerate, and quinalphos. However, triazophos and carbaryl were observed to cause phytotoxicity in certain soybean genotypes.

Insect Pests of Sweet Potato

Defoliators

Although over 180 insect species feed on sweet potato foliage, only *Herse (Agrius) convolvuli* L. and to some extent *Herse cingulata* F. (Lepidoptera: Sphingidae) cause significant yield loss over an appreciable area.

Herse (Agrius) convolvuli (Fig. 10.44)

This lepidopterous pest occurs practically all over Africa and Asia.

Biology. The eggs are laid singly on the stem or the underside of the leaves and after 6 to 10 days of incubation, the larvae emerge and start feeding on the foliage. The green

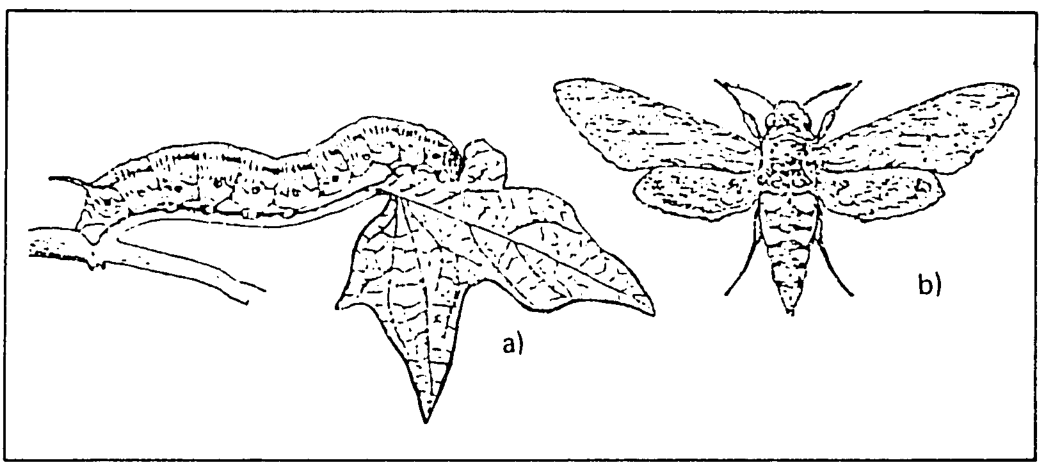

Fig. 10.44. ***Herse (Agrius) convolvuli.***

caterpillars are large and voracious feeders. The larval period lasts for three to four weeks. Pupation takes place in an earthen cocoon in the soil. Pupation lasts for about a month.

Damage. In some parts of Africa, this pest can cause serious defoliation and yield loss between 20% and 50%.

Control. Very little information exists on the control measures for this pest. On small-scale planting, collection and destruction of the larvae and plowing of infested field soon after harvest to expose the pupae are suggested. If insecticide application becomes necessary, a relatively safer and cheaper chemical, like malathion, will control this pest.

Vine Borers

Although several insect species feed on sweet potato vines, only *Megastes grandalis* Guen. and *Omphisa anastomasalis* Guen. (Lepidoptera: Pyralidae) cause significant yield loss.

Megastes grandalis

This vine borer is found in Brazil, Guyana, Trinidad, and Tabago.

Biology. The eggs are laid singly or in rows on leaf petioles or on either side of the leaves. After one week, the freshly emerged larva bites the surface of the vine and bores through the stem just above the ground. The larval stage lasts for five to seven weeks. Full-grown larva forms a long silken cocoon very near an exit hole where the adult moth will emerge. Pupal period lasts from 13-16 days. Soon after emergence, the adults mate in the early morning hours and lay most of their eggs the following night.

Damage. The larva feeds inside the underground part of the stem which bears the tuberous roots. During the dry season such damage causes stunted growth and shedding of leaves. Tuberous root may not develop. If roots are formed, the larva enters through the roots and leaves hidden tunnels which are visible only when such roots are cut open. Up to 95% of the sweet potato roots may be damaged during severe infestation.

Control. Prior to the introduction of modern organic insecticides, some researchers have successfully controlled insects by dipping sweet potato cuttings with Bordeaux mixture and lead arsenate before planting, and by spraying with this mixture twice a month. In the Philippines, *M. grandalis* is controlled by dipping the sweet potato cuttings in 0.5% a.i. dieldrin followed by a fortnightly application of methomyl and malathion (1.4 kg a.i./ha).

Cultivation of tolerant cultivars will enable growers to obtain normal yields in areas where *M. grandalis* thrive.

Omphisa anastomasalis (Fig. 10.45)

This vine borer is distributed in Asia and the Pacific.

Biology. Eggs are laid singly on leaves and stems and are hatched after five to six days. The caterpillar tunnels through the vines for about 35 days. Then, it constructs a

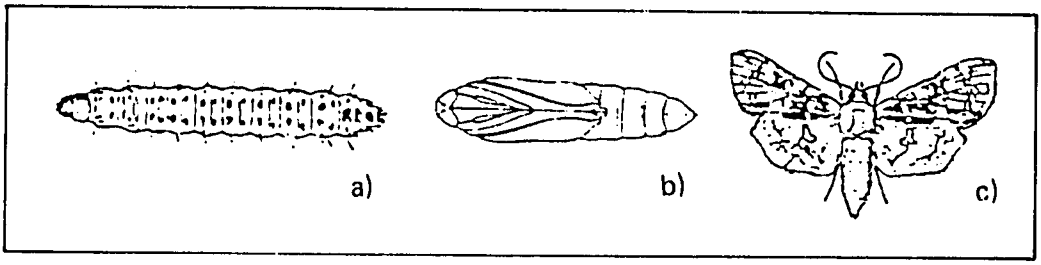

Fig. 10.45. ***Omphisa anastomasalis.***

silken cocoon and pupates in the stem near an exit hole it made before pupation. Pupation lasts for 14 days, after which the adult emerges.

Damage. Major damage is caused by the boring of caterpillars into the main stem leading to tuberous roots. Severely tunnelled vines show weak growth and poor foliage which appears yellow and wilted during the dry season. Caterpillars also bore into the roots and damage the tubers. In Hawaii, this pest sometimes causes death of the sweet potato plant. In Malaysia, infestation reduces yield by about 30%. In Taiwan, over 89% of the plants sustain damage and the yield reduction is about 50%.

Control. Since the insect lays eggs on the foliage and stem, dipping sweet potato cutting in a suitable insecticide solution before planting effectively lessens the sources of infestation. In studies at Penghu Island in Taiwan, biweekly sprays of deltamethrin at the rate of 0.025 kg a.i./ha or broadcasting of carbofuran granules at the rate of 2 kg a.i./ha around the stems gave excellent pest control and doubled the root yield (AVRDC 1981). The latter treatment, however, is not very economical. Two AVRDC accessions, 155 and 192, remain consistently least damaged. The accession 155 is now being utilized in AVRDC's sweet-potato breeding program for vine borer resistance.

Root Feeders

Root feeders, mainly weevils, are by far the most destructive pests of sweet potato in the tropics and the subtropics. Several weevil species reportedly feed on sweet potato roots, but not all are economically important.

Sweet Potato Weevils (Fig. 10.46)

Cylas puncticollis Boh. (the African sweet potato weevil) is confined only to several countries in Africa. *Cylas formicarius* F. (the sweet potato weevil) has two subspecies, namely: *C. formicarius formicarius* distributed mainly in Asia, Africa, and the Pacific, and *C. formicarius elegantulus* found in North and Central America, the Caribbean islands, and Hawaii. On Okinawa island in Japan, both subspecies of *C. formicarius* occur.

Biology. The biology of the two sweet potato weevils is similar. Eggs are deposited singly in cavities in the root or stems. After five to six days of incubation, the eggs hatch and the larvae start boring into the root or stem where the eggs have been laid. They feed inside the roots for 25-35 days during which they complete three larval instars. Pupation which lasts for six to eight days takes place inside the root. Pupal period lasts for six to

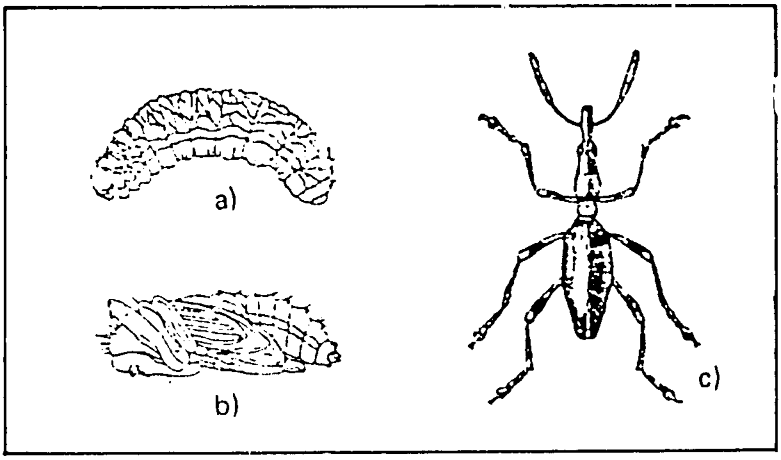

Fig. 10.46. Sweet potato weevils.

eight days. Soon after emergence, the adult stays in the pupal chamber and then cuts its way through the plant tissue.

Damage. Larval feeding in the roots causes major damage. The feeding tunnels are filled with rotten frass which gives the damaged tissue the characteristic terpene odor; thus, even the slightly damaged roots are unfit for human consumption. Adult weevils also feed on foliage. Such feeding is only occasional in the case of *C. puncticollis* but is quite common in *C. formicarius*. However, the influence of such defoliation on root yield has not yet been documented.

West Indian Sweet Potato Weevil

Euscepes postfasciatus (Fairmaire), the West Indian sweet potato weevil, is found in the Caribbean, Hawaii, Fiji, Tonga, and Okinawa island in Japan.

Biology. Eggs are laid in shallow pits in tuberous roots or stems and are covered with secretions which seal them from outside. After six to eight days of incubation, the larva bores directly from the oviposition pit into the root or stem. Larval period lasts for 18-30 days. Pupation takes place in the roots or stems for about seven to nine days. Adult insects are sturdy and can survive without food in the soil for several months. They can also withstand considerable periods of flooding.

Damage. Adults feed on the vines or roots. The larva bores down into the roots or stems from the oviposition site and creates winding tunnels which are packed solidly with frass. At times the entire root is riddled with holes filled with frass. A characteristic terpene odor similar to the one caused by the sweet-potato weevil is also found in the affected tissues of the West Indian sweet potato. Damaged vines darken and damaged main stems become swollen, malformed, and cracked.

Control. Since the biology and nature of damage of all three weevil species are similar, it is possible to control these pests by adopting common control strategies. The inability to fly makes it easy to control these weevils through simple cultural practices such as crop rotation, clean cultivation, frequent irrigation, and mulching. Other possible cultural practices which may help reduce weevil damage are, as follows: deep planting of cuttings, using deep-rooted cultivars, selecting new planting area far from an infested field, harvesting the crop as soon as it has developed roots of acceptable size, and removing alternate hosts growing near the planting site.

Sex pheromones can help monitor the start of weevil infestation and the mass-trapping of male adults entering the field or emerging from previously infested plants in the field. It, therefore, reduces the overall future infestation of the crop. especially on small-scale farms.

Spraying of chemicals on the foliage during root enlargement kills the adults migrating from outside. Broadcasting insecticides around the stem at this stage kills on contact the adults searching for roots through land cracks. Dipping sweet potato cuttings in a systemic insecticide solution for 10-20 minutes prior to planting, allows enough insecticide to penetrate the vine to kill the eggs and larvae inside. Such treatment reduces infestation by killing the adults.

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CHAPTER 11

Mechanization in Vegetable Production

The traditional systems of vegetable production are labor-intensive. As shown in Chapter 1, the labor requirements for growing 1 ha of tomato can be as high as 8,000 man-hours. In developing countries where farms are small and labor is cheap, the traditional systems are able to produce good quality vegetables at fairly low prices. However, these prices are becoming increasingly noncompetitive in free-market situations, because the highly mechanized production systems in developed countries are producing better quality products at much lower costs. The noncompetitive position of developing country farms is further threatened by society's need to increase farm wages and the shift of the labor force to industries.

In the final analysis, therefore, the only route for a long-term survival of these farms is to increase labor productivity, which can be achieved through the same high level of mechanization, as that of industrialized countries. The use of machineries will dramatically increase labor productivity, making it possible to increase farm wages and produce more vegetables with less farm hands. However, the use of machines may require a shift in crop variety and alteration of management practices, such as spacing and farm layout. As a rule, the more sophisticated the machines are, the more specialized are their functions. To maximize their efficiency, they should not be introduced in isolation but rather as part of a "technology package" that provides the proper conditions for the use of the machine.

The Question of Appropriate Farm Mechanization

Although the concept of mechanization seems to be universally accepted, there is much disagreement on the level of technology that is appropriate for a given set of conditions. In developing countries, many farmers do not have the capital to acquire and maintain sophisticated equipment, thus mechanization is usually limited to hand-tool and animal-draft technology. Small landholdings (if farmed independently) also make it inappropriate to invest in large machineries.

There are many levels of farm mechanization combining different proportions of hand-tool, animal-drawn, and mechanical power technology. In the same manner, there are many kinds of farmers even in developing countries. Some are more willing to invest in higher levels of technology than others. A group of farmers, each operating a small farm, may organize a cooperative or a corporate farm for the purpose of consolidation, making it possible to justify the use of sophisticated machines. The question of "appropriate mechanization", therefore, is best left to the farmer acting as the farm manager himself. Subsequent sections in this chapter describe the various types of machinery that are available to the enterprising farmer, leaving it to him to choose which combination of machinery or technology is best suited to his conditions.

Hand-Tool Technology

This is the simplest and most primitive form of mechanization, characterized by the use of human muscles as the source of power. Manual implements used in this technology are simply extensions of the human limb; their use slightly increases the efficiency of human muscles. Simple, manually operated machines were invented in recent years to increase manpower efficiency.

In the highlands, where vegetables are grown on terraced steep slopes, farmers do not have a choice but to rely on hand-tool technology because it is difficult to operate such farms with animals, much less, with tractors. In relay-intercropping systems involving annual crops, the nature of the main crop may only allow hand-tool operations. In very small, intensive farms such as the market, home, and school gardens the conditions are also favorable for the use of hand tools.

Tools for the Nursery

The job of pricking (transplanting in nursery beds) can be facilitated with a spotting board shown in Fig. 11.1. Soil blocks for raising seedlings can be made quickly with the soil block machine shown in Fig. 11.2.

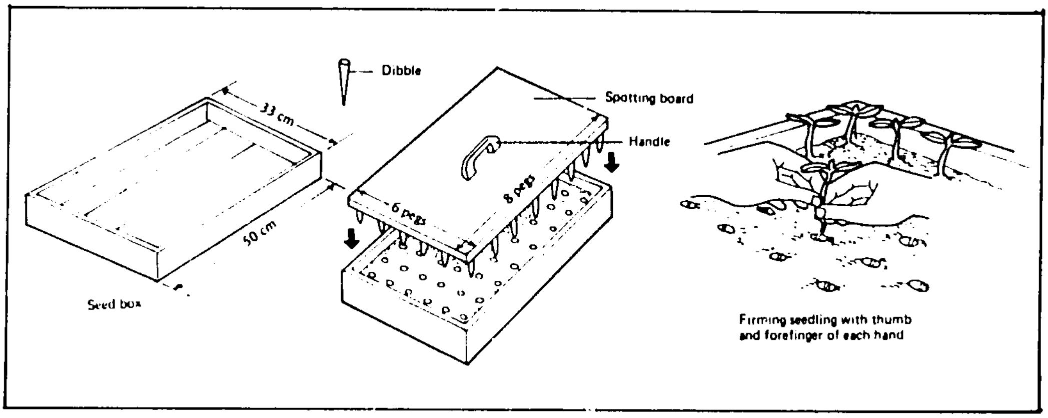

Fig. 11.1. The use of a spotting board to facilitate seedling transplanting in the nursery.

Tools for Land Clearing and Tillage

For land clearing, the main tools are knives which are available in different designs, weights, and sizes (Fig. 11.3). Heavy knives are used for clearing woody bushes; lighter knives are used for clearing succulent weeds. Curved knives are specially designed for cutting grasses.

For digging, the usual tools are shown in Fig. 11.4. The flat-tip hoe (such as the grab hoe) is ideal for loamy soil, while the heavier fork-tip (Chinese) hoe is used for clayey soil. The hoe is also used for cutting the soil clods into smaller particles; thus it serves the function of the plow and harrow at the same

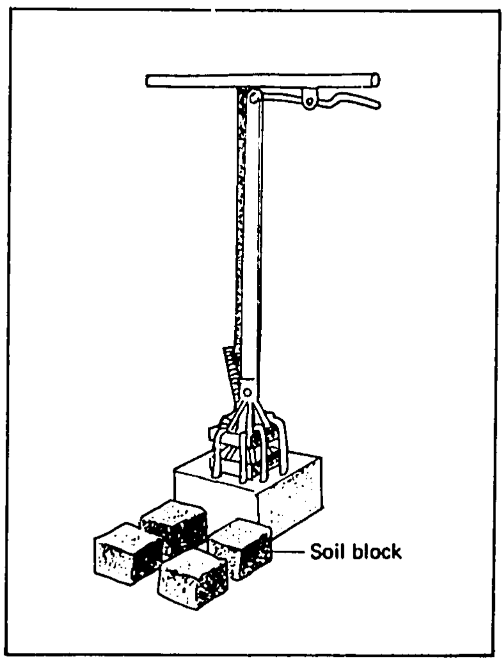

Fig. 11.2. Soil block machine.

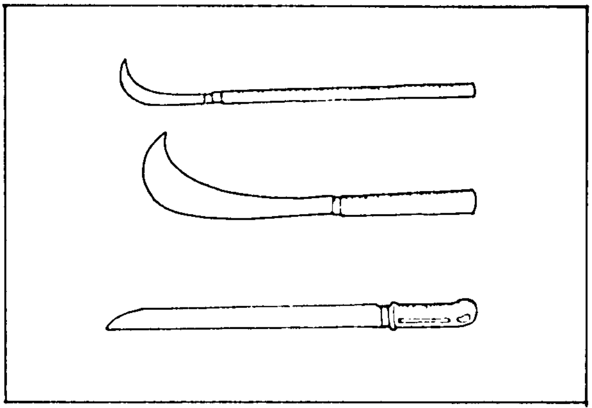

Fig. 11.3. Knives for land clearing.

time. The spading fork is best fitted in loamy soils where deep tillage is desired. The spade is used for making beds, while the rake is used for leveling.

Small Implements for Sowing

The traditional method of vegetable seeding is by dropping the seeds by hand and covering these with the foot. This method can be simplified with the uni-automatic hand jabber

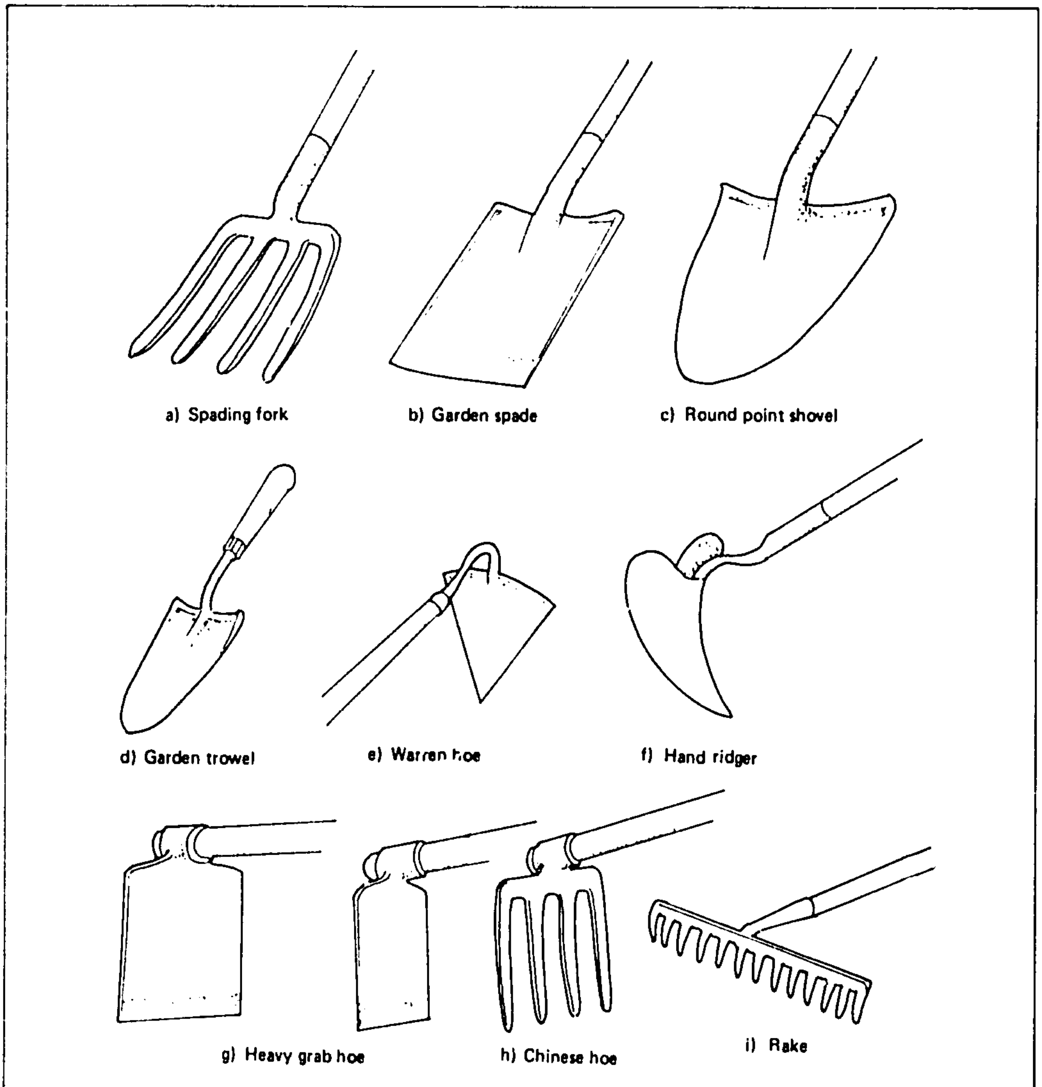

Fig. 11.4. Tools for digging, leveling, and ridging.

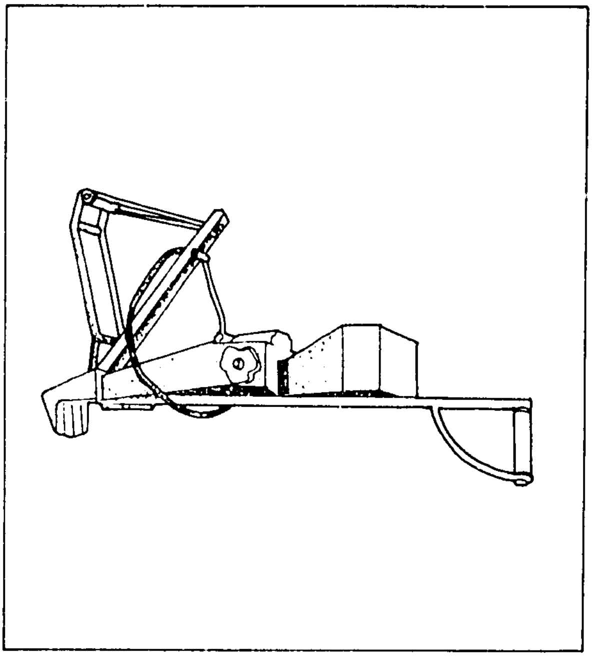

Fig. 11.5. Uni-automatic hand jabber for direct-seeding.

(Fig. 11.5) developed by the University of the Philippines at Los Baños. The planter has an adjustable metering device. The depth of seeding car be varied from 0-.0 mm and is controlled by a depth regulator. During planting, the operator jabs the equipment to the desired depth and pushes it forward. This deflects the actuating level upwards, and simultaneously actuates the metering device and opens the flap. On the average, the planter can achieve a capacity of 0.05 ha/hour.

The rolling injection planter design by the International Institute for Tropical Agriculture (IITA) and the International Rice Research Institute (IRRI) can be used under different tillage and weed-mulch treatments (Fig. 11.6). On the average, the capacity of the planter could reach 16,000 hills/hour at an in-row seed spacing of 18 or 25 cm. Through

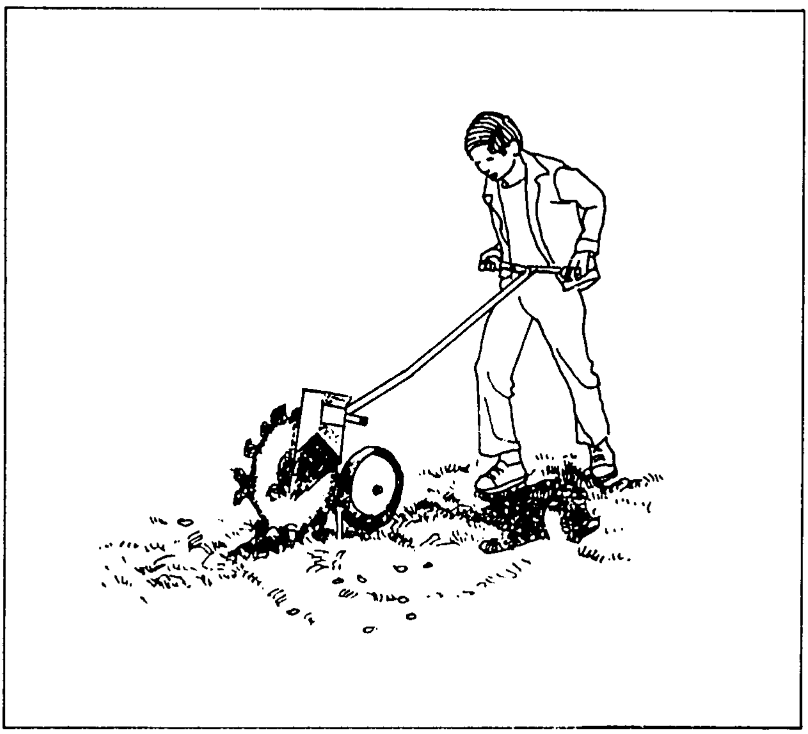

Fig. 11.6. Rolling injection planter.

simple adjustments of the metering roller, it could plant different types of seeds, such as corn, mungbean, cowpea, and soybean.

Tools for Weeding and Cultivation

Many designs are available for weeding with hand tools (Fig. 11.7), ranging from hoes and trowels to wheeled cultivators. Each type is recommended for a specific purpose. For example, the sod hoe which is operated by pushing with a scraping action is ideal for weeding viny crops, such as squash.

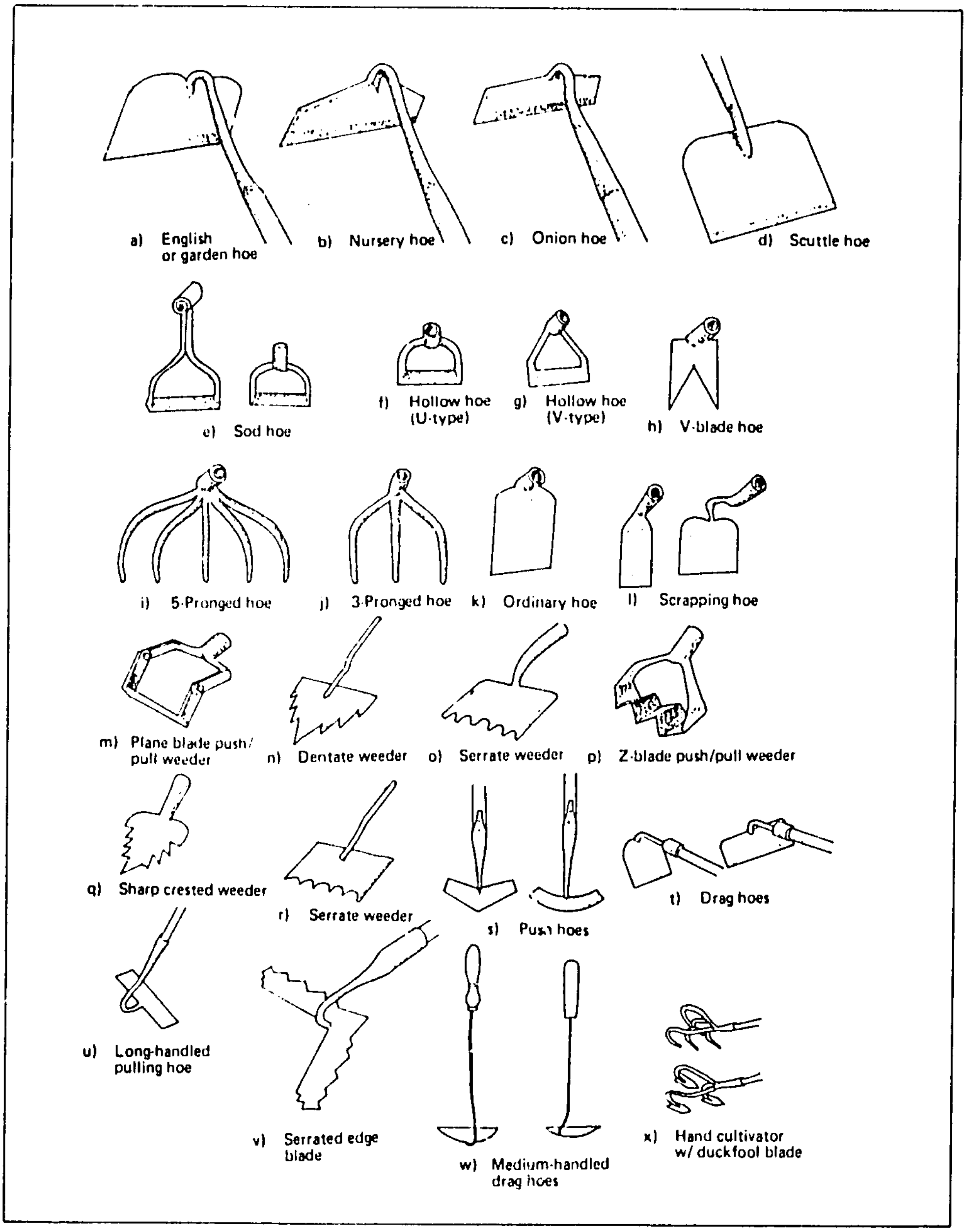

Fig. 11.7. Tools for weeding and cultivating.

The Philippine Root Crops Research and Training Center (PRCRTC) in Leyte has designed a hand wheel cultivator (Fig. 11.8) which enables an operator to weed and/or cultivate 0.2-0.5 ha per 8-hour day in an upland field.

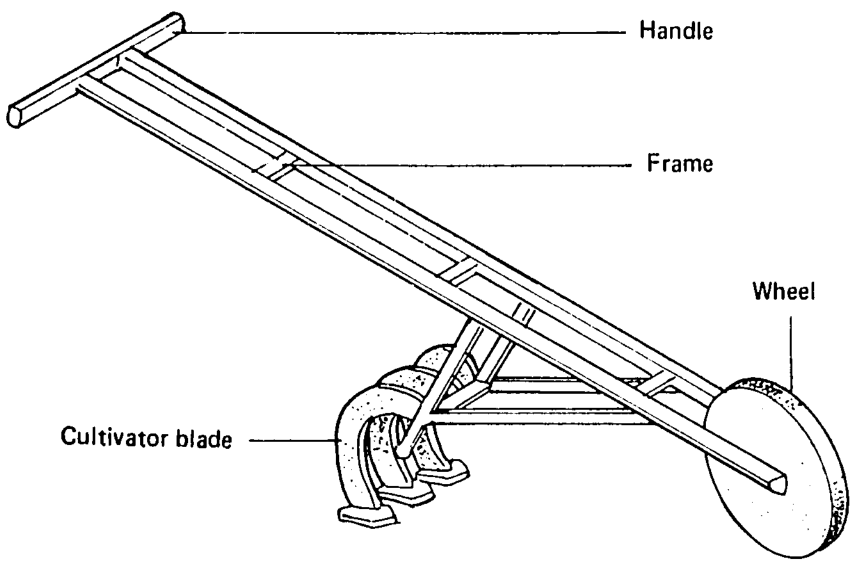

Fig. 11.8. Hand wheel cultivator.

Manually Operated Pumps for Irrigation

The International Rice Research Institute (IRRI), in cooperation with the Philippine government agencies, has designed two pumps that are operated by human energy. These are described by PCARRD (1988) as follows:

1. "Tapak-tapak" pump (Fig. 11.9). This pump can be portable or stationary. It is suitable for open-fit wells, tube wells, canals, lakes, and rivers. No priming is required for depths of up to 5 m.

Due to the effective use of the body weight and the twin pump cylinders, the capacity is higher than for most low-cost manual pumps. Pumping capacity varies with depth of lift — for a 2-m lift, it can have a capacity of 2 liters/second, while for a 5-m lift, its capacity is 1 liter/second.

The operator stands on his two feet, rests and shifts his weight from one foot to the other. This compresses one of the twin cylinders forcing water from the outlet valve. By alternately shifting his weight in a rhythmic manner, the operator pumps a continuous flow of water.

2. Diaphragm pump (Fig. 11.10). This foot-operated pump can lift up to 2 liters of water per second to a height of 1-2 m. It is well-suited for pumping water from irrigation ditches, open channels, river banks, and shallow wells. Unlike most pumps, it can handle water with mud and other impurities. The pump is similarly operated as the "tapak'tapak".

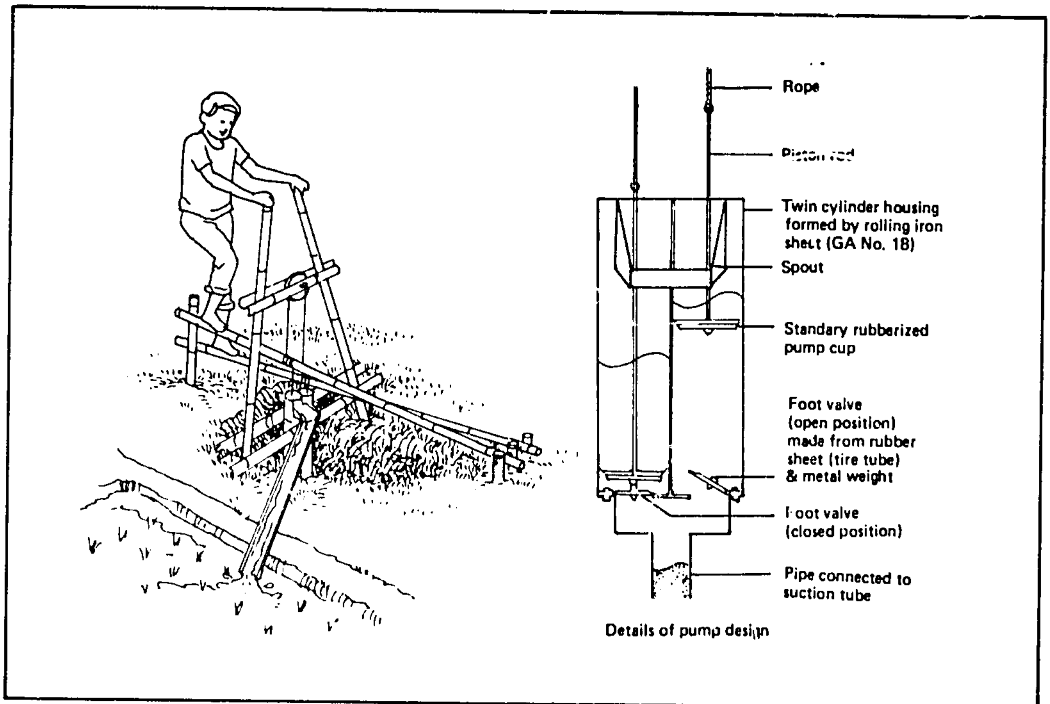

Fig. 11.9. "Tapak-tapak" pump.

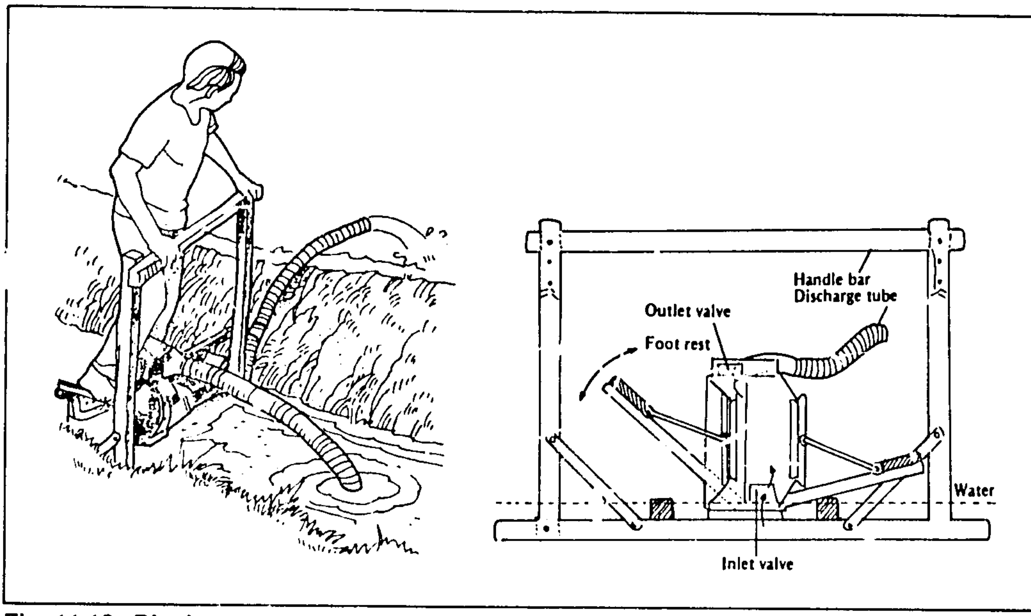

Fig. 11.10. Diaphragm pump.

Hand-Operated Knapsack Sprayer

A knapsack sprayer with piston pump is shown in Fig. 11.11. The applicator continuously pressurizes the tank with a piston pump and at the same time directs the spraying nozzle to the desired location. This simple sprayer is widely used in small vegetable fields and in seedling beds.

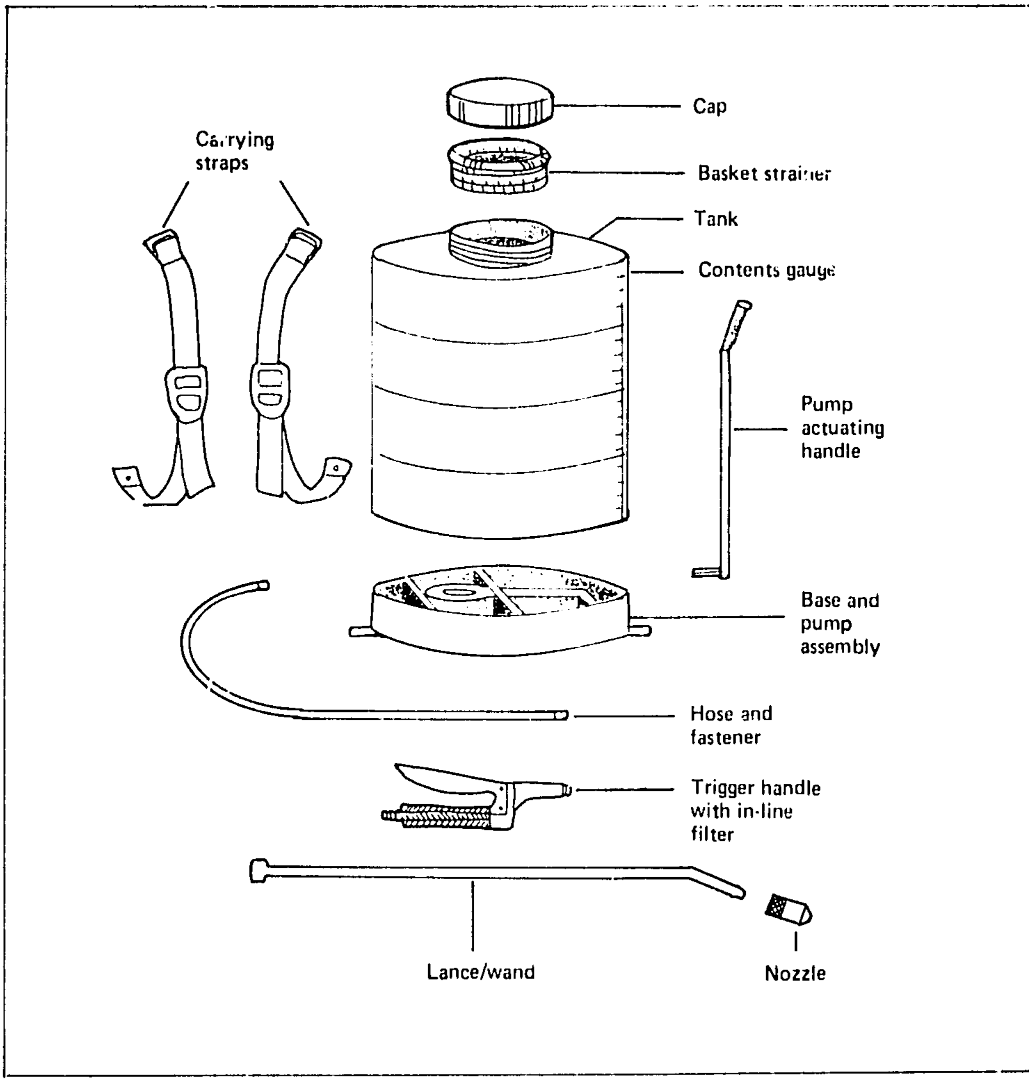

Fig. 11.11a.
Details of parts of a knapsack sprayer.

Fig. 11.11b.
Knapsack sprayer in operation.

Push Carts

The traditional push cart made of wooden wheels is too heavy and requires a lot of energy to push. With the use of pneumatic wheels, such as bicycle or motorcycle wheels (Fig. 11.12), the push cart can be very light and easy to operate. This type of cart can be used for transporting farm supplies, implements, and vegetable products over short distances.

Animal-Draft Technology

The animals that are used for vegetable farming are water buffalo, cattle, and horses. The water buffalo, being adapted to paddy as well as upland soils, is probably the most flexible, but it has limited strength of about 0.75 hp. Cattle and horses are better suited to upland farms.

Implement for Clearing

To clear a field of weeds and debris before plowing, a spike tooth harrow is used (Fig. 11.13). The traditional design is entirely made of hardwood, but these are now replaced by metals. The harrow pulled by the draft animal is passed over the field several times until the weeds are uprooted. The debris is then moved to one side of the field by the same implement.

Implements for Tillage

Primary tillage is accomplished with the mouldboard plow (Fig. 11.14). Subsequently, the soil clods are broken using the same spike tooth harrow used for clearing. A double gang harrow was developed by PRCRTC which is made of galvanized iron pipes and deformed steel bars (Fig. 11.15). This type of implement can attain a capacity of 1-1.8 ha/8-hour working day.

Leveling can be achieved with the traditional single gang harrow (Fig. 11.16), modified by inserting bamboo strips between the teeth to achieve a scraping action instead of combing.

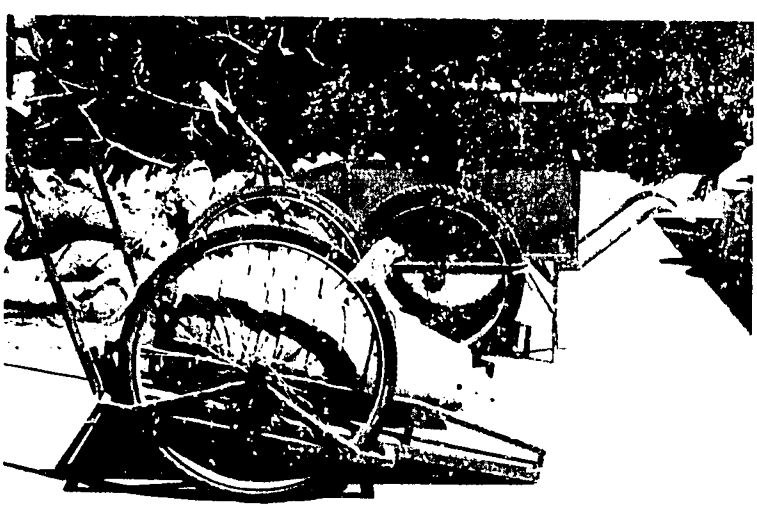

Fig. 11.12.
Push carts with pneumatic tires.

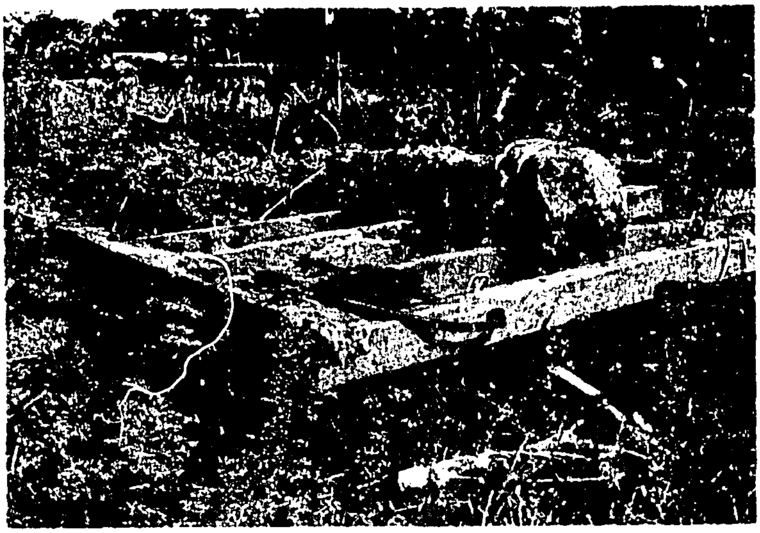

Fig. 11.13.
Animal-drawn spike-tooth harrow.

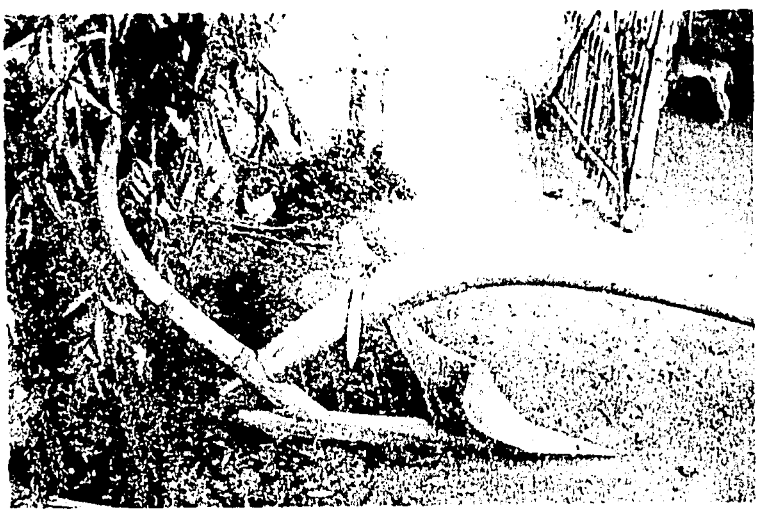

Fig. 11.14.
Animal-drawn wood moulboard plow with metal blade.

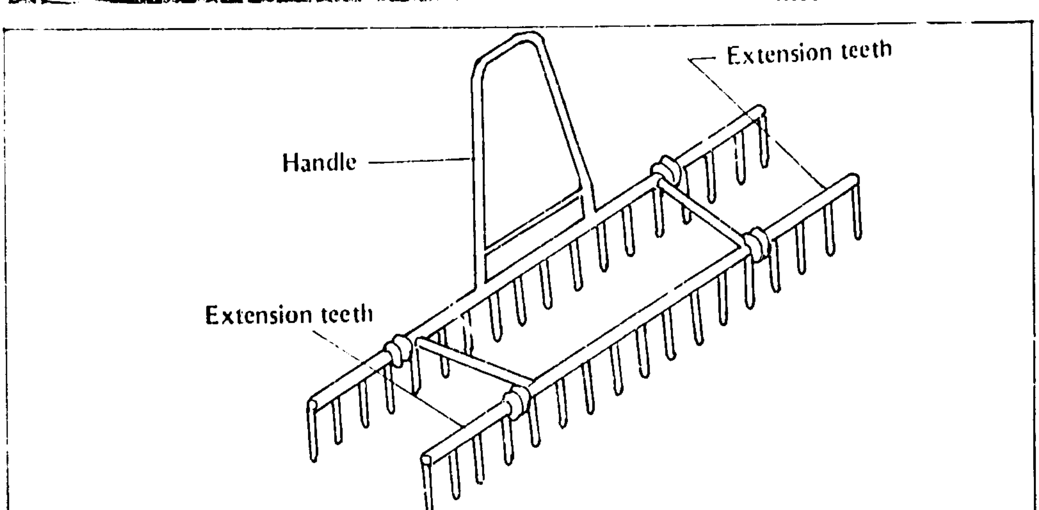

Fig. 11.15. Animal-drawn double gang harrow.

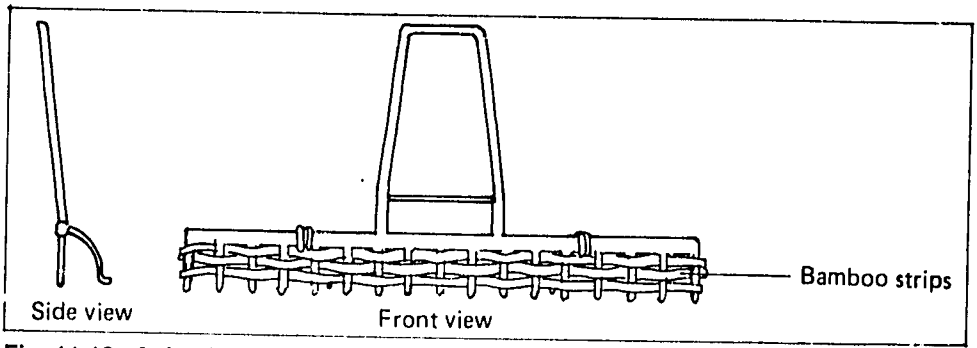

Fig. 11.16. Animal-drawn modified single gang harrow for land leveling.

Ridging is traditionally done with the mouldboard plow. This can be done more efficiently by using the furrower plow (Fig. 11.17).

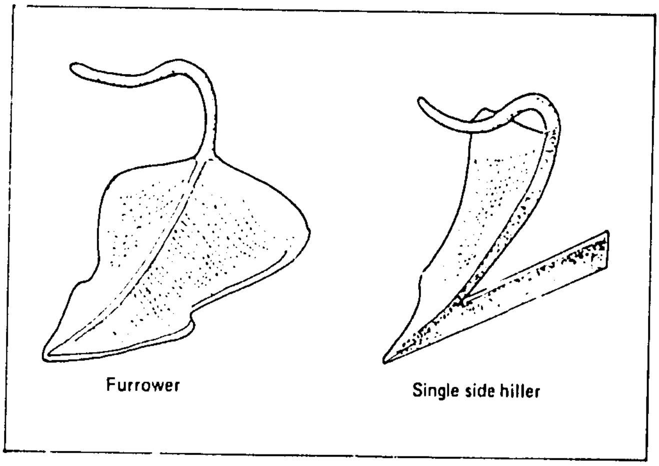

Fig. 11.17. Animal-drawn furrower plow.

Weeding and Cultivation

For row crops such as sweet corn, vegetable legumes, tomato, and eggplant off-barring and hilling up are done with the mouldboard plow. These operations control weeds and loosen the soil.

Mechanical Power Technology

Tractors

The tractor is one of the most important equipment required in mechanical power technology. To support the needs of large farms in industrialized countries, larger tractors (40 hp and above) are introduced with a trend towards tractors with sturdier tractor body and four-wheel drive design. However, the use of tractors is not common in developing countries. A worldwide study on the agricultural machinery industry prepared by the United Nations Industrial Development Organization (UNIDO) in 1979 showed that only 3%-5% of the farmers in the Third World use tractors.

For the developing countries of the ASEAN Region, the ASEAN Agricultural Machinery Federation gives the following criteria for an appropriate tractor:

1. The tractor should range from about 15-25 hp.
2. It should be low-cost and simple to operate.
3. It should have four wheels with two-wheel drive.
4. It should be applicable for wet and dry land farming.

Commercially, tractors are available in a wide range of sizes and capabilities. The smallest tractors are usually two-wheel in design and are commonly used for operating rototillers. With increasing size, the capabilities also become more varied. The range of sizes of tractors is illustrated in Fig. 11.18.

Tractors serve as a mobile power source for many kinds of farm machinery, including plows, rototillers, and harvesters. When stationary, the tractor's power take off (PTO) device can be connected to a water pump or a power generator. When hitched to a trailer, the tractor can serve the transport needs in the farm. The varied uses of the tractor are illustrated in Fig. 11.19.

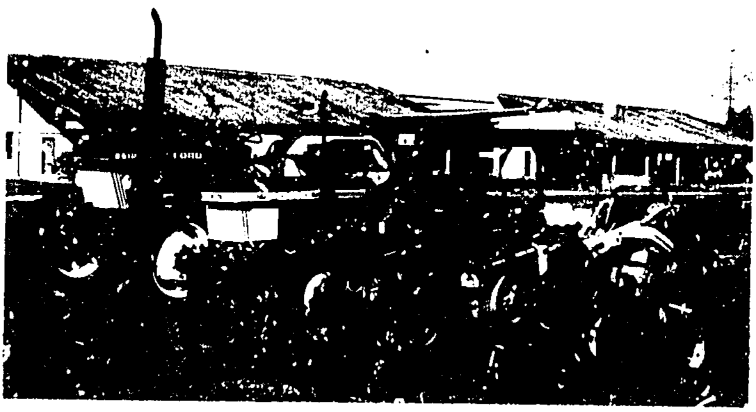

Fig. 11.18. Different models of tractors.

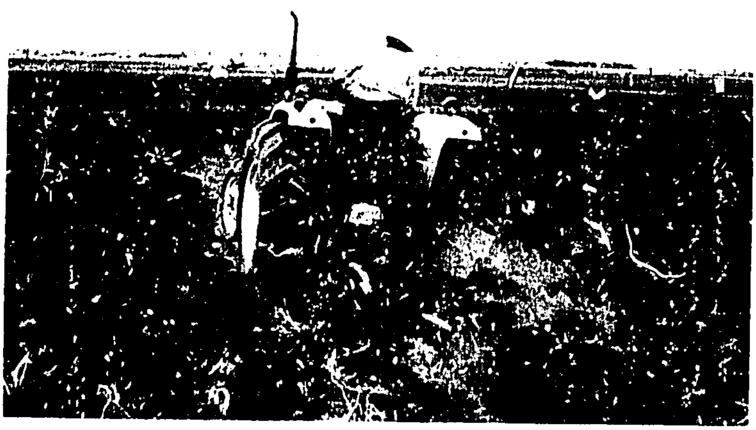

Fig. 11.19 a

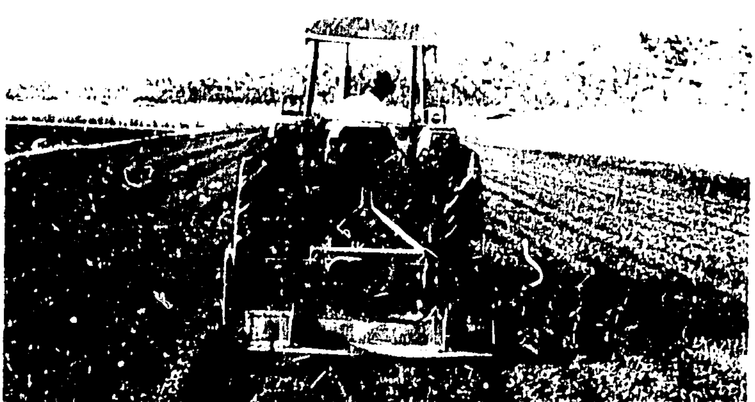

Fig. 11.19 b

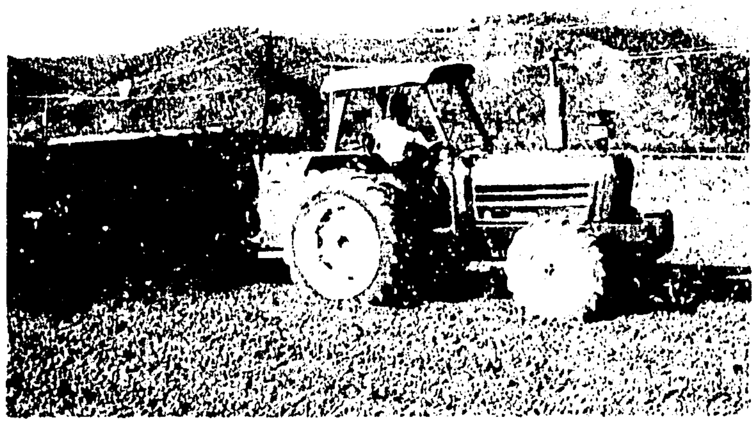

Fig. 11.19 c

Fig. 11.19 d

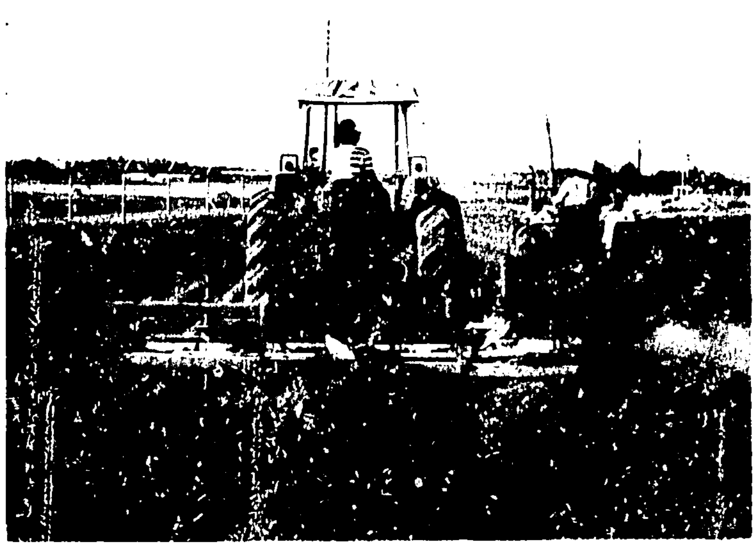

Fig. 11.19 e

Fig. 11.19 f

Fig. 11.19 a-f. Varied uses of a tractor: a) plowing, b) rototilling, c) spreading of manure, d) interrow cultivation, e) bedding, and f) transport.

Implements for Field Preparation

Clearing or Mowing

Weeds or plants of the previous crop are cleared with a rotary slasher or rotary mower (Fig. 11.20). The height of cut of rotary mowers is usually adjustable: higher for taller grasses and shorter for smaller grasses. Rotary mowers are available in different sizes (width of cut) to suit different tractor sizes. Mowers are also useful in weed control in the border areas of the farm and along roadsides. Mowers can easily do the job of 100 workers using the traditional scythe (Fig. 11.21). However, mowers are suited only for flat or gently rolling terrain. For irrigation and drainage ditches, as well as in areas with obstructions such as along the fence lines in small operations, a portable brush cutter (Fig. 11.22) is more appropriate. A special kind of tractor-mounted heavy-duty mower, called the ***hydro-mower*** is designed especially for clearing ditches and other sloping areas (Fig. 11.23).

Fig. 11.20. Rotary slasher.

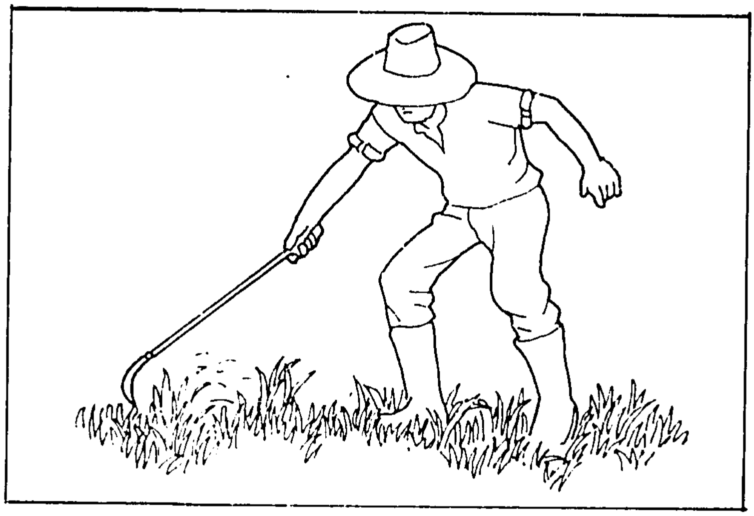

Fig. 11.21. Traditional scythe used for cleaning.

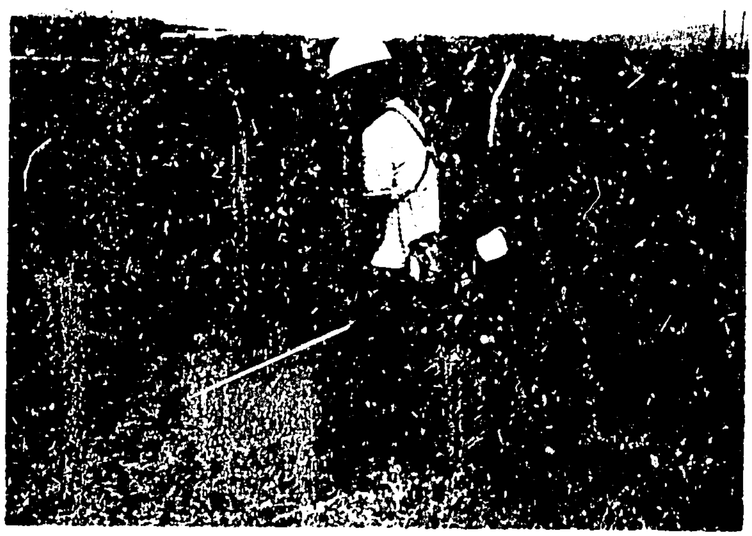

Fig. 11.22. Portable brush cutter in operation.

Fig. 11.23. Hydromower in operation.

Tillage

The tillage operation can be performed with different machineries, each designed for a specific purpose. The hoe probably served as inspiration for the development of the plow, the most basic tillage implement, which evolved as shown in Fig. 11.24. The plow was originally pulled by men or animals. With the development of the tractor, plowing became easier and faster; tillage equipment became more varied and sophisticated. These now include disc plows, mouldboard plows, vibrating harrows, disk harrows, rotary cultivators, ridgers, and subsoilers.

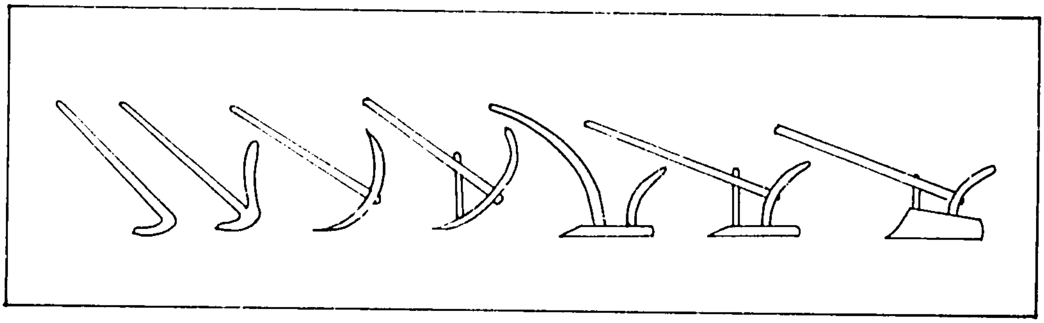

Fig. 11.24. Evolution of the plow from a curved wooden stick (left) to the prototype of the modern moulboard plow (right).

Subsoilers. With continuous use of machinery, the vegetable field develops a hard pan which becomes a barrier for drainage or physically restricts root growth. Some soils naturally have hard pans. Subsoilers are used to break this pan. Subsoilers consist of a chisel-like hard metal which raises the subsoil and breaks it up (Fig. 11.25). Some subsoilers are mounted behind the plow (Fig. 11.26). The subsoiling operation requires much power, particularly if done on heavy soil. It should be done when the soil is dry. The distance between two passes of the subsoiler should be two to four times the working depth. If power is insufficient to achieve the desired depth, the operation may be repeated.

Fig. 11.25. A subsoiler.

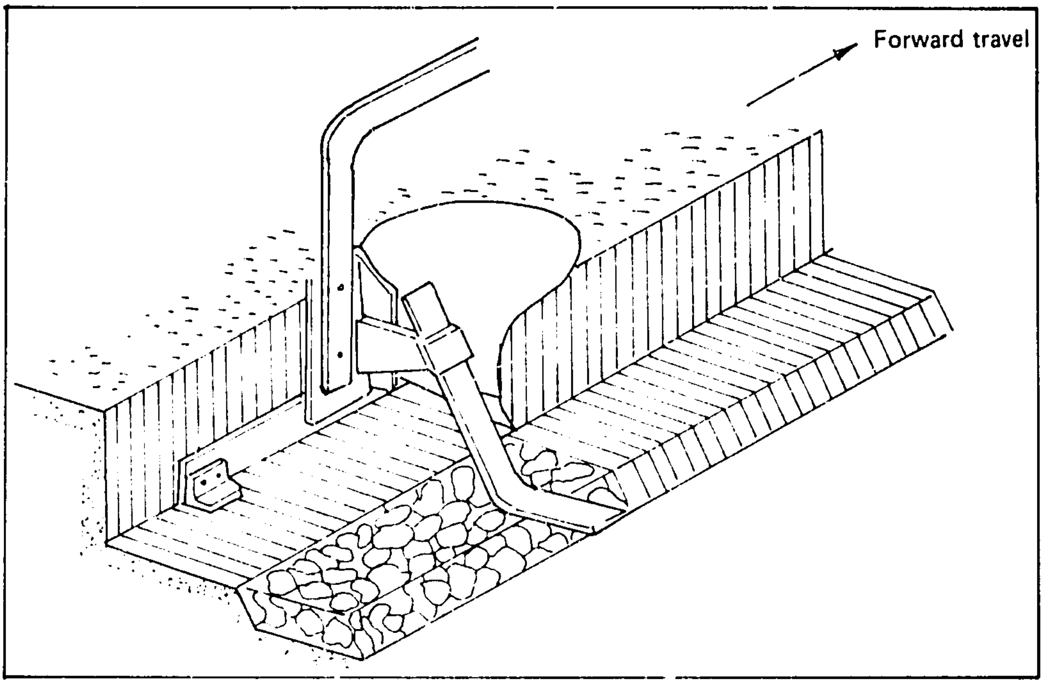

Fig. 11.26. Subsoiler in combination with a plow.

Plows. Plows are used for primary cultivation. Two types are available: ***disc plow*** and ***mouldboard plow***. The disc plow resembles the disc cultivator and will be described together in the subsequent section. Mouldboard plow (Fig. 11.27) is more common in small farms. This is used to turn and break the furrow slices. The degree of turning and breaking depends on the design of the mouldboard, thus there are many types of mouldboard plows.

Fig. 11.27. Tractor-mounted modern mouldboard plow.

Harrows. Harrows are used for secondary cultivation. Two types are used: ***disc harrow*** and ***tine harrow***. The disc harrow (Fig. 11.28) is used for weed control and mixing the soil. The angle of the harrow blade is adjustable between 0° and 30°; large angles are used for deep penetration and for breaking up the soil. Small angles are used for shallow penetration, for cutting up the soil, and consolidation after plowing.

Tine harrows (Fig. 11.29) are intended for shallow soil preparation. They are used just before sowing when the broadcast method will be used, and after sowing to cover the seed. It is also used for collecting debris on top of the soil after initial clearing or harrowing.

Cultivators. There are three types: disc, rotary, and tine cultivators. The disc cultivator (Fig. 11.30) is used to break up stubbles to promote weathering; the turning effect on the soil is small unlike the disc plow. It differs from the disc plow in the following aspects: 1) not every disc has its bearing, 2) the angle of the discs cannot be changed.

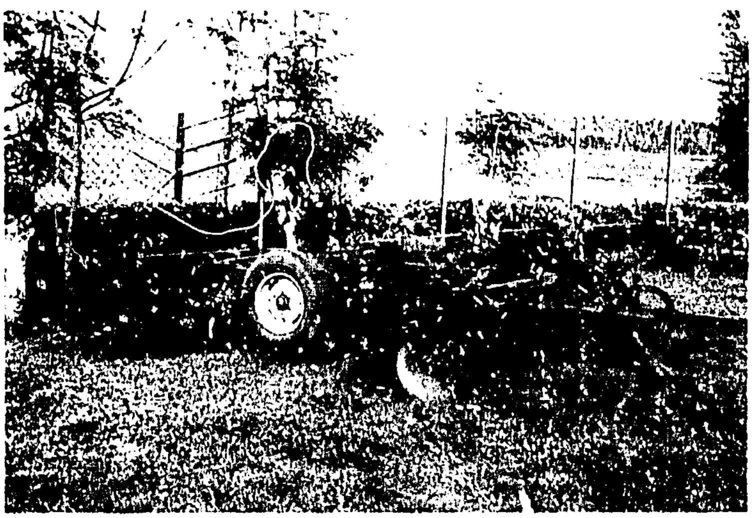

Fig. 11.28. Disc harrow.

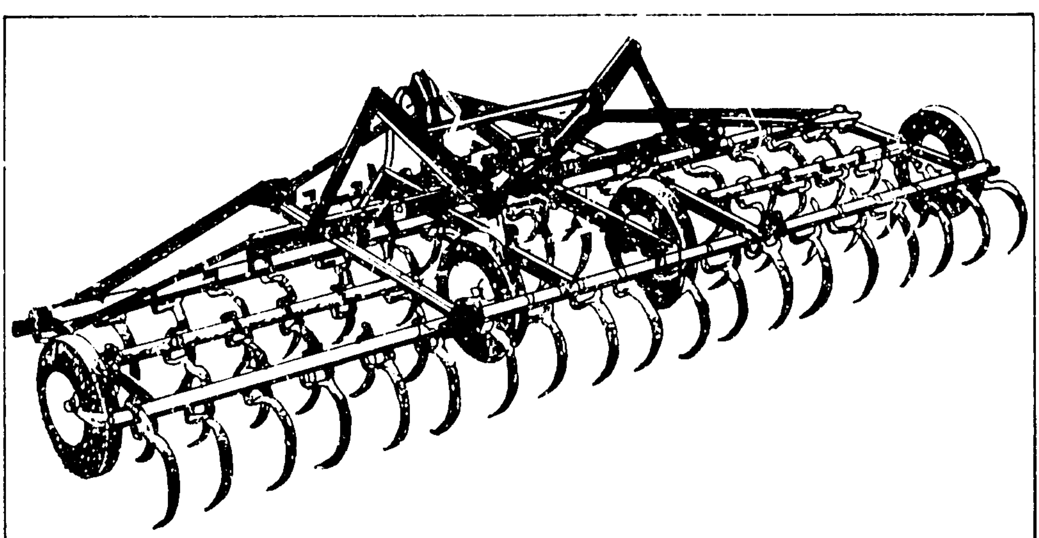

Fig. 11.29. Tine harrow.

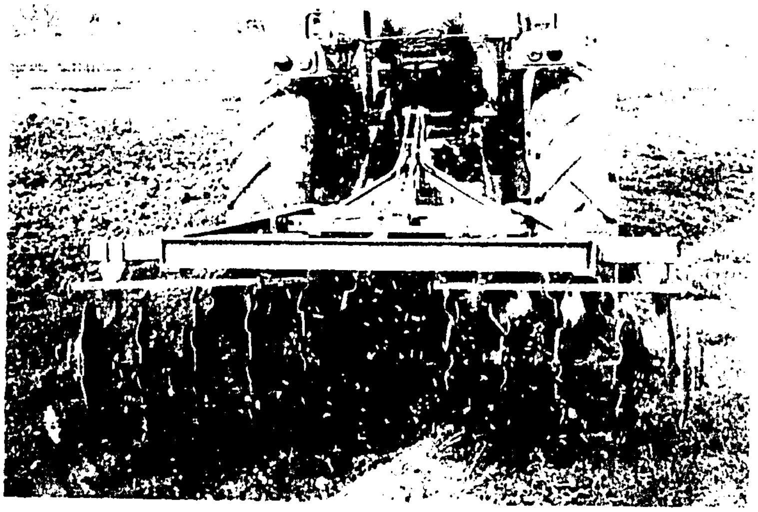

Fig. 11.30. Disc cultivator with notched blades.

Rotary cultivators (Fig. 11.31) come in different sizes. The smaller ones are the first to be used, specifically for weeding and seedbed preparation. Larger cultivators perform a combination of plowing and harrowing; thus, they have high power requirements. In specialized vegetable production areas that are used intensively for vegetable growing, the rotary cultivator is sufficient for tillage operations.

Tine cultivators (Fig. 11.32) are of different types for specific purposes. Spring tine cultivators are used for breaking up the surface soil, for seedbed preparation, and for weed control. Rigid tine cultivators are used to break up compact layers of soil to improve drainage.

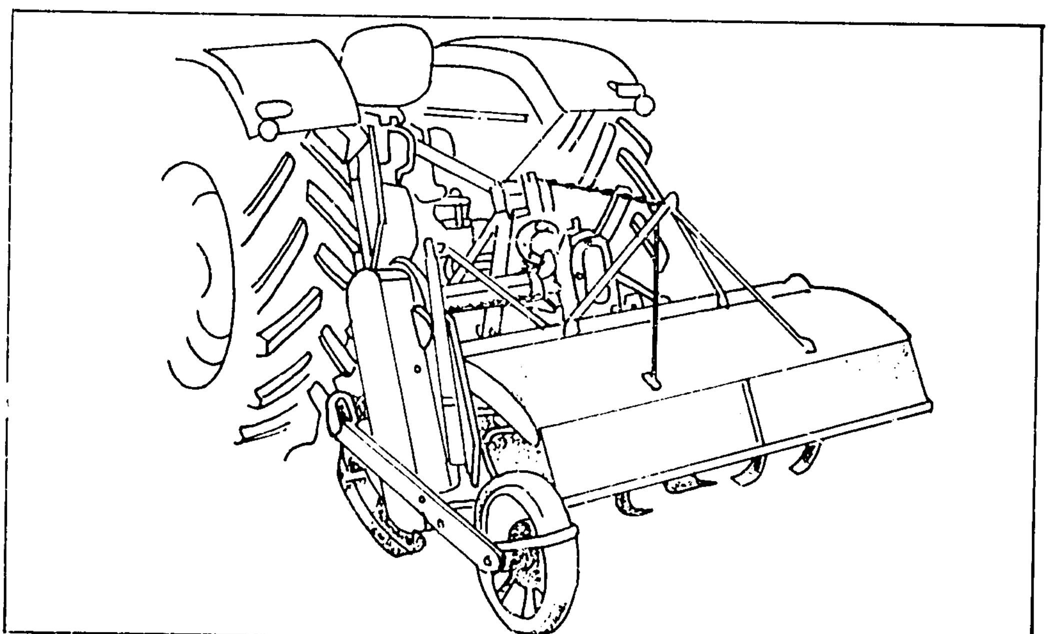

Fig. 11.31. Rotary cultivator (See Fig. 11.19d in page 366 for photograph of the equipment in operation).

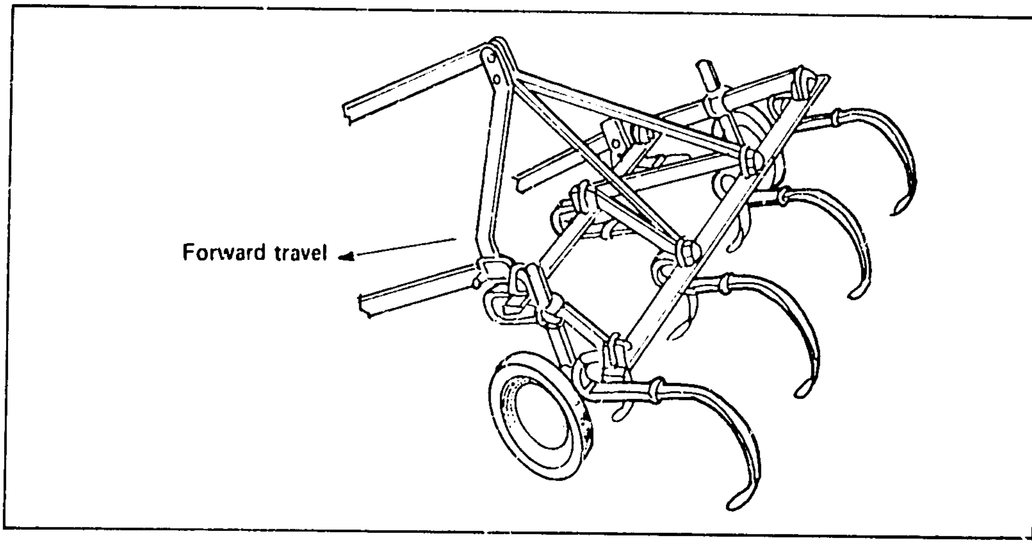

Fig. 11.32. Tine cultivator.

Rollers and land plane. These implements are used to pulverize the soil clods and level the soil. Like the subsoiler, these equipment are not needed every season; hence, the leveling operation in many farms, except in very big farms, can simply be contracted out.

Ridger. This implement (Fig. 11.33) is used for making the seedbed. In the more advanced designs, this is combined with the rotary cultivator (Fig. 11.34) to make a well-formed seedbed.

Manure spreader (Fig. 11.35). This implement is used for spreading dry manure. To facilitate the work, the manure is dumped on one corner of the field and loaded into the spreader with a mechanical loader. This is an optional equipment for most modern tractors.

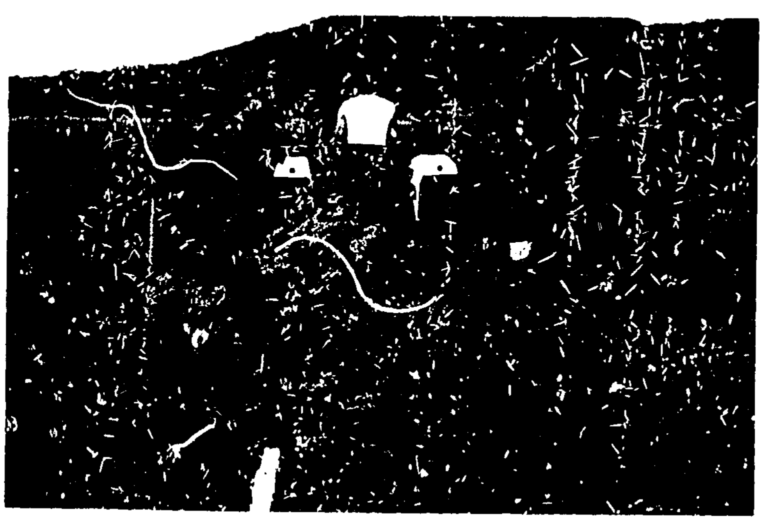

Fig. 11.33. Ridger in operation.

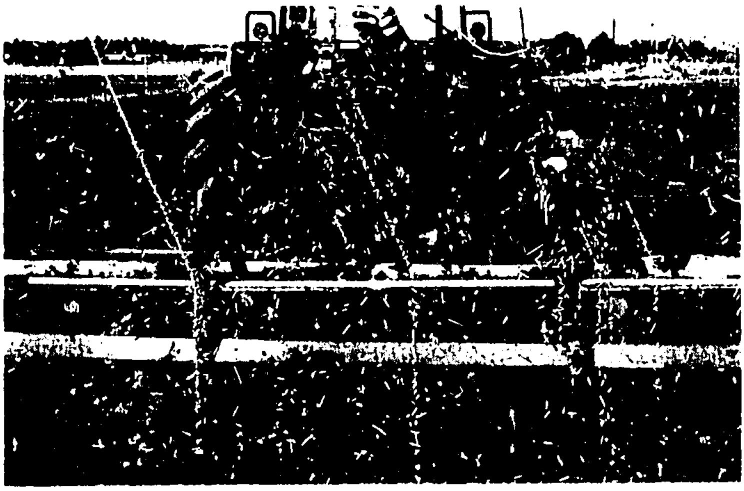

Fig. 11.34 a

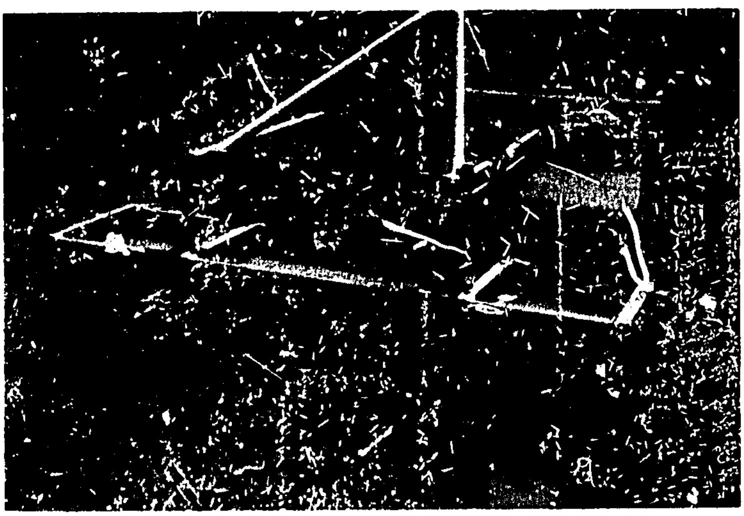

Fig. 11. 34 b

Fig. 11.34a & b. Ridgers for making the seedbed: a) ridger-bedder, b) rotovator combined with ridger-bedder.

Fig. 11.35. Manure spreader. The implement in operation is shown in Fig. 11.19c in page 366.

Nursery Operations

Mixing the Nursery Soil Mix

For large-scale operations, the components of the soil mix can be mixed mechanically with a commercial cement mixer (Fig. 11.36). The soil should be dry to facilitate mixing.

Soil Sterilization

Steam sterilization uses a steam generator (boiler) and a steam conveyance system. Modern steam sterilization includes an aerator device installed after the steam generator to lower the sterilization temperature to 70°C (Fig. 11.37).

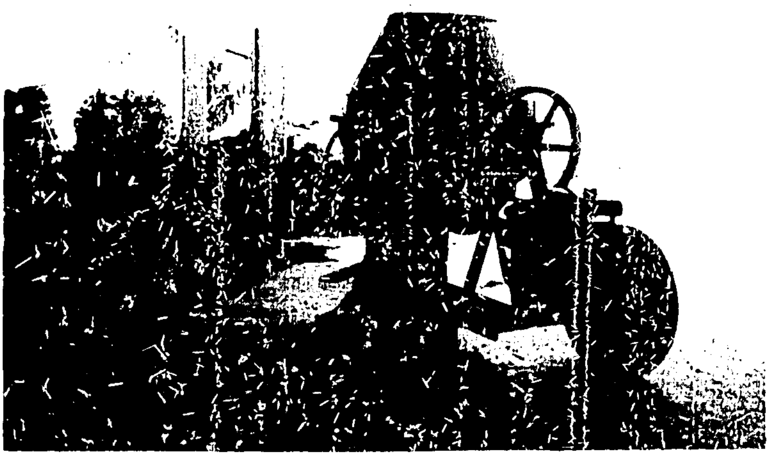

Fig. 11.36. Mixer for the nursery.

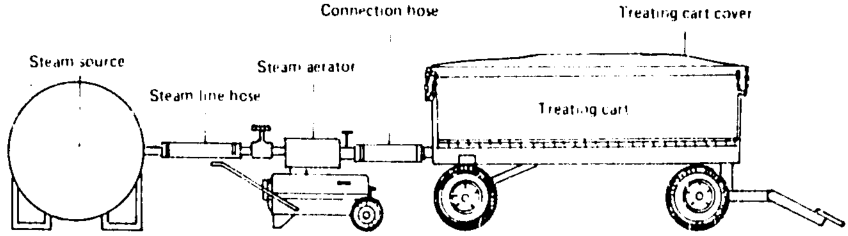

Fig. 11.37. Aerated steam sterilizer.

Mechanization in Seedling Production

The introduction of the cellular type of seedflats or nursery boxes (See Chapter 7) has greatly improved nursery techniques. In some specialized production areas, seedling production has become an enterprise by itself, i.e., some farmers produce seedlings in commercial quantities for sale to other farmers.

Seeding in the nursery One of the most difficult components in the nursery operation is the precise work of seeding into the cellular type of seedflats. The laborious and less efficient seeding work by hand has not been completely replaced by suitable machines. Therefore, missing seedlings in the seedflat are common if the seeder is not carefully operated. However, four prototypes of vacuum seeders have been developed recently by the Tao-Yuan District Agricultural Improvement Station in Taiwan.

1. Portable vacuum seeder — Fig. 11.38 shows a portable vacuum seeder which employs the vacuum pick up principle. The seeder utilizes an ordinary vacuum pump with

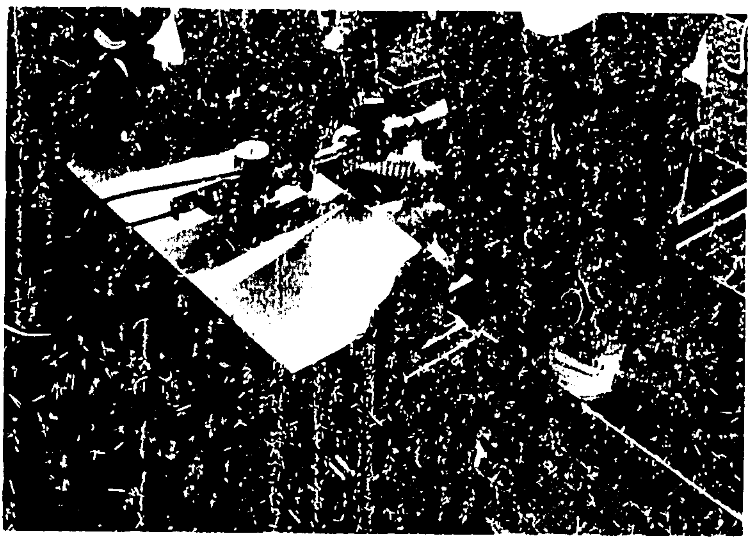

Fig. 11.38 a

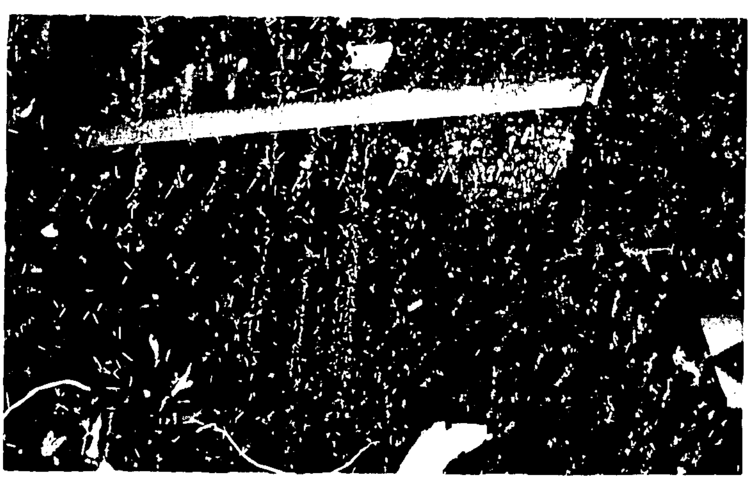

Fig. 11.38 b

Fig. 11.38. Portable vacuum seeder: a) in operation, b) details of device for delivering seed.

valving to pick up orifices. The number and arrangement of orifices are designed based on the dimensions of the nursery flat. With appropriate pressure difference, the orifices precisely pick up individual seeds. The device then can be placed on the nursery box with orifices corresponding to each individual seed compartment. The operation is completed after the seeds are dropped into the compartments by releasing the pressure. This vacuum seeder is very efficient in terms of its precision and operation time. For example, depositing cabbage seeds into a nursery box takes only about six seconds, which is 35 times faster than that by hand.

2. Semi-automatic hand seed pusher — A semi-automatic vacuum seeder is shown in Fig. 11.39. This machine is mainly composed of three parts: the base frame for the seedflat, the metering system, and the seed tube manifold. The seed-tube manifold is mounted on the base frame which is of the same size as that of the nursery box. The number of the seed tubes is the same as the number of the seed compartments in each nursery box. The base frame is equipped with rollers allowing the seeder to move forward to the next nursery box after each seeding operation. This has greatly increased the mobility and convenience of the seeder as compared with the vacuum seeder introduced

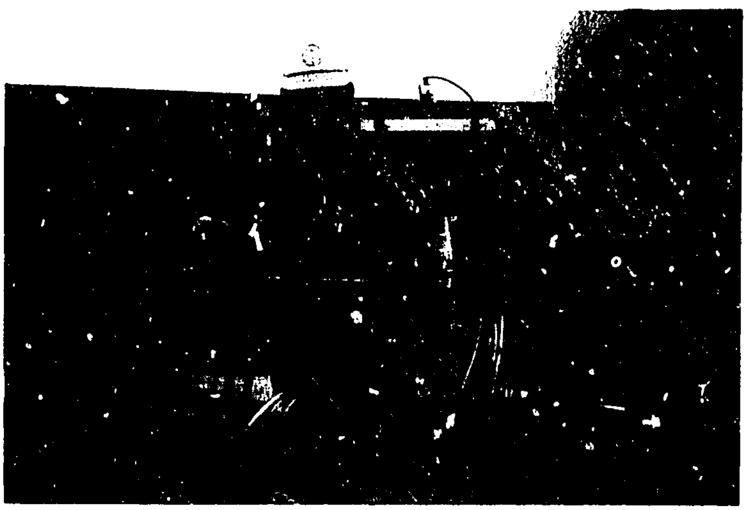

Fig. 11.39. Semi-automatic hand seed pusher.

in the previous section. For depositing the cabbage seeds into a nursery box, with the vacuum adjusted at 30 mm Hg (using 0.72 mm orifice), the operation can be completed in six seconds.

3. Stationary vacuum seeder — This type of vacuum seeder is capable of precisely picking up bare seed, therefore, the coating process for seeds is not necessary for this seeder. For relatively larger vegetable seeds, such as cabbage, rubber adapters are attached to the suction holes on the metering disc. For smaller seeds, the rubber adapters are not used. The seeds are picked up during the initial 3 4 revolution of the metering disk and are dropped to the nursery box with airflow during the final 1/4 revolution. Excess seeds are knocked off with a soft brush during the pick-up phase. Fig. 11.40 shows the

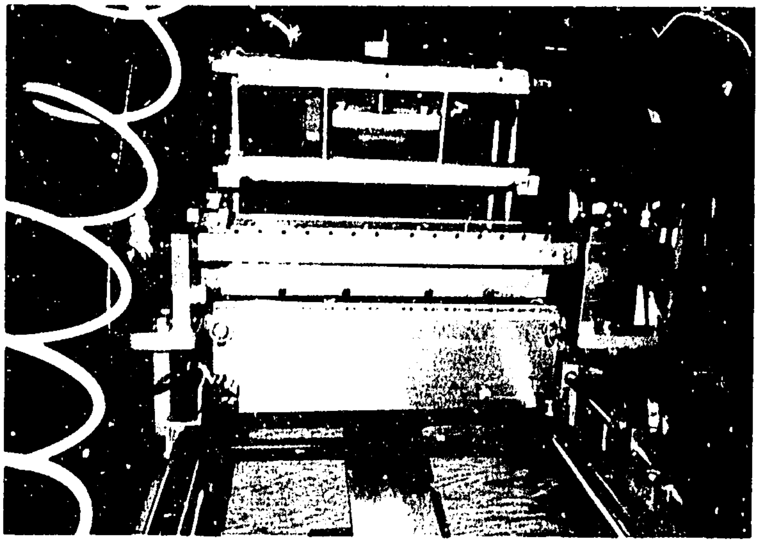

Fig. 11.40. Stationary vacuum seeder.

vacuum seeder with a vibrator which enhances more precise seeding. At a vacuum of 20 mm Hg and airflow pressure of 15 psi, 400 nursery boxes for cabbage (128 compartments per seedflat) can be seeded in an hour with 96% precision.

4. Continuous operation seeder — Fig. 11.41 shows a continuous operation seeder which is more appropriate for larger vegetable nursery operations. The whole seeding operation comprises several steps from loading the seedflats, filling the soil, watering the seeds, covering the soil, and unloading the seedflat. Fig. 11.42 details the vacuum seed metering device of the seeder. Cabbage seeds have been used to test the performance of this continuous operation seeder. Using orifices of 0.72 mm inner diameter and operating at a vacuum of 20 mm Hg with additional airflow device, 240 seedflats (about 360 seedflats are required for each hectare) can be seeded in one hour. The seeding speed is about 35 times faster than that by hand.

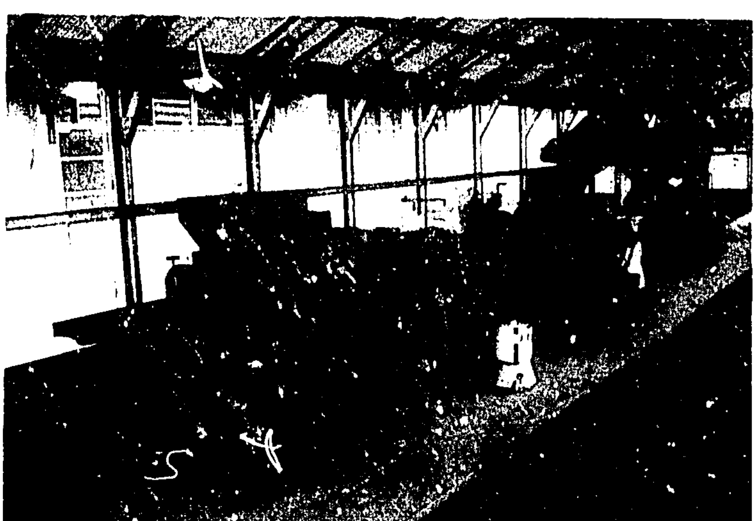

Fig. 11.41a

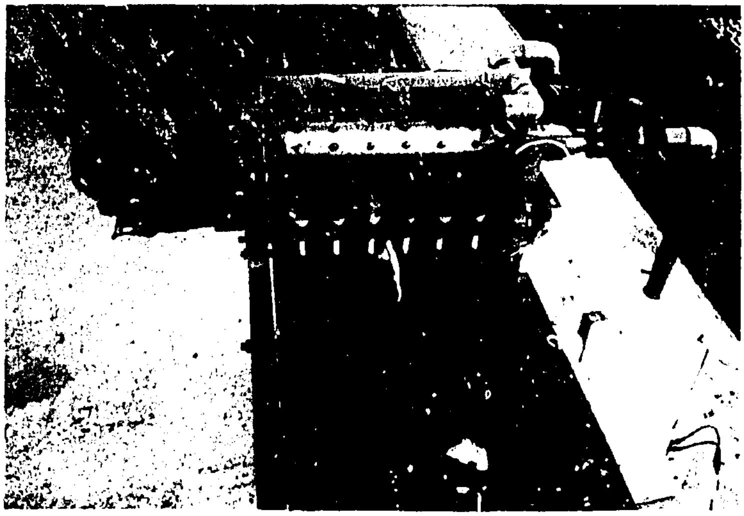

Fig. 11.41b

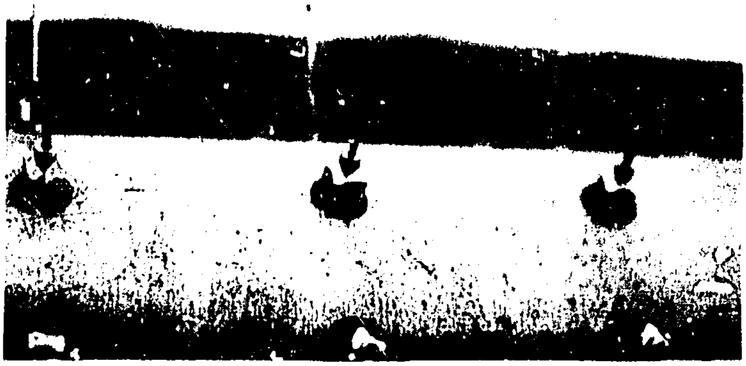

Fig. 11.41c

Fig. 11.41a-c. **Continuous operation seeder: a) view of the entire machine, b) seeds are sown by the vacuum seed metering device, c) close-up of orifices that deliver the seeds.**

Watering. Another laborious operation in the nursery is watering. This can be facilitated by using the microsprinkler system shown in Fig. 11.43. The system can be provided with timing devices attached to solenoid valves to control the interval and duration of watering. A fertilizer injector can be hooked to the system to mix fertilizers with the water so that fertilizing and watering can be combined into one operation.

Field Operations

Direct-Seeding

Sowing machines are powered by tractor, draft animal, or man. Many models have been designed; very few are in actual use in developing countries, except in the more

Fig. 11.42. View of vacuum seed metering device.

progressive farms. A typical sowing machine consists of a frame supporting a hopper with a driven metering unit which delivers the seed into the seed tubes. The seed tubes release the seed into furrows that are opened by a V-shaped coulter at the end of the seed tube. The metering device regulates the number of seeds that pass the tube into the furrow.

Vertical plate seeder. The seed is fed into a vertical plate containing cells that are large enough for single seeds. As the plate rotates, the upper portion of the rim passes through the bottom of the hopper, where the cells are filled with seeds. The seeds are ejected from the cells at the bottom of the wheel (Fig. 11.44).

Inclined plate seeder. This type of seeder has cups or cells around the periphery of the inclined plate metering device that pass through the hopper. Individual seed is fed to each cell by gravity and lifted as the plate rotates, and finally discharged to the delivery tube

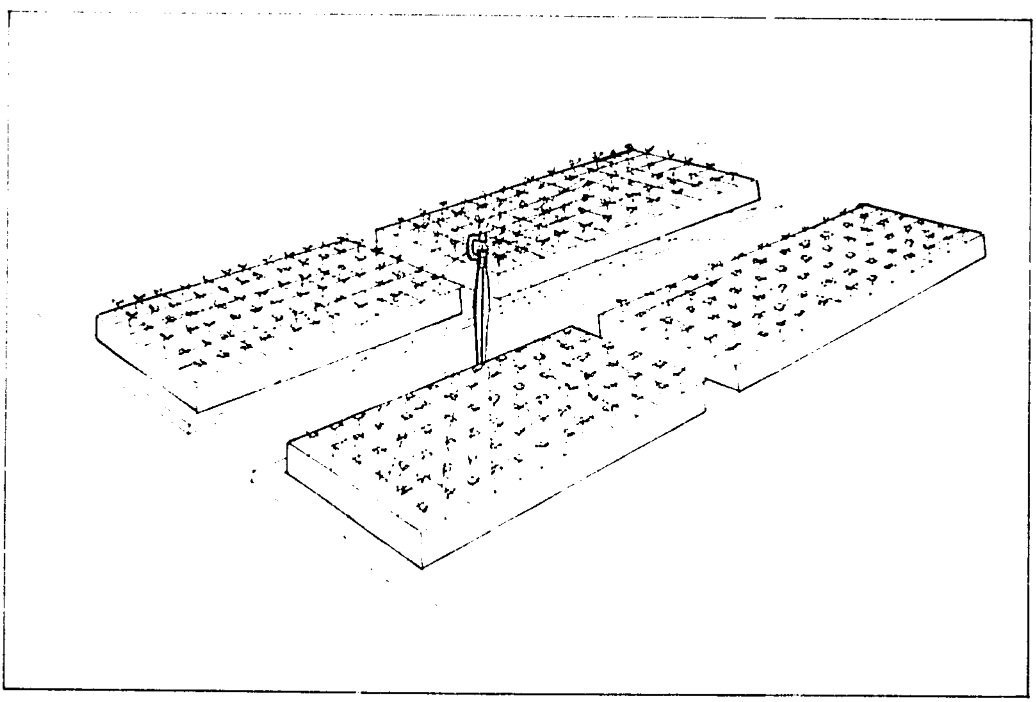

Fig. 11.43. Micro-sprinkler system for watering the nursery seedflats.

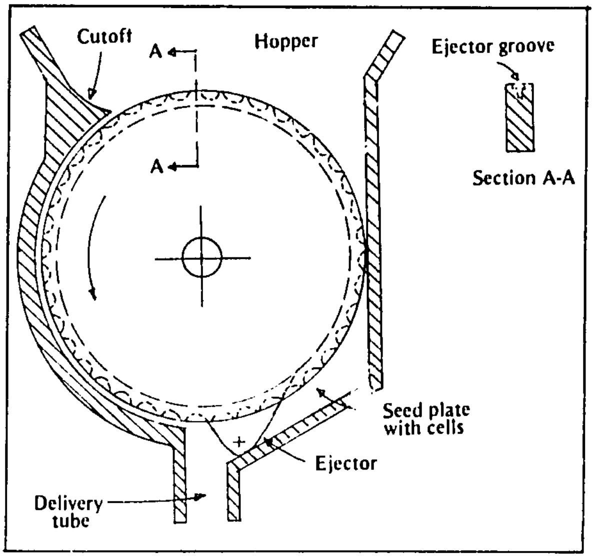

Fig. 11.44. Vertical plate seeder showing details of working parts.

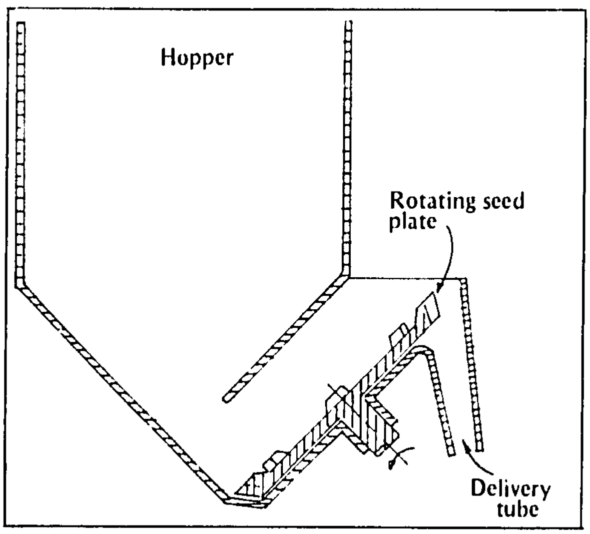

Fig. 11.45. Inclined plate seeder showing details of working parts.

(Fig. 11.45). Since the seed is not carried in a tight-fitting cell, injury to the seed is avoided.

Belt-type seeder. This type of seeder operates like the two seeders previously described except that a belt-type seed metering device is used for distributing and conveying the seeds. The cells on the belt are sized to fit the seeds. Seeds in the cells are conveyed over the base and discharged from the belt beneath the seed repeller wheel (Fig. 11.46). It is particularly useful for seeding seeds that are easily damaged, such as peanuts and vegetable legumes.

Vacuum seeder. Vacuum metering devices employ the vacuum pick-up principle for more precise seeding, such as the seeding devices used in the nurseries. Seeds are picked up individually by pressure difference with a rotating disk or orifices. Discharge of seeds is commonly achieved by using a brush, airflow, or simply relieving the pressure difference. It is ideal for vegetables, such as crucifers.

Seeding with seed tape. Seeds are deposited on a water-soluble tape under controlled conditions. The seed tape is then unrolled and placed at the desired field spacing beneath the soil by a simple planting unit, such as a seeder. This type of seeder is ideal for relatively small and flat seeds such as tomato.

Performance and Characteristics of Seeders

A hand pull seeder employing the vacuum seed metering device is shown in Fig. 11.47. Vacuum orifices and fingers are attached to the hollow shaft of wheels, therefore, the operations of picking up and discharging of seeds are accomplished as the seeder

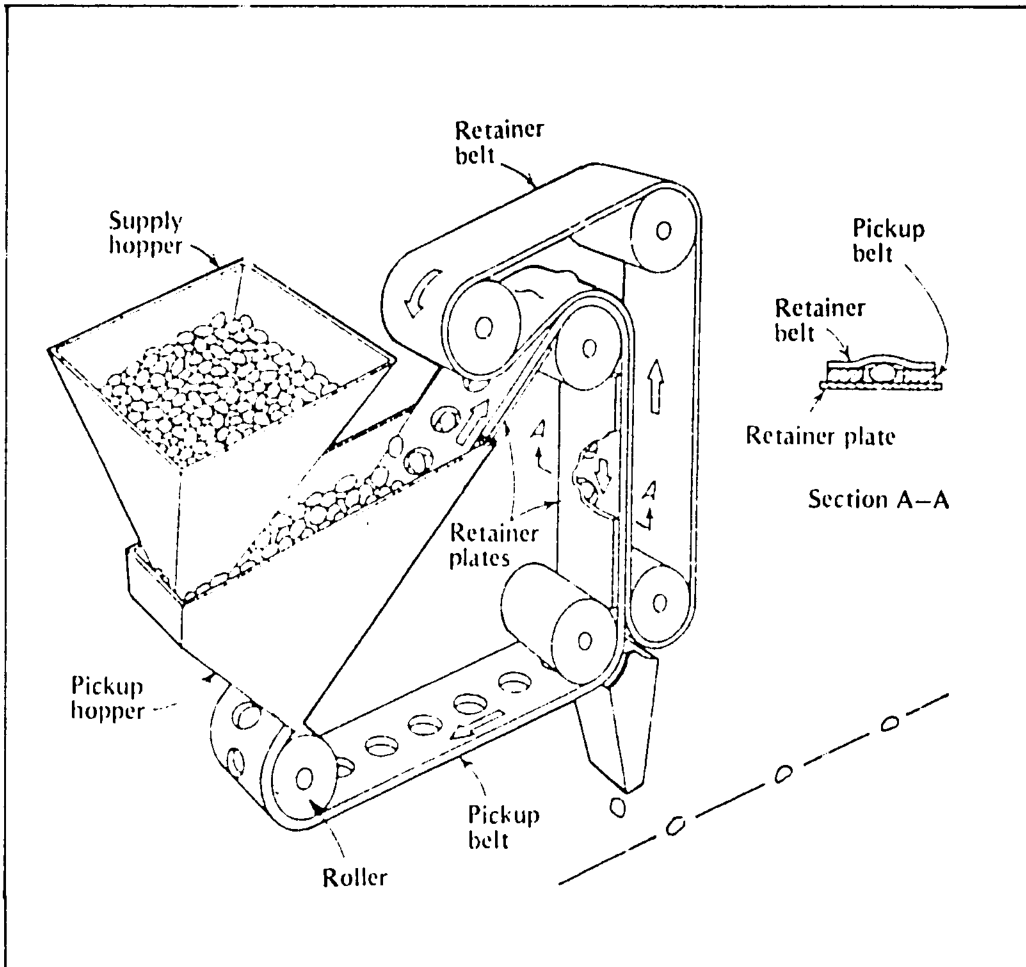

Fig. 11.46. Belt-type seeder showing details of working parts.

travels. Since the distance between individual seeds can be easily adjusted between 4-12 cm at an interval of 2 cm, this seeder is suitable for seeding operation of various types of vegetables. The spaces between rows and individual plants are uniform and thinning is not required (Fig. 11.48).

Fig. 11.49 shows a hand pull seeder which is flexible in adjusting the size of the cells in the metering device, so various sizes of seeds can be used without replacing the seed distribution mechanism. The speed of seeding is about 3.5 times faster than seeding by hand, and the growth and productivity of vegetables seeded with this seeder have been found better than that of vegetables seeded manually.

A multicrop upland seeder developed by IRRI (Fig. 11.50) can plant two crops at the same time and apply fertilizer while seeding. It can plant soybean, corn, and mungbean. Powered by a draft animal or a 6-8 hp tiller, it can be operated by one man. The maximum number of rows at 20-cm spacing is five.

For large-scale farming operations, seeding, fertilizing, and herbicide spraying can be done simultaneously by the appropriate implements mounted on a tractor. Fig. 11.51 shows a vegetable seeder mounted on a tractor. Seeds are distributed with vacuum

Fig. 11.47 a

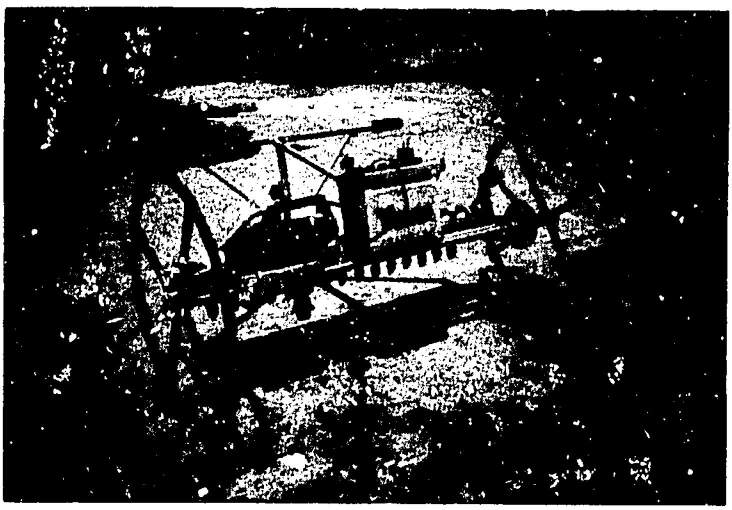

Fig. 11.47 b

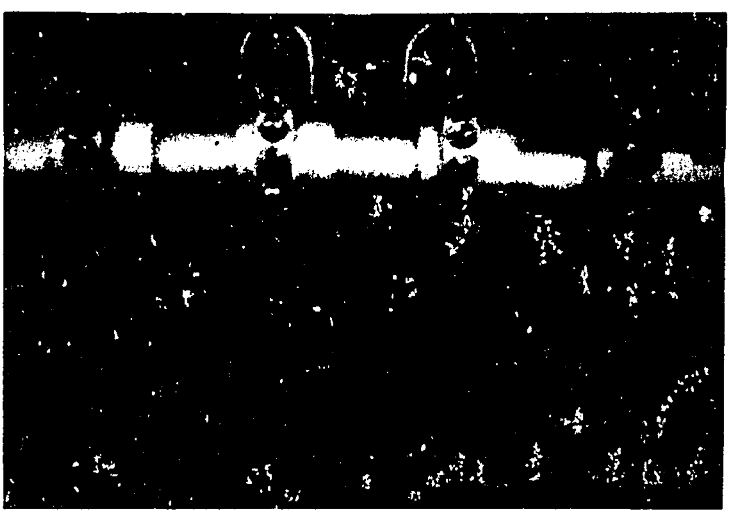

Fig. 11.47 c

Fig. 11.47. A hand-pull seeder using the vacuum seed metering device: a) close-up of the seeder, b) seeder in operation, c) close-up of the metering device.

Fig. 11.48.
Stand of seedlings that was sown using the hand-pull seeder illustrated in Fig. 11.49.

Fig. 11.49.
A hand-pull seeder with flexible metering device.

metering device whose vacuum pump is PTO-driven. Six ridges can be seeded for each pass of the tractor. Plates, belts, or vacuum metering devices with different cells are available for the mounted seeders.

Transplanting

Transplanting machines range from large units that are mounted on a 4-wheel tractor or small units mounted on a 2-wheel cultivator. Depending on the type of seedling and the seedflat used for growing the seedling, the following are the types of transplanters:

1. Transplanter for seedling with soil
   a. Cup-type transplanter
   b. Transplanter with seedling grip
2. Disc-type transplanter for bundled seedlings.

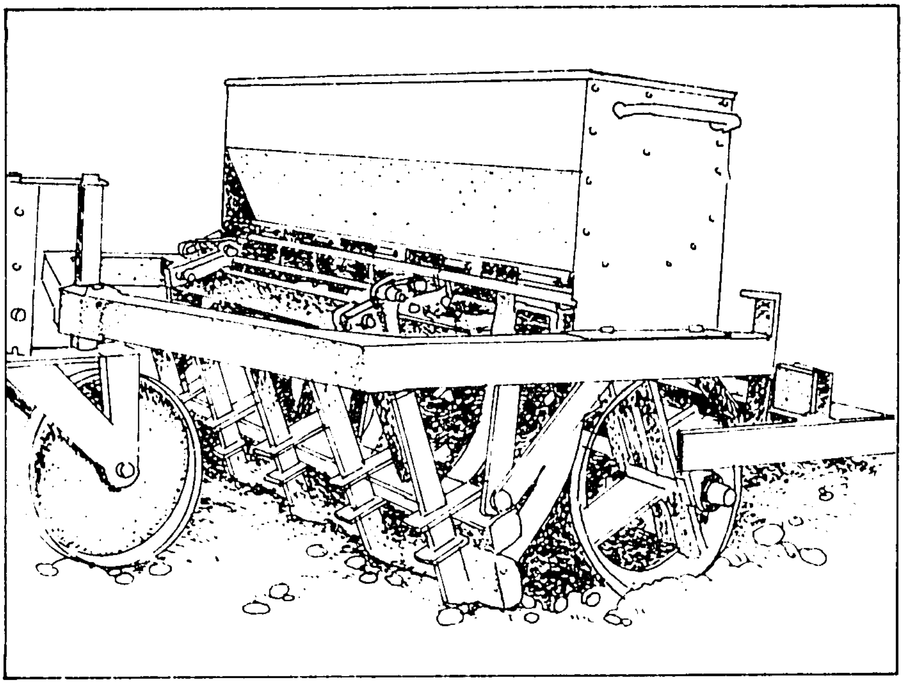

Fig. 11.50. Multicrop seeder.

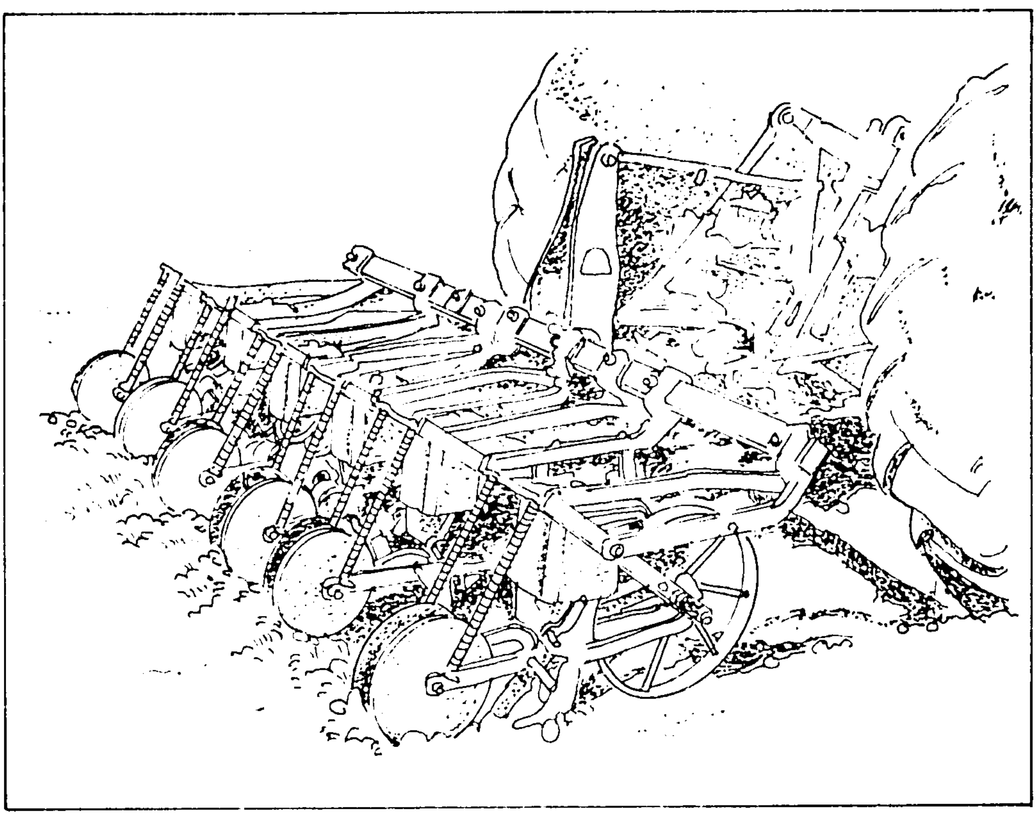

Fig. 11.51. A vegetable seeder mounted on a tractor.

3. Transplanter for seedling without soil
   a. Transplanter with disc-type seedling grip
   b. Transplanter with paper-tape seedling grip
4. Transplanter for nursery box
   a. Cup-type transplanter
   b. Transplanter with seedling grip

Automatic Transplanters

Cup-type transplanter. When the seedlings in a nursery box are ready to be transplanted (Fig. 11.52), a small cup-type transplanter can be used. Fig. 11.53 shows an automatic transplanter which is driven by an ordinary engine for a cultivator (6 hp). Power is transmitted via a gear box to a push rod which synchronizes the travelling speed of the transplanter. Seedlings in each compartment of the nursery box are ejected from the box by the push rod and conveyed to the cup-type transfer device for uniform placement of the seedling on the ridge.

Ridge forming is required before the seedlings are transplanted. For cabbage, ridges are prepared which are 20 cm in height, 30 cm in furrow width, and 45 cm in bed width. A single row of seedlings is transplanted each trip with a 40-cm distance between two seedlings. However, the distance between two seedlings can be adjusted from 35 to 50 cm. Various other vegetables, such as cauliflower, tomato, sweet pepper and cucumber, have been tested successfully with this transplanter. For the vegetables tested, transplanting of a 1-ha field needed only about 15 hours.

Automatic transplanter mounted on a tractor. Fig. 11.54 shows an automatic transplanter mounted on a tractor. Two air compressors are driven by the PTO to generate pneumatic power for the fast operation of eight push rods. The push rod is a two-section

Fig. 11.52. Vegetable seedlings ready for transplanting.

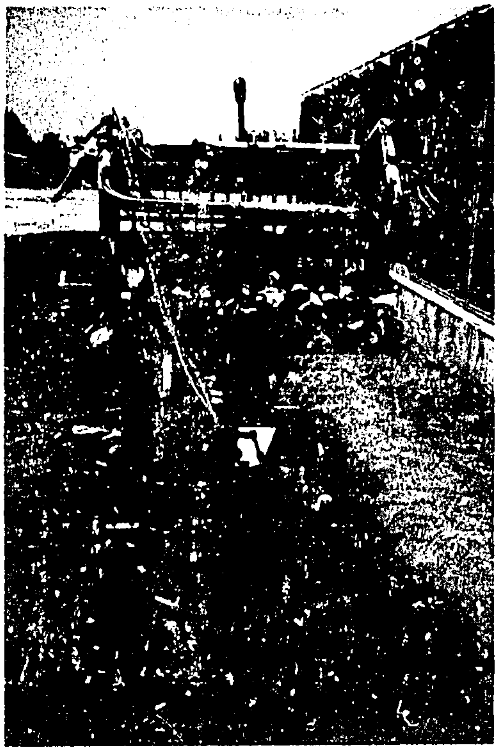

Fig. 11.53. Automatic transplanter driven by a 6 hp cultivator engine.

cylindrical rod which is 25 cm long. The outer section (10 mm diameter) of the push rod pushes the seedling to near the surface of the ridge and an inner section (5 mm diameter) sets the seedling into the soil to about 4-5 cm deep. Transplanting of seedlings (with soil clump) 5-6 cm high and with at least three leaves can be performed by this transfer mechanism without difficulty. The nursery box has a dimension of 90 cm long, 30 cm wide, and 4 cm high seedling compartments in it. For lettuce transplanting, ridges are prepared which are 20 cm in height, 40 cm in furrow width, and 90 cm in bed width. At each trip, eight rows of seedlings can be transplanted (2 rows in each ridge, 40 cm between rows (30 cm between individual seedlings).

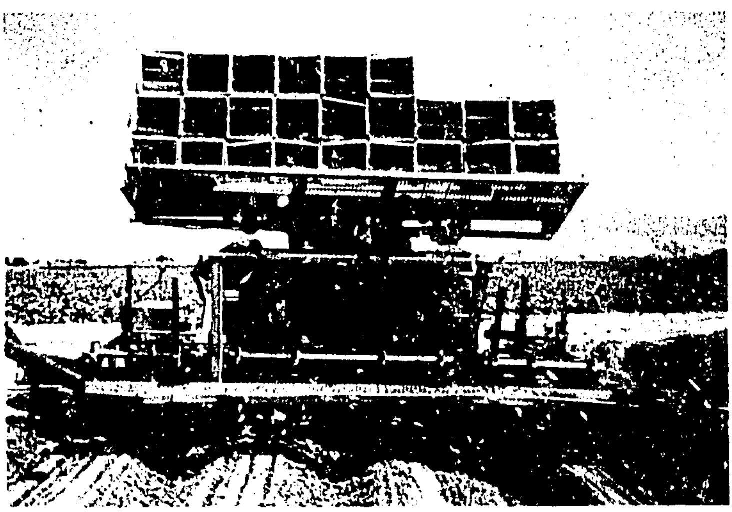

Fig. 11.54. Automatic transplanter mounted on a tractor.

Semi-automatic Transplanter

Semi-automatic transplanters are commonly mounted on a tractor for operation. There are essentially four different types of semi-automatic transplanters: disc-type, finger-type, rotary disc cup-type, and crank cup-type.

The disc-type transplanter is the simplest in terms of structure. Distance between transplanted seedlings may be adjusted by altering the configuration of the disc and is usually between 25-35 cm. All these four types of semi-automatic transplanters have a common characteristic; that is, they require manually feeding of seedlings into the transfer device.

A finger-type transplanter is shown in Fig. 11.55. Seedlings are manually fed to the rubber fingers and then transferred via a conveying chain and rotary mechanism into the ridge. For this particular transplanter, the row width can be adjusted from 45 to 60 cm, and the distance between seedlings can be adjusted from 12 to 30 cm. Two, four, or eight rows of seedlings may be transplanted, depending on the type of transplanter used. Frequently, sprayers are incorporated to the transplanter for herbicide application. A water tank attached to the tractor is also used to water the seedlings immediately after transplanting.

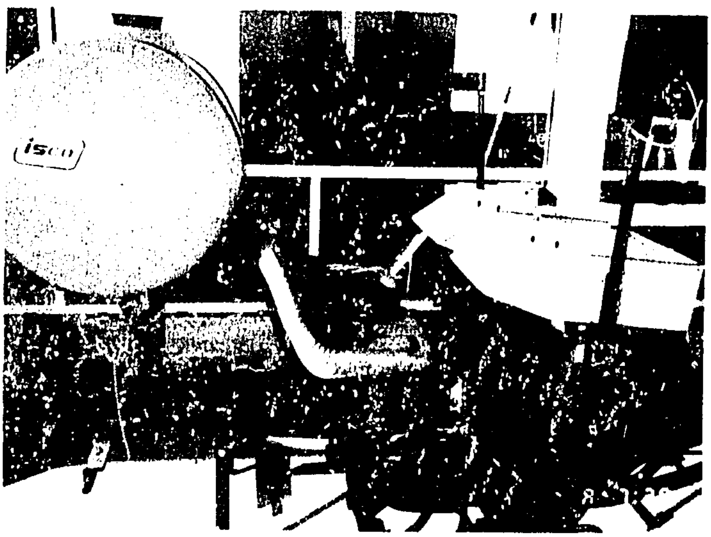

Fig. 11.55.
Finger type transplanter.

Interrow Cultivation and Mechanical Weed Control

The basic types of cultivators are described earlier in this chapter under the section "Tillage". The same implements are used for interrow cultivation, but modifications in design and attachment to the tractor are often necessary to avoid damage to the crop.

Because of the development of various cultivating implements, the capability and versatility of cultivators have increased to encompass many operations, such as ridge forming, hilling, furrowing, and plastic sheet (mulch) covering. There are self-contained cultivators using small engines (5-7 hp) as propelling power source. Fig 11.56 shows a self-contained cultivator performing weeding operation. For some types of vegetables, such as tomato and lettuce, direct seeding on ridges is frequently practiced. Interrow cultivation is necessary when seedlings reach the height of 10-15 cm. Other operations, such as hilling and ridge forming, can also be achieved simultaneously with a furrower (Fig. 11.57).

Fertilizer Application

With regard to time of application, fertilizers are applied as basal (before or during planting) or top dress (also called side dress) which is applied during the growing period

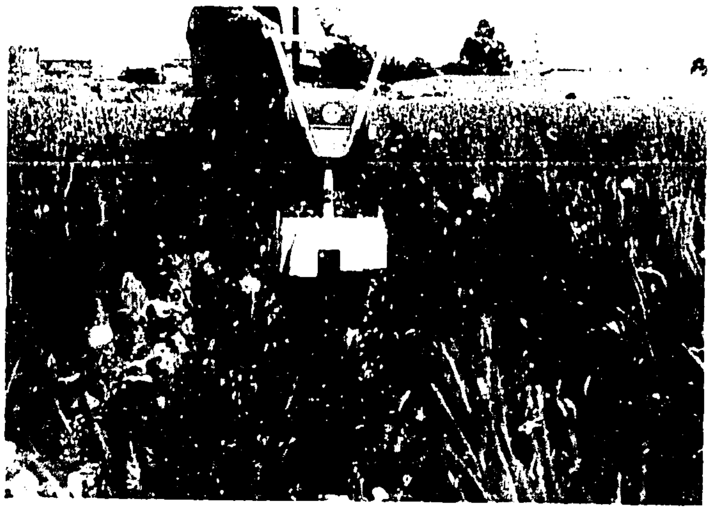

Fig. 11.56.
A rotary tiller mounted on a walking tractor.

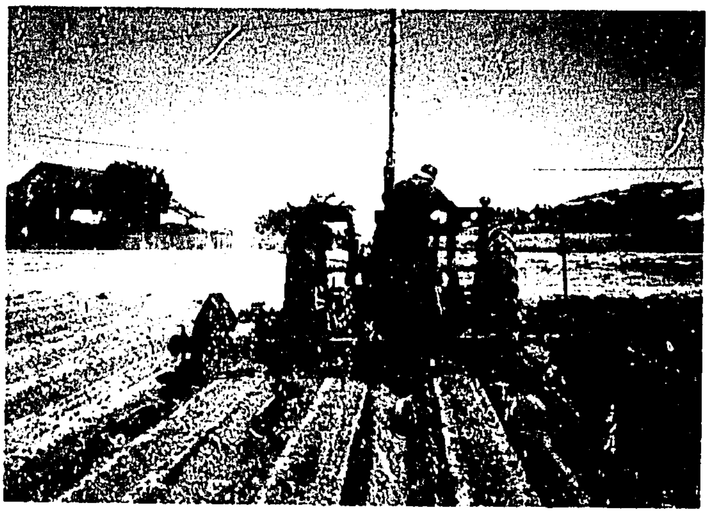

Fig. 11.57.
Cultivating implements mounted on a tractor performing weeding and milling operations.

of the crop. Fertilizers may be in solid, liquid or gaseous forms. Various fertilizer applicators have been developed for these forms of fertilizers. Typical examples are high-pressure fertilizer deep applicator, high pressure fertilizer sprayer, and double purpose seeding and fertilizer applicator. Fertilizers are also applied through the irrigation water, particularly with drip irrigation equipment.

Mechanized basal application of fertilizers can be achieved by broadcasting before final cultivation with a fertilizer spreader (Fig. 11.58) or by row application during planting combined with the seeding equipment. Top dressing can be combined with interrow cultivation using a double purpose fertilizer deep applicator with a liquid fertilizer tank (Fig. 11.59).

Spraying

Power sprayer. The power sprayer uses an internal combustion engine to generate pressure for spraying, usually using the air blast principle (Fig. 11.60). One advantage of using the power sprayer is the uniformity and continuity of the spray. The power source is usually around 1.5-2.5 hp, operating at 60-120 rpm. Pressure is maintained from

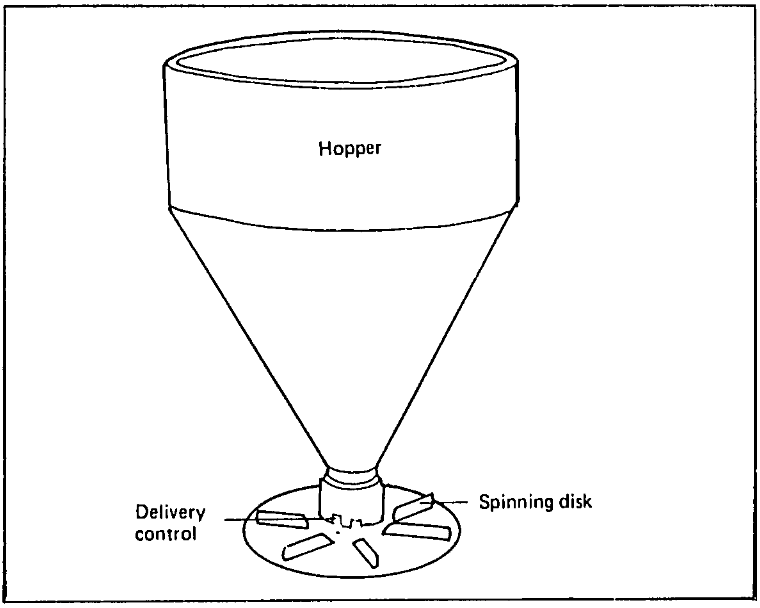

Fig. 11.58.
Centrifugal fertilizer distribution machine.

Fig. 11.59.
Fertilizer deep applicator with a liquid fertilizer tank.

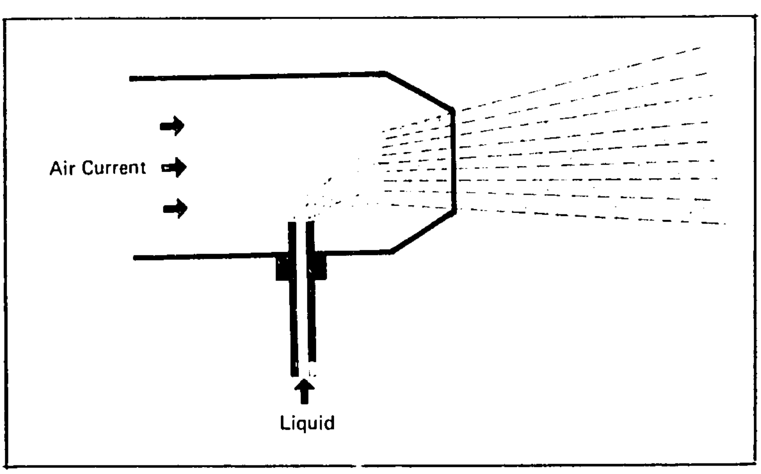

Fig. 11.60.
The air blast principle in a power sprayer.

14-18 kg/cm². There are two types of sprayer commonly used for vegetables: the knapsack type (Fig. 11.61) and the semiportable bucket type (Fig. 11.62).

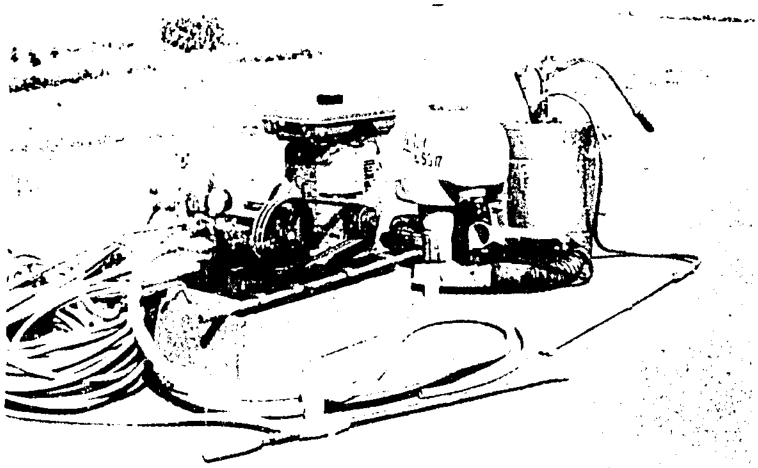

Fig. 11.61.
Knapsack type of power sprayer (middle) with knapsack type of manual sprayer (left) and bucket type power sprayer (right).

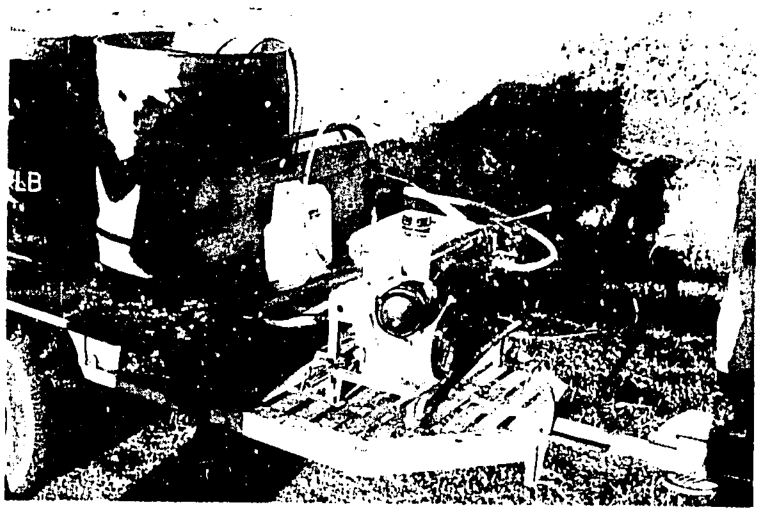

Fig. 11.62.
A semi-portable bucket type of power sprayer: a) close-up of engine and container of pesticide solution, b) in operation.

Fig. 11.62a.

Fig. 11.62b.

High-pressure sprayer. Fig. 11.63 shows a recently developed high-pressure sprayer with elevated frame mount on a 20 hp tractor.

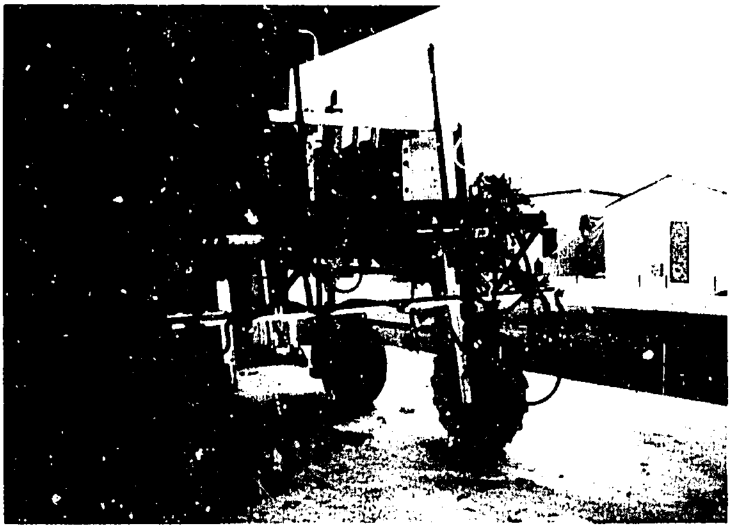

Fig. 11.63. A high-pressure sprayer with elevated frame mounted on a 20-hp tractor.

Ultra low-volume (ULV) sprayer. In this type of sprayer (Fig. 11.64), the spray mixture is fed to a rotary atomizer (disc) by gravity. The disc is driven by a constant speed motor powered by batteries. This type of sprayer is ideal for farms that are far from the water source.

Duster. A duster (Fig. 11.65) is a simpler machine than a sprayer, and no water is needed for its operation. The spread of dust particles is sometimes more efficient than the spray of liquid particles. The application rate for liquid spraying is about 20-40 kg/ha; for dust application only 0.6-1.2 kg/ha is required. All dusters utilize an air blast in which the dust particles are mixed into the air and then deposited on the crops. The air-blast power sprayer can be easily converted into a duster.

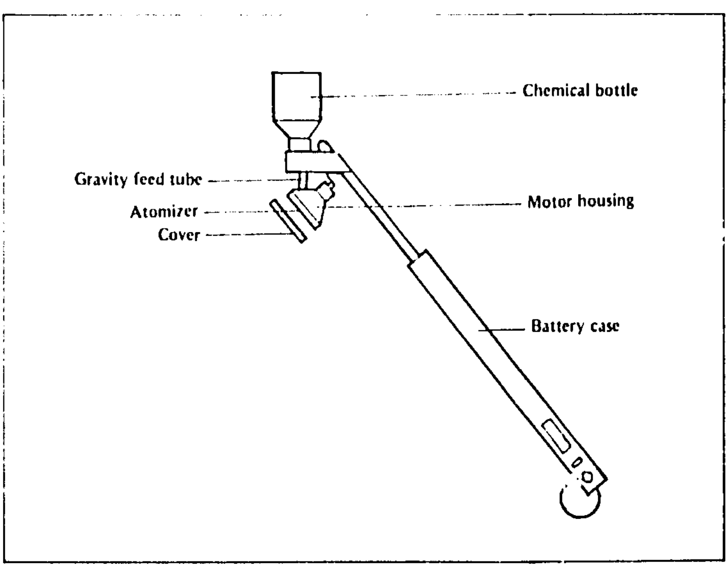

Fig. 11.64. Ultra low-volume sprayer.

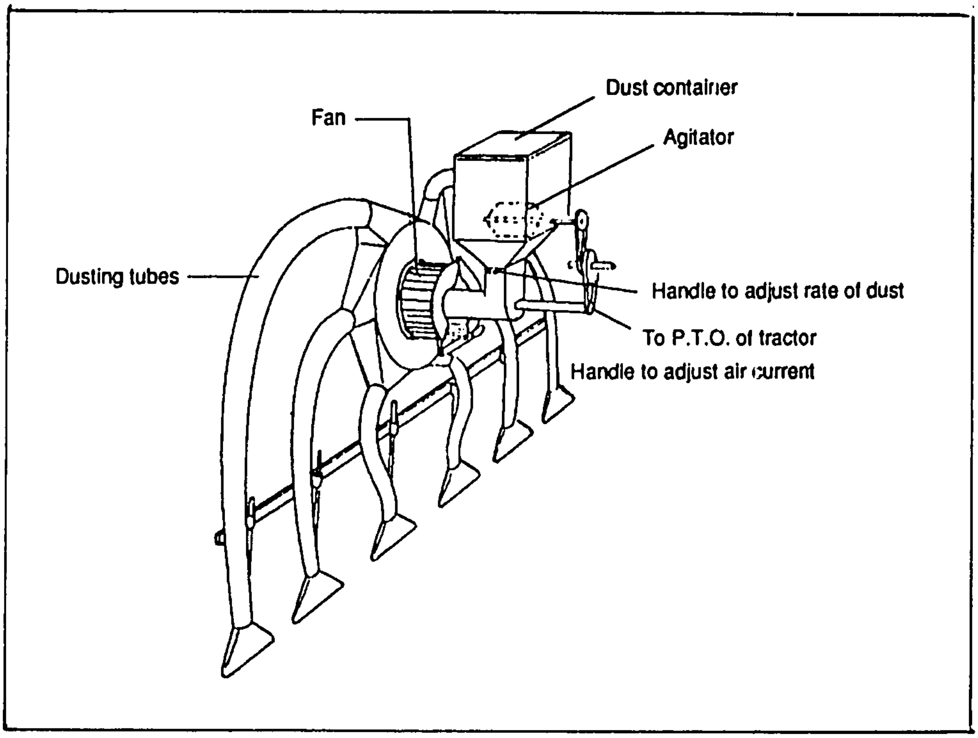

Fig. 11.65. Tractor-mounted duster.

Irrigation Pumps

For small vegetable farms where labor is cheap and the source of water is close to the field, irrigation with the use of watering cans is practical. In bigger farms that are served by water from an elevated source and conveyed by open canals, furrow or flood irrigation can be easily achieved without any equipment, except for siphons which are used to convey water from the channel to the field. If water is conveyed from the elevated source to the farm through a closed system of pipes, sprinkler and drip irrigation can also be used without the use of water pumps. In many situations, however, water is drawn in big volumes from a river or wells which may be several meters lower than the elevation of the field. Under this condition, a water pump is an indispensable equipment.

Power sources. Water pumps are relatively simple in construction and can be obtained commercially at relatively low cost. It is the power source that requires a sizeable investment. We have shown earlier that human muscle can provide the power source, but this is not very efficient. Several alternative power sources are available.

1. Electric motor — This is suitable for stationary pumps where electricity is cheap.
2. Internal combustion engines — Diesel or gasoline engines are used for mobile or stationary pumps. The tractor may also be used if the power take-off unit is suitable.
3. Wind or solar power — These are nonconventional power sources which can be tapped if conditions are favorable.

Pumps for small farms. PCARRD (1988) provides the following descriptions of pumps that are suitable for small farms that use energy other than that provided manually as described earlier in this chapter.

1. **Axial flow pump** (Fig. 11.66). Simple in construction, the pump can be directly coupled to an engine or belt driven by a power tiller. Two men can conveniently transport the whole unit because of its light weight (45 kg). Since the pump impeller is submerged, it is self-priming. Run by a 5-hp engine or a 3-hp electric motor, it can attain a capacity of up to 50 liters/second. The discharge tube has a diameter of 150 mm. The total lift is 1-4 m.

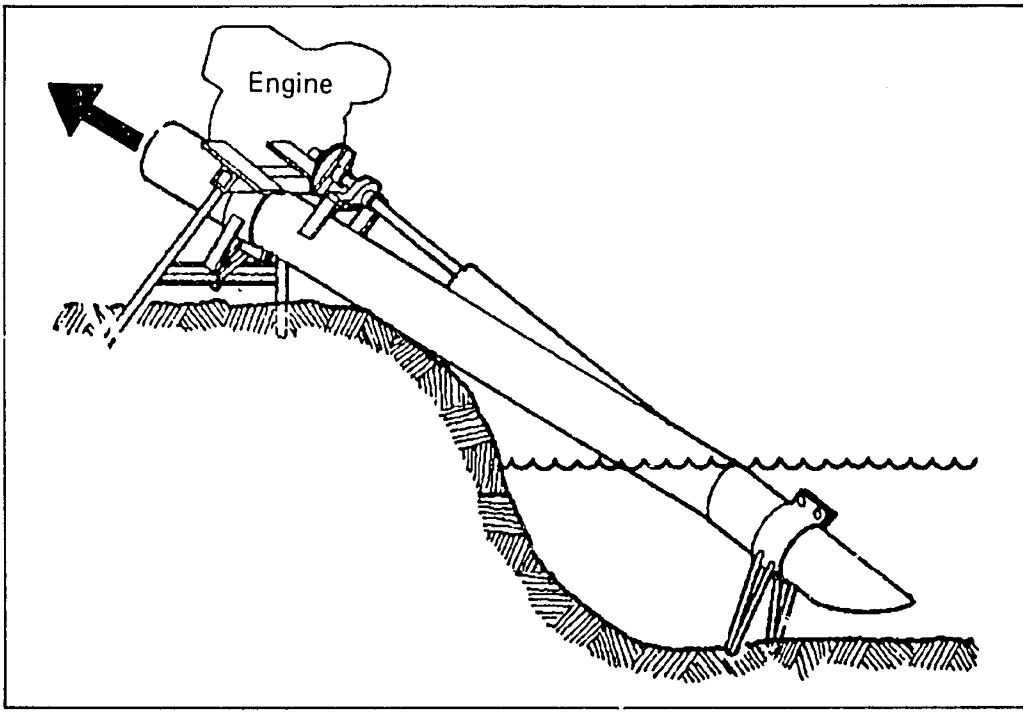

Fig. 11.66. Axial flow pump.

2. **Savonius windmill and piston pump** (Fig. 11.67). This vertical axis windmill and piston pump combination provides low-cost water pumping in areas where wind speed averages at least 16 kph and the water level is not more than 4.6 m below the ground. Its pumping capacity ranges from 4,600-148.400 liters per hour on a suction lift range of 1.5-6.1 m and with a wind speed range of 24-48 kph.

3. **"Sipa" pump** (Fig. 11.68). This is a portable, easily installed and self-priming pump. It is ideal for low-lift applications where water must be raised to only 1-2 m. It is 15 cm in diameter powered by a 7-hp engine. It has an output of approximately 40 liters/second for lift of 1.5 m which is two to three times higher than that of either a centrifugal pump or an axial-flow pump using a boat propeller, for the same lift nd engine power.

4. **Modified small electric pumpset**. (Fig. 11.69). The potential areas for this small electric pumpset are farms where 1) electric lines exist near the fields, and 2) water may

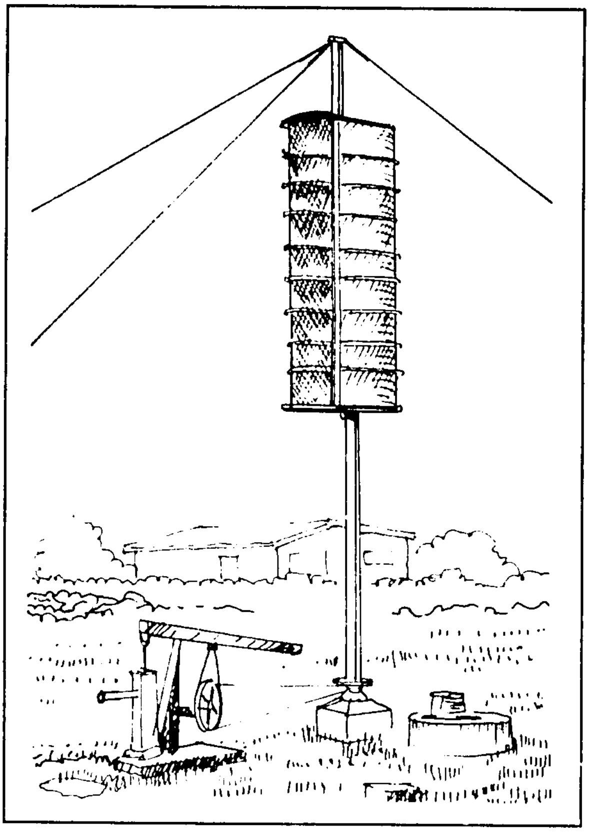

Fig. 11.67. Savonius windmill and piston pump.

be obtained from shallow tubewells or surface sources, such as lowland rainfed areas with electricity. This small elecric purmpset has an output capacity ranging from 2 liters/second at 8m lift to 6 liters/second at 10 m total head using only 0.25 hp-1.5 hp electric motor, respectively. The equipment is sufficient to irrigate fields up to 3 ha, depending upon the total head and number of hours of operation. Thus, preliminary studies indicate that the pumpset offers these benefits: a) it is suitable for low-capacity tubewells, without producing excessive draw-downs, b) the initial and operating costs are lower than those of existing pumpsets, and c) it is simple to operate and maintain.

Mechanical Harvesters

Harvesting is one of the most laborious operations in the whole process of vegetable production. So far only few harvesting machines

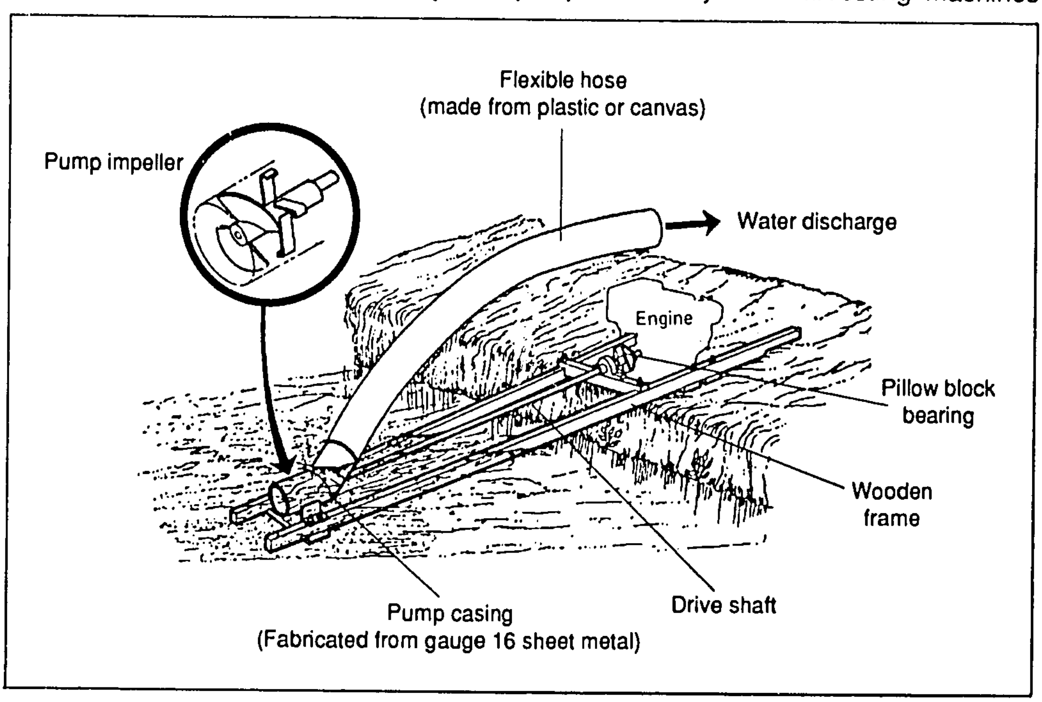

Fig. 11.68. "Sipa pump".

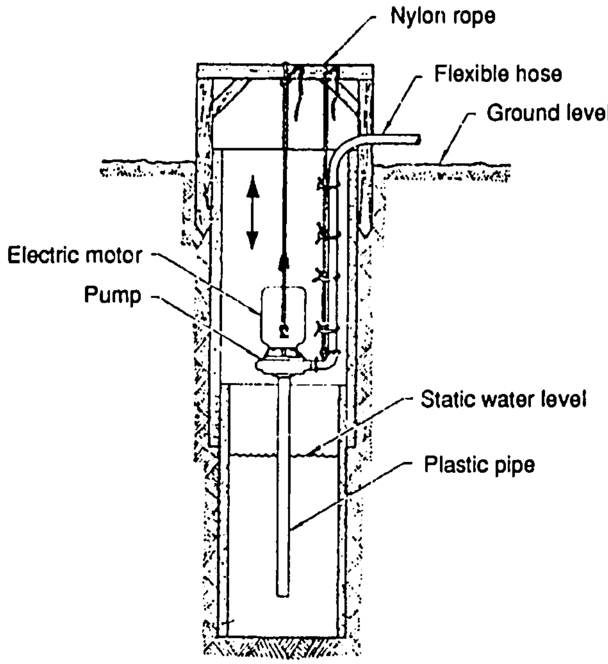

Fig. 11.69. Modified small electric centrifugal pump.

have been developed for certain vegetables while most harvesting operations are still done by hand. This is especially true for leafy vegetables, which cannot stand rough handling and need to be taken to the market immediately.

Mechanical harvesting is usually a once-over process. It requires the use of varieties with concentrated maturity and a market that can absorb huge quantities of vegetables at any given time, such as processors. It also requires complementation with field management practices, such as land preparation, leveling, and row spacing.

Root crop harvester. Some harvesters were successfully developed for root crops, such as radish, onion, sweet potato, and potato. There are essentially three types of harvesting machines for root crops:

1. Pitman digger — This type of digger utilizes the power of a 5-7 hp two-wheel tractor for digging of root crops (Fig. 11.70).

2. Shaker digger — This type of digger has a relatively smaller pulling resistance. The digger scoops up the potatoes and the soil and separates the potatoes and soil by vibratory motion. The potatoes may be further conveyed to a collector or left on the ground for later collection. Fig. 11.71 shows the operation of a potato harvester.

3. Mounted harvester — Fig. 11.72 shows the operation of a sweet potato harvester mounted on a tractor. The sweet potatoes and soil are dug, raised, and separated

Fig. 11.70.
A potato digger powered by a two-wheel tractor.

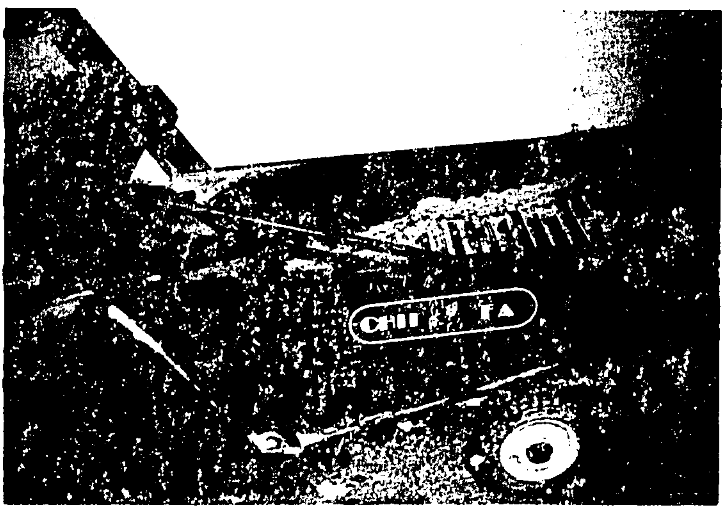

Fig. 11.71.
Close-up of shaker-digger for harvesting white potato.

Fig. 11.72.
A sweet potato harvester in operation.

with digger blades and digger chains. Separated sweet potatoes are left behind and picked up by hand. This harvester has a higher power and is faster in operation than the shaker digger.

Lettuce harvester. Fig 11.73 shows a self-propelled lettuce harvester. During the harvesting process, lettuce is fed and conveyed by a pair of revolving rubber rollers. The orientation of the lettuce is properly controlled before it is cut by a disk cutter.

A more sophisticated lettuce harvester can selectively harvest lettuce (Fig. 11.74). The selection of lettuce is either mechanically determined from its size and hardness by

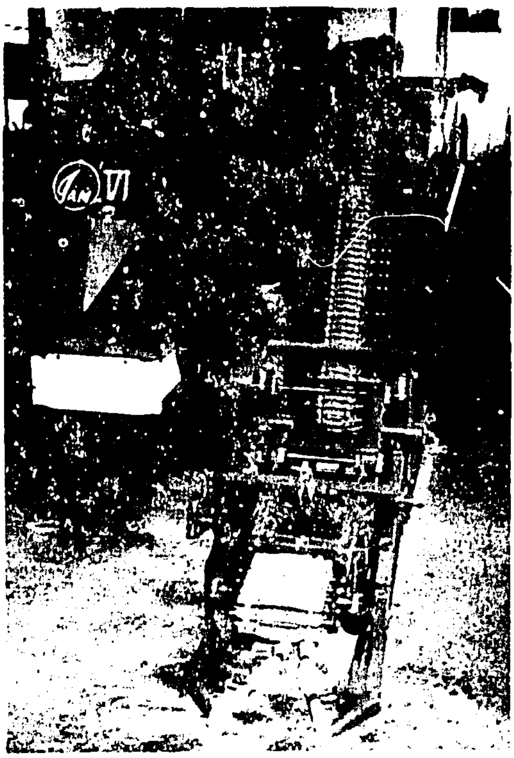

Fig. 11.73. A self-propelled lettuce harvester.

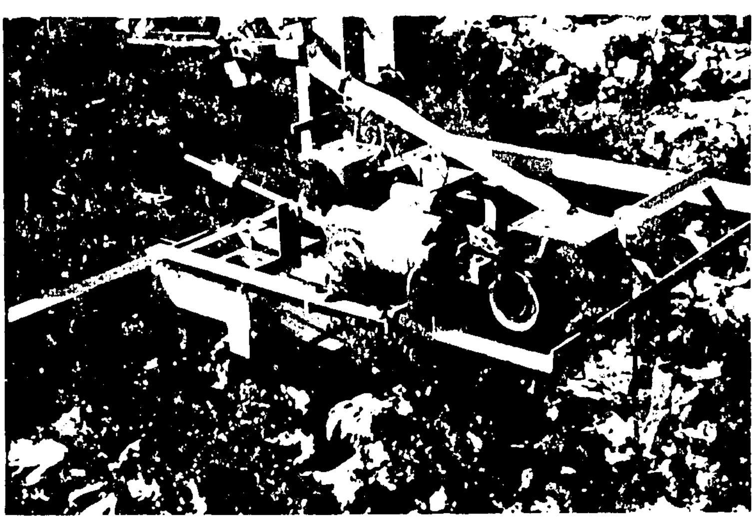

Fig. 11.74. A lettuce harvester which can selectively harvest lettuce.

a linkage mechanism or determined from its size and density by gamma rays and sensors. Lettuce packing operation is also incorporated in the harvesting operation in other machines.

Cabbage harvester. Fig. 11.75 shows a cabbage harvester developed for once-over harvesting. Cabbages are pulled up by a circular disc and transferred to conveying chains. The conveying chains ensure the proper positioning of the root before it is raised to a cutter. Following cutting, the cabbage is conveyed to the collection box. Boxes of cabbages are then transported to factories for further processing, such as washing or shredding.

Tomato harvester. Like cabbage harvesters, tomato harvesters are once-over machines (Fig. 11.76). Plants stems are usually detached or the whole plant is uprooted before conveying them into the machine where the fruits are detached by shaking (Fig. 11.77). Leaves, dust, and other unwanted debris are separated from the fruits with a blower. They can also be further separated by hand. Ripe tomatoes can be selected and differentiated from unripe tomatoes based on their color with a photo-electric sensor.

Fig. 11.75.
A cabbage harvester for once-over harvesting.

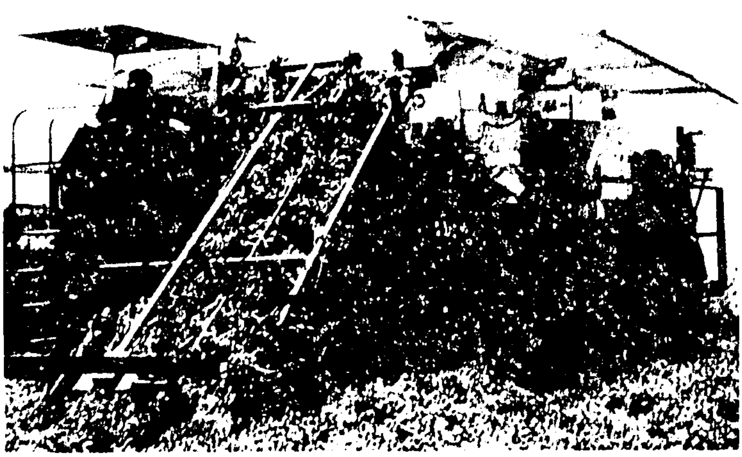

Fig. 11.76.
Once-over tomato harvester in operation.

Fig. 11.78 shows the sorting device. The process of selection and separation with this set-up is quite fast and precise. The harvested fruits are immediately conveyed into bins on a special trailer beside the harvester (Fig. 11.79). For this highly efficient system, harvesting rate is about 0.5 ha/hour with 6% loss.

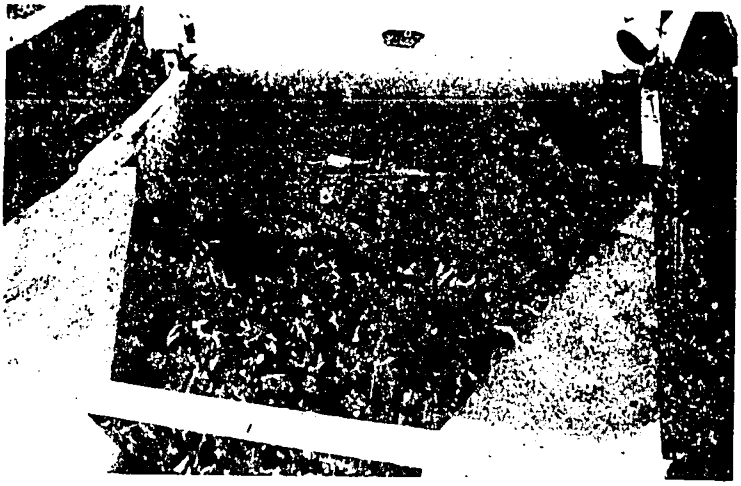

Fig. 11.77.
Tomato fruits are detached by shaking.

Fig. 11.78.
A sorting device for differentiating ripe and unripe tomatoes using a photo-electric sensor.

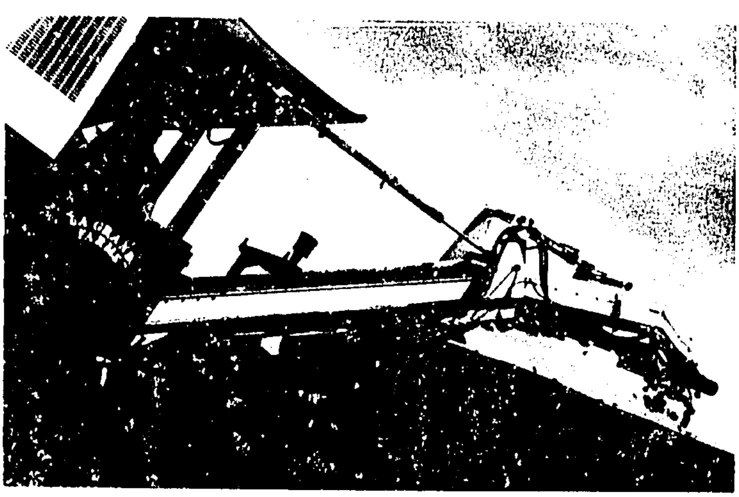

Fig. 11.79.
Harvested fruits are immediately conveyed into bins on a special trailer.

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CHAPTER 12

Postharvest Technology for Vegetables

During the last decade, vegetable production in most countries has been characterized by a tremendous increase in yield and improvement in the quality of the produce. This was brought about by improved agricultural technologies as well as the increasing demands for both local and international markets. These developments, however, do not guarantee sufficient supply of good quality vegetables. More vegetables produced apparently do not mean more vegetables to eat or to sell.

Postharvest losses of vegetables can and do occur at any point from harvest through collection and distribution to the final purchaser. Under the traditional handling system and with the lack of facilities, postharvest losses are considerably high. The amount of fruit and vegetable losses in various countries ranges from 10%-50% of the annual production (Table 12.1).

Table 12. Fruit and vegetable losses as reported by region and country. [a]

Reported % Loss	Region/Country
Asia/Far East	(20-42)
Philippines	28-42
Malaysia	20
India	20-30
Indonesia	25
Thailand	23-28
Sri Lanka	20-40
Middle East	(10-40)
Egypt	25-40
Jordan	10
Iran	14-28
Africa	(10-50)
Rwanda	10-40
Sudan	50
Ghana	30-35
Nigeria	10-50
Latin America	(10-40)
Bolivia	17-30
Brazil	10-40
Chile	30
Dominican Republic	25

[a]Source: National Academy of Science, USA, 1978.

Losses are much higher in developing countries than in developed countries. According to the Food and Agricultural Organization of the United Nations (FAO) "Computed from moderate estimates, postharvest wastage robs millions of people in developing countries of the food they might be eating." Producers, however, especially the small farmers, are seldom aware that such losses can be prevented.

Postharvest loss of this magnitude represents a significant food loss to consumers and considerable economic loss to producers and traders. It is a waste of effort, time, and money to produce a crop, only to lose it after harvest. A large fraction of a cabbage crop that takes four months to raise can be lost in a few days, and the monetary value of the remainder may decrease appreciably.

It is of utmost importance to maintain the freshness of vegetables or at least to minimize their deterioration from harvesting to the time they are consumed. The techniques involved in harvesting, handling, moving, and storing the crop to reduce losses and to keep them fresh is ***postharvest technology***; and the whole chain of movement and operations is ***postharvest handling***.

Proper postharvest handling can complement improved production technology in its goal to meet the demand for this perishable commodity especially in developing countries. However, postharvest handling practices cannot be generalized for all vegetables. They are highly dependent on the commodity, location, and situation. A technology may or may not be practical depending on the vegetable, the type of market and marketing systems, the economic situation, and other conditions.

Besides the physical loss of the vegetable itself, the money spent for handling is also lost when the vegetable is discarded. This covers all the cost for packing materials, transportation, handling, labor, and energy consumption. It also means additional cost for reconditioning such as trimming, repacking, and waste disposal especially at the wholesale and retail ends.

Causes of Postharvest Losses

Postharvest losses of vegetables could be due to causes that are technological in nature (technology can solve them) such as decay, yellowing and wilting, or non-technological such as lack of transportation and storage facilities, adverse weather conditions, inefficiency of distribution, and lack of market demand. They could also be direct (effect is readily seen) or indirect (effect is exerted through another process and therefore does not seem to be the cause).

Some of the postharvest losses of vegetables due directly to changes in the commodity are obvious such as yellowing, softening, rotting, and sprouting, all of which will result in the direct loss of food and/or commercial value of the vegetable (Table 12.2). Such losses usually contribute considerably to the total postharvest losses of the vegetable.

However, there are several other subtle but less obvious changes that add to the losses of the commodity. Deteriorative changes in texture, flavor, and aroma which affect the quality of the vegetable may occur. Example of such losses are the development of pithiness in radish, celery, and cucumber and the toughening of beans. These changes are accompanied by a decrease in the nutritive value of vegetables. These types of losses are called ***physiological losses*** since they are caused by changes in physiological processes.

Losses due to rough and careless picking, packing, loading, or unloading are common. The damages may be in the form of cuts, punctures, cracks, splits, changes in form, and shape (distortion) or partial to full separation of the outer covering (abrasion). An alteration in the appearance of a commodity may occur. These types of damages are called ***mechanical damage***.

Usually, rots are the greatest single cause of loss. However, most microorganisms enter through mechanically damaged tissue. Weakened tissues caused by natural (physiological) deterioration are also very susceptible to microbial attack.

Table 12.2. Physiological changes of vegetables other than wilting or shrivelling that cause deterioration.[a]

Vegetables	Deterioration Changes
Leafy vegetables	Yellowing
Cauliflower and broccoli	Opening of florets, softening
Sweet corn and young cob corn	Loss of sweetness
Okra	Softening
Cucumber	Yellowing
Beans	Toughening, yellowing
Chayote, tomatoes and pepper	Seed germination
Asparagus	Elongation and feathering[b]
Onions, garlic, sweet potato, potato, ginger	Sprouting and rooting
Carrot	Softening

[a]Bautista 1990.

[b]Spreading out of the buds.

Insect attacks after harvest are not as serious as rots, but they become a major problem when vegetables are exported to countries which do not want to risk bringing in new insect pests.

Basis of Postharvest Technology

Perishable Nature of Vegetables

Vegetables are very perishable except those that are utilized for their roots, such as bulbs and tubers. This is so since harvested vegetables are living things which undergo all biological processes associated with life. To sustain these processes, vegetables draw energy through respiration from their reserves of starch, sugars, and other products of photosynthesis.

Before harvest, the materials for respiration are continually replaced through photosynthesis. However, once the vegetable (be it a leaf, fruit, root or stem) is harvested, the supply of raw materials for photosynthesis is cut off and the transport of the products of photosynthesis essentially stops. Hence, there is no replacement for the lost reserves in the harvested vegetable. As energy and simple substances, which are the products of respiration, become scarcer, the biological processes that keep the cell alive slow down and the cell structure breaks down. Hence, vegetable quality deteriorates. Senescence and death of cells eventually follows.

The rate of respiration is, therefore, a good index of the potential postharvest life of the vegetable; since the rate of respiration, increases with the rate of deterioration. Very fast respiration rates are typical of growing tissues or plants such as asparagus, mushroom, partly developed flower buds like broccoli, developing seeds like peas, and immature fruits like young cob corn, and okra (Table 12.3). Respiration rate is low in storage organs with dormancy periods, like potatoes, carrots, onions, and garlic. The rates of fruit and leafy vegetables are in-between the rates of growing tissues and storage organs. At the same time, storage organs have more food stored for respiration, which make their rate of deterioration slower than that of leafy vegetables or fruit vegetables.

Table 12.3. Classification of vegetables according to their respiration rates.[a]

Class	Range at 20°C ($mg\ CO_2/kg\text{-}hr$)	Vegetables
Low	< 20	Garlic, onion, potato, sweet potato, taro
Moderate	20 - 200	Beet, cabbage, cucumber, pepper, potato (immature), radish (topped), tomatoes, carrot, celery, leek, lettuce, squash, parsley
Extremely High	> 200	Asparagus, broccoli, mushroom, okra, pea, spinach, sweet corn, young cob corn

[a] Bautista 1990.

Therefore, maintaining freshness or minimizing deterioration of vegetables calls for good production practices in order to provide greater sources of energy. Respiration must be slowed down for these energy sources to last for a longer time.

Vegetables contain as much as 80%-95% water. This is lost to the atmosphere through transpiration especially if it is hot and dry. Before harvest, the water lost is continually replaced by water absorbed from the soil. After harvest, water lost can no longer be replaced since the part desired is already separated from the whole plant. With lesser and lesser water in the cells, the leafy, stem, and flower vegetables wilt, root crops shrivel, and fruit vegetables change in texture (either become limp or tough). A loss of 5%-10% water can cause wilting or shrivelling. Thus, transpiration must also be slowed down to keep the commodity fresh.

After harvest, growth and development continue in asparagus and bean sprouts (elongation); root, tuber and bulb crops (sprouting and rooting); and in sweet peppers, tomato, and chayote (seed germination). The slower these changes are, the slower is the deterioration.

Differences in Morphology, Structure and Chemical Composition

The changes in vegetables after harvest vary considerably because of their differences in morphology, structure, and chemical composition.

The change depends on what morphological part the vegetable is. If it is a leafy vegetable, it will wilt and turn yellow; if it is a fruit vegetable, it will ripen and eventually become overripe; if it is a flower vegetable, it will open; and if it is a modified stem (such as potato, ginger, and taro), it will produce new buds and sprouts.

Postharvest changes in vegetables also depend on the structural differences of each morphological part. Vegetables with bigger and more stomates, like leafy vegetables, necessarily have faster transpiration and to a certain extent respiration; since stomates are also passageways of oxygen for respiration. Leafy vegetables also have an upper and lower surface; so it has a greater surface area for transpiration and gas exchange for respiration. Fruit vegetables, roots, tubers, and bulbs have lesser surface areas and few or no stomates but have a few lenticels (the circular group of air-filled cells with central opening that takes the place of stomates in some stems, fruits, and roots).

Hairy extensions of the epidermal cells (trichomes) could increase the surface area of the vegetable through which water and gas could pass; hence, they promote transpiration and respiration, thus, okra wilts more easily. Pechay has no trichomes while Chinese cabbage has plenty, which explains their relative difference in rate of wilting. Younger muskmelon fruits and winged bean pods also have trichomes but they disintegrate as vegetables reach commercial maturity. This is one reason why immature fruits deteriorate faster.

Vegetables vary in the thickness of the cuticle (the noncellular covering of plant parts). The thicker the cuticle, the greater the protective capacity against moisture loss, penetration of microorganisms, mechanical damage, temperature changes, and the escape of flavor. As the plant parts develop, their cuticles also thicken. The thickened cuticle of more mature vegetables is a major reason why they have to be harvested at the proper stage of maturity.

The amount of wax, which is the outermost part of the cuticle also partly determines the rate of deterioration in vegetables. Vegetables with more of the natural wax lose water at a very much slower rate than those which have less because the wax slows down loss of water and passage of gases. The wax sometimes appears as a slightly bluish powdery substance on the surface of the vegetables. Wax gourd and cabbage have high amounts of wax. It is, however, easily removed by repeated handling of the commodity. Thus, the deterioration rate is slower when vegetables are handled less.

Response of Vegetables to Environment

Respiration, transpiration, and other metabolic processes of harvested vegetables change in response to the environment. Temperature, relative humidity, gases, microorganisms, and insects are the most important environmental factors.

To slow down respiration and transpiration and prevent the attack of microorganisms, the environment under which vegetables are handled, transported, stored, or sold must therefore be controlled to slow down these processes. Temperature must be low; relative humidity, high; and source of infection or infestation, nil. If a storage life longer than what can be achieved with low temperature is desired, oxygen must be lower and/or carbon dioxide higher than normal.

Temperature. By far, temperature is the most critical environmental factor that influences the deterioration rate of harvested vegetable. A decrease in temperature decreases respiration, transpiration, microbial and insect growth. At temperatures for normal cell functions (physiological temperature range), the rate of metabolic activity increases with increase in temperature. A general rule is that for every decrease of 10°C, the metabolic rate decreases by half.

While deterioration is generally slower at lower temperature, there is a particular temperature at which the commodity can be stored for a maximum length of time. This is the ***optimum temperature***. When storage temperature is not optimum, vegetables deteriorate fast.

The faster the respiration, the greater the heat produced. If the heat cannot escape, the respiration rate increases faster and vegetable temperature rises more, thus rapidly destroying the vegetable.

Relative humidity. The atmosphere or air normally contains water vapor. Sometimes the air contains all the water vapor it can hold, in which case it is said to be ***saturated***. Most of the time though, the air contains less moisture, then it is said to be dry. The ratio of the amount it actually contains and the amount it can hold when it is saturated is called

relative humidity. If the air is saturated, its relative humidity is 100%. The lower the relative humidity, the drier the air.

Since a vegetable contains 80%-95% water, it will lose its water to the atmosphere, if the air is not saturated. The lower the relative humidity of the atmosphere at the same temperature, the faster the rate, and the greater the amount of water lost. As a consequence, the vegetable will eventually wilt or shrivel.

Gases in the atmosphere. The air contains 78% N_2, 21% O_2 and 0.03% CO_2 and some other minor gases. If the participant in a reaction (reactant) is decreased or the resulting compound (product) is increased to a certain level, the reaction is slowed down. Since O_2 participates in respiration, respiration slows down if O_2 is reduced below 21%. On the other hand, if CO_2, which is a product of respiration, increases above 0.03% for some crops, it slows down the respiration process.

A decrease in O_2 and/or increase in CO_2 is the basis of a controlled or modified atmosphere to further prolong the postharvest life of vegetables transported or stored at low temperature. Each vegetable can tolerate a certain level of O_2 and CO_2 at which its respiration is at a minimum. However, if O_2 is reduced below this level to less than 2%-3% for many vegetables, it will result in abnormal respiration (anaerobic respiration) instead of slow but normal respiration. Anaerobic respiration gives off an alcoholic odor and an off-flavor to vegetables.

A very high level of CO_2 (more than 5% for most vegetables), however, results in CO_2 injury which is shown by the appearance of black or brown spots, undesirable odor, and flavor. An example is the brown stain of lettuce which develops when CO_2 is greater than 1%.

Ethylene also affects the storage life of many vegetables. Ethylene is given off by ripening fruits, injured or infected vegetables, and some leaves. Acetylene is a related compound that has similar but lesser degree of effects as ethylene. Both ethylene and acetylene are found in smoke and exhaust of vehicles. Their presence in the air causes leafy vegetables to turn yellow, fruit vegetables to ripen, root vegetables and tubers to sprout, asparagus and beans to toughen, carrots to turn bitter, and lettuce to develop reddish spots (russet spotting). Ethylene is, thus, helpful when the fast ripening of fruit vegetables is desired and is undesirable when the goal is to maintain the freshness of other vegetables.

Microorganisms and insects. Microorganisms and insects constitute a part of the environment of a vegetable after harvest. A vegetable is not only a rich source of food for man, it is also food for microorganisms and insects. The more we keep them away or minimize their growth and reproduction, the longer we can keep the vegetables from rotting or spoiling. Insect bites also cause mechanical damage.

Reducing Losses During Postharvest Handling

Production ends in harvest and handling of the commodity starts from harvest. The application of postharvest technology thus begins in the field during the harvest operation. The vegetable is placed in picking containers emptied into field or collection containers. Then they are brought to a packing area which may be a building, a shed or a shady area, unless rain is a problem.

Depending on whether it will be marketed or stored first and whether it is for an export or domestic market, the vegetables are subjected to different operations. It is cleaned.

sorted, graded, treated with chemicals, packed, transported to market or stored before selling. The number and complexity of steps also vary with the kind of crop, desires of the consumer, and purpose for growing the crop.

The techniques of reducing losses during all these operations can be grouped into four:

1. Start with good quality vegetables
2. Avoid physical damage
3. Control environmental factors
4. Use proper procedures

It must be remembered that the success of these methods depends on how they fit in the entire system of handling.

Start with Good Quality Vegetables

The quality of the vegetable at harvest determines to a great extent how long its freshness can be maintained. The quality of the vegetable refers to any characteristic in relation to size, shape, color, texture, weight, and nutrient content. These are characteristics which a consumer considers when selecting a vegetable. A vegetable may not come up to the standards of excellence desired by the consumer, in which case, it is rejected.

Once harvested, the quality of the vegetable can only be maintained but not improved. It is best, therefore, to start with a good quality vegetables and maintain its freshness and good quality characteristics rather than start with poor quality and maintain its poor quality characteristics.

The variety, conditions during growth, the amount of care provided during production in terms of water supply and nutrient elements, and the control of insect pests, diseases, and weeds determine the quality of the produce at harvest and consequently after harvest.

Role of variety. The variety has to be considered from the time the vegetable production enterprise is being planned. A variety should not only possess the characteristics that a farmer wants, such as high yield or resistance to diseases but also possess the quality desired by the consumer to fulfill a certain purpose. A vegetable may look attractive but if the buyer does not find it desirable then he will reject it.

Different groups of consumers want different characteristics of vegetables which are expressed in a variety. In an area where long eggplants are preferred, round eggplants will hardly sell. The Japanese prefer okra that are 6-8 cm long, while most Southeast Asians like it any size; provided they are still tender.

Processors will reject vegetables offered to them if they do not have the characteristics desired for processing. Processing varieties are different from table varieties, although the former could also be acceptable for the table. Salad tomatoes are large, red, juicy, and slightly sweet. Tomatoes for catsup production should have thick flesh, red, pH below 4.4, and no green coloration on the flesh upon attaining the red ripe stage. A variety lacking one of these characteristics can still be processed but the processors will have to make some modifications which might be expensive. Onions or potatoes intended for storage until the next harvest the following year are those with long dormancy periods, so they will not sprout in storage.

Influence of environmental conditions. The quality of vegetables at and after harvest is affected by temperature, light, rainfall, and other environmental factors during production. For example, tomatoes developed at a temperature higher than normal tend to have a blotchy ripening. They also develop yellowish or orange color rather than red when they ripen. In general, the initial composition of the crop is affected. So, if the amount of total soluble solids in watermelon is low, for example, then it will lose its sweetness faster.

Effect of cultural management. A produce may be of the right variety, but if it was not watered or fertilized, sprayed or weeded adequately, the size, color, shape, or other aspects of quality may not be up to the standards desired by the consumer.

Well-cared plants give better quality crops. They produce more carbohydrates or protein which could be used as energy source for respiration, hence have a longer potential postharvest life.

Most of the diseases and insect pests that occur after harvest begin in the field. A produce may be infected but may produce no visible symptom at harvest. If the control of such diseases and insect pests during production was adequate, then the disease or insect would not be much of a problem after harvest.

Avoid Physical Damage

A simple and inexpensive way of minimizing losses after harvest is to practice care in harvesting and throughout the handling chain. When the workers are uninformed, they usually throw vegetables about, force them into containers, step or sit upon them provided they do not see any visible injury.

More vegetables are probably lost due to carelessness in picking and handling than to any other factor. This carelessness can result in physical or mechanical damages or injuries which may not be immediately visible but may be manifested later. Mechanical damage could be brought about by repeated bouncing, weight or pressure exerted by other vegetables or containers, and impact caused by dropping or throwing. These injuries increase the rate of respiration and transpiration, and hence result in faster ripening, sprouting, yellowing or discoloration, shrivelling, and wilting. They also serve as entry points for disease organisms, so rotting becomes faster.

Moreover, the injured cells produce ethylene (stress ethylene) and show its ill effects on the quality of the vegetable thereafter as described earlier in this chapter. All of these contribute to the rapid deterioration of injured commodities and make them less pleasing in appearance. When vegetables are handled frequently, there are more chances of incurring mechanical damage.

Vegetables vary in their resistance to mechanical damage, depending on their morpho-anatomical features such as the presence of a thick cuticle. It is, therefore, important to handle more fragile vegetables carefully. The root and bulb crops, melons, and squash are sturdier than most vegetables.

Control Environmental Conditions

Many of the techniques used to prolong the postharvest life of vegetables are based on the control of environmental conditions, such as using low temperature (refrigeration) during transport or storage and the application of chemicals to control postharvest decay.

Temperature management. High temperature must be avoided throughout the handling chain. Refrigeration is the most effective means of lowering temperature to optimum. If a vegetable is kept below the optimum temperature for a considerable length of time, its biological processes become abnormal. Its storage life will be shortened and will deteriorate rapidly after being transferred to room temperature. Such abnormal behavior is called ***chilling injury***. Chilling injury is characterized by sunken areas in the skin of the vegetable (pitting), discoloration, and in tomatoes failure to ripen. Chilling injury is affected by both temperature and length of exposure to the low temperature. For example, exposure of okra to 5°C for a week is just as injurious as exposure to 10°C for two weeks.

Tropical vegetables are generally more sensitive to low temperatures than subtropical or temperate vegetables (those grown high up in the mountains or those coming from temperate countries). They cannot tolerate temperatures below 12°C, while temperate crops like cabbages are kept best at or near zero.

In the absence of refrigerated facilities, methods of avoiding the ill-effects of high temperatures are as follows:

1. Harvest as early or as late in the day as possible.
2. Avoid exposing the vegetables to direct sunlight at any time. Keep the vegetables in the shade.
3. See to it that there is sufficient ventilation in the container, in the transport vehicle and storage room to remove the heat of respiration.
4. Use white-colored canvas for covering vegetables during transport or paint the roof of the market-preparation area (packinghouse) white to reflect heat, thereby reducing temperature.
5. Travel as early as possible if the vehicle used is not refrigerated.
6. Use evaporative cooling methods, as discussed later in this chapter.

Relative humidity management. In most cases, the general problem about relative humidity is how to increase it to at least 85%. Many cold rooms do not have good humidity control. Methods of increasing relative humidity are as follows:

1. If possible, wet the floor of the area where the vegetables are kept (vehicle or room).
2. Introduce a fine mist of water or steam into a ventilating fan.
3. In a small room keep open containers filled with water.
4. Use evaporative cooling.

Control of gases in the environment. A decrease in O_2 and/or an increase in CO_2 makes transport and storage in low temperature even more effective. The common application of this, however, is the use of polyethylene bags which allows the accumulation of CO_2 and the depletion of O_2 inside the bag. Since it is also possible that CO_2 might accumulate and O_2 might decrease too much, then a few holes have to be made for ventilation.

On the other hand, ethylene is to be avoided except where ripening is involved. Ways of avoiding ethylene effects are as follows:

1. Ensure good ventilation to dilute the concentration of ethylene or remove it.
2. Do not store ripening fruits with vegetables in the same room.
3. Practice care in handling.
4. Sort produce and separate diseased and injured vegetables.
5. Avoid keeping vegetables in enclosed areas where there is smoke or vehicle exhaust.

Control of diseases and insects. The development of diseases after harvest is dependent upon the presence of the organism causing the disease, an entry point and favorable conditions for their growth and development. Methods of keeping microorganisms away or from multiplying rapidly are as follows:

1. Make sure that vegetables, containers, vehicle, and room are clean. Most postharvest diseases are spread by contact. When vegetables are dirty, these, together with equipment or tools contain millions of microorganisms. Used containers should be washed thoroughly with hot water if possible, or with water and detergent, or with 0.25% sodium or calcium hypochlorite before reusing. Walls and floors of the vehicle and room should also be cleaned with hypochlorite especially if rotten vegetables have come in contact with the walls or floor. Sodium hypochlorite is household bleach so it is easy to obtain it.

   Dirty harvested vegetables should be washed to remove some of the surface microorganisms which cause decay during transport or storage. Clean vegetables are more appealing to the eye, have a ready market, and command a better price. Cleaning can be done by wiping or manual removal of clods of dirt. Most importing countries strictly require a clean commodity, hence cleaning is necessary.

   Adding 1-2 tbsp bleach for clothes used for cleaning vegetables (sodium hypochlorite in 5 gal of wash water) can minimize decay, if the particular rot organisms are only on the surface of the vegetables.

   Root and bulb crops should not be washed until they are ready to be sold to the final user. Washing hastens sprouting and rotting.

   When a commodity is cleaned by washing, surface moisture must be removed before packaging, transport, or storage to prevent the growth of microorganisms. Air-drying can be done when relative humidity is low. If fast drying is desired, artificial means are used, such as passing the vegetable through a tunnel of heated air or using a blower.

2. Handle vegetables carefully to reduce injuries which serve as passageways for microorganisms.

3. Avoid hot and moist conditions. Do not pack moist vegetables because this will favor very fast multiplication of microorganisms when it is hot.

4. Sort the produce and separate diseased vegetables, no matter how small the infection, to minimize contamination. Padding the sorting table with styrofoam will provide added protection for the vegetable.

5. If vegetables are likely to be infected, treat them with chemicals toxic to microorganisms but not to vegetables or consumers. Only some chemicals are approved for the postharvest control of diseases in vegetables.

   Alum at 15% applied on the stem end (butt) of cabbage can control bacterial soft rot to a great extent after harvest (Borromeo and Ilag 1983). Alum can inhibit the activity of the pathogen present within the cabbage, thereby minimizing decay.

   Common lime or calcium oxide is as good as alum if the butts are coated with the powder before the bacteria have established themselves in the cabbage (Borromeo and Ilag 1983). It serves as a physical barrier against the disease organism. In Chinese cabbage, lime is applied by pressing their butts into the lime powder spread on a flat surface.

6. Cure root and bulb crops before storage or transport to distant markets. Curing is the process of skin hardening and rapid healing of bruises and skinned areas in root and tuber crops and the rapid closing of the neck of bulb crops before storage. The healed surface of white or sweet potato and the dried scales and closed neck of bulb crops serve as efficient barriers against microbial infection.

   The length of the curing period depends on the kind of vegetable and its requirements for temperature and relative humidity. It can range from a few days to two weeks. For potatoes and sweet potatoes, the best temperature to maintain is that which allows rapid healing of bruises.

   For onions and garlic, it is the temperature at which excess moisture in the skin and tops is removed with a minimum removal of moisture from bulbs. This is usually between 20°-25°C for potatoes and 25°-35°C for sweet potatoes and onions or garlic. Root and tuber crops require a high relative humidity of about 95% for efficient wound healing, while the bulb crops require a much lower relative humidity of about 80%.

   Methods of controlling insect damage after harvests are few. Preharvest control is even more important than for postharvest diseases and removing insect-infested ones becomes necessary. Ethylene dibromide which used to be acceptable as a quarantine treatment has been withdrawn because of its carcinogenic (cancer causing) effect. Methyl bromide, phosphine, and sodium or potassium cyanide are still being used provided the maximum residue levels are not exceeded. Some vegetables are susceptible to injury from some of these chemicals.

Use Proper Procedures

Harvesting. Pick at the right stage of maturity. A very common cause of poor product quality at harvest and rapid deterioration thereafter is harvesting immature vegetables. A vegetable is said to be commercially mature when the plant parts have developed the characteristics preferred by consumers. Vegetables harvested immature or overmature usually do not keep long. Fruit vegetables harvested too early (immature) lose water fast and are more susceptible to mechanical damage and microbial attack. Those that are ripened like tomato tend to have irregular ripening. Potatoes, onion, tomato, muskmelon, and cabbage that are immature are easily detected (Table 12.5).

An overmature vegetable is more susceptible to decay, has passed its best eating quality, and deteriorates faster.

Maturity of vegetables is usually determined by visual and physical methods, such as size, shape, color, firmness, and texture. Table 12.6 shows some of the maturity indices of selected vegetables.

Most of these maturity indices can be seen. The effect of environmental conditions on these indices should be considered in using them. For example, the maturity index for potatoes and onions is the drying up of the plant body. However, this may sometimes be deceiving because lack of water or the presence of diseases may also cause premature drying of the plant body.

Another common method used is counting the number of days from flowering up to the stage of acceptable maturity. Different varieties have different number of days from flowering to acceptable maturity.

The distance to market and delays in bringing to market should be considered in harvesting vegetables which can be harvested over a wider range of growth or development stages without undue decline in quality. For example, tomatoes which would take

Table 12.5. Signs of immaturity.

Vegetables	Signs
Potato	It easily feathers (the skin incompletely separates in certain parts giving the appearance of feathers)
Onion	Large neck
Tomato	If a sample is cut, the seeds are also cut. Then the appearance of such samples can be compared with the other fruits
Muskmelon	The stem scar is rugged (the fruit pedicel could not easily be separated)
Cabbage	It is puffy inside (the spaces inside the head are not all filled up). To detect this, press the head with the thumb and if the head yields, it is immature.

more than a day's travel to reach the market have to be harvested at the green, mature stage to prevent overripening as it passes through market channels (from trader to trader). Moreover, mature green tomatoes are less susceptible to damage than ripe ones.

- Pick vegetables properly — Vegetables that are harvested by pulling, twisting or bending such as beans, eggplant, and okra can be harvested with clippers (scissors or shears) or knives. This will avoid leaving a portion of the fruit behind as in beans or exerting too much manual pressure on the vegetable.

- Pick at the right time of day — In some crops, the time of harvesting is very critical. Sweet corn, for example, loses its sweetness faster when harvested late in the morning or early in the afternoon than when it is harvested early in the morning. The conversion of starch to sugar is faster at higher temperature.

  When harvested in the latter part of the morning or late in the afternoon the petioles of leafy vegetables break less easily and their leaves are more resistant to tearing, since they have lost water through transpiration and therefore are less brittle. Cucumbers are also less prone to injury when it contains less water (less brittle); which means, it should be harvested in the late morning when it is to be transported under less than ideal situation.

Trimming. If the unwanted or undesirable parts can be removed leaving a more desirable vegetable, then, such parts should be removed. The process is called ***trimming*** and is done to enhance the saleability of the commodity, to reduce the cost of transport, and to minimize infection. Trim vegetables soon after harvest. Leaves of carrot, radish, and cauliflower are removed to minimize loss of water.

When onion and garlic are harvested when their tops dry up, topping, as the trimming of onions and garlic is called, may not be done since the moisture content of bulbs and tops have reached a relatively low level, provided the buyers do not mind the presence of these dried tops. When leaves of the bulbs are still green, topping 2-3 cm above the neck is done since the green tops break down rapidly forming favorable conditions for microbial growth.

If no part of the tops is retained, shrivelling will be greater after several weeks in storage since the tissues at the neck of the bulb are more succulent and do not close up sufficiently to reduce loss of water to a minimum.

Table 12.6. Maturity indices of vegetable crops.[a]

Crop	Index
Root, bulb and tuber crops	
Radish and carrot	Large enough and crispy (overmature if pithy)
Potato, onion, and garlic	Tops beginning to dry out and topple down
Yam bean and ginger	Large enough (overmature if tough and fibrous)
Green onion	Leaves at their broadest and longest
Fruit vegetables	
Cowpea, yard-long bean, snap bean, batao, sweet pea, and winged bean	Well-filled pods that snap readily
Lima bean and pigeon pea	Well-filled pods that are beginning to lose their greenness
Okra	Desirable size reached and the tips of which can be snapped readily
Upo, snake gourd, and dishrag gourd	Desirable size reached and thumbnail can still penetrate flesh readily (overmature if thumbnail cannot penetrate flesh readily)
Eggplant, bitter gourd, chayote or slicing cucumber	Desirable size reached but still tender (overmature if color dulls or changes and seeds are tough)
Sweet corn	Exudes milky sap when thumbnail penetrates kernel
Tomato	Seeds slipping when fruit is cut, or green color turning pink
Sweet pepper	Deep green color turning dull or red
Muskmelon	Easily separated from vine with a slight twist leaving clean cavity
Honeydew melon	Change in fruit color from a slight greenish white to cream; aroma noticeable
Watermelon	Color of lower part turning creamy yelow, dull hollow sound when thumped
Flower vegetables	
Cauliflower	Curd compact (overmature if flower cluster elongates and become loose)
Broccoli	Bud cluster compact (overmature if loose)
Leafy vegetables	
Lettuce, pechay	Big enough before flowering unless flowers are desired
Cabbage	Head compact (overmature if head cracks)
Celery	Big enough before it becomes pithy

[a]Bautista and Mabesa 1977.

For cabbage, leave only two to three wrapper leaves for protection, if mechanical damage is likely to be high during handling, such as those transported in baskets over roads that are not always paved.

Sorting. Sort at harvest or immediately after harvest. Damaged, discolored, and diseased vegetables should be separated from the sound ones because they can ruin an entire load of vegetables. If there are grade standards to follow or buyers' specifications to fulfill, use them in sorting. The grade standards specify the quality desired for each grade or grouping and are established by a designated government agency in cooperation with growers and traders.

Each grade or grouping defines the maturity, cleanliness, condition of the vegetables in terms of decay and defects. Vegetables that are mature, clean, and free of defects and decay have the highest grade. The grade standards also include size groupings. Without such standards, the process of arbitrarily classifying into quality groups is called ***sorting.*** Grade standards are usually voluntary and are implemented only by those who want to make use of them.

Grading facilitates marketing of vegetables by establishing a common language for traders, producers and consumers, and among members of a cooperative. Storing graded produce results in longer storage life of the commodity because poor quality produce are not mixed with the good quality ones, and produce of one level of maturity or ripeness stage are not mixed with others. If the produce is intended for export, processing plants, or for institutional buyers, such as hotels and restaurants, grading becomes more important because the users are more exacting in their demands.

Packaging. Use proper containers. The use of suitable containers will help a lot in maintaining the quality of fruits and vegetables. A good container should not only be used to contain the vegetable but should also protect it from mechanical damage and unfavorable environmental conditions. As much as possible, its contents should be identified and its sale should be promoted whenever possible.

An ideal package depends on the commodity, type of loading (whether mechanical or manual), type of treatments it will be subjected to, method of selling, distance of market, environmental conditions during handling, cost effectiveness, convenience, and availability. It should be strong enough to provide protection from mechanical forces during handling, smooth enough to prevent abrasion, shallow enough to avoid crushing the vegetables in the lower layers, sufficiently available to be convenient, and cheap enough to warrant profitability.

In many countries of Asia, the use of bamboo container is very common since it is cheap, readily available, light, and easy to stack when empty. They vary in shape and size. Some are more sturdy and more expensive than other types.

Most designs, however, have sharp sides which damage the commodity and lack enough sidewise strength to withstand pressure during transport. The sharp sides can be partially remedied by using liners, such as straw, banana leaves, banana bracts, paper, or polyethylene film with a few pinpricks. For added protection, paper can be placed in between vegetables as in the case of cauliflower.

The insufficient supportive strength of bamboo containers is more difficult to remedy. In Thailand and Singapore, however, they remedy this by resting planks of wood from side to side of the truck just above the bamboo containers to support the next layer of containers. Then some more planks are placed above the second layer of containers and so on.

Mesh bags can be used to transport sturdy vegetables (not easily crushed) like bulb onion to nearby markets and those that are not to be held for long periods. Big boxes made of wood, wire, or fiberboard (bulk bins) can be used if mechanical loaders (forklifts) are available for loading and unloading them. Potatoes are usually transported in mesh bags.

Rigid plastic crates offer maximum protection from mechanical damage, however, they need an effective mechanism for return and are often very expensive and heavy.

There are some plastic crates that are one trip packages and are also less expensive, but these are not as sturdy as the returnable crates.

Where readily available, wooden crates are thus used to transport commodities over long distances, since they are cheaper than plastic crates but lack some of the good features of plastic crates like ease of stacking (nestable) and flip-on metal handles. Use of liners can minimize the damage of vegetables in wooden crates still further, especially where the inner sides of the crates are rough.

Fiberboard containers (cartons) provide adequate protection when they are of the right thickness and height. They are very light and could be made waterproof by waxing them. They also offer the additional advantage of being printable. However, in some countries, cartons are more expensive than wooden crates.

Vegetables intended for retailers with stores that have good environmental control (supermarkets and green grocers) can be packed first in small mesh or plastic bags (with holes) or in trays overlaid with plastic film before they are packed in a carton for transport.

- Pack vegetables properly — The method of packing also determines the extent of damage. When packed, the vegetables should stay in place and not move around in the container during transport. This is easy to do when the vegetables packed in one container are of one size. Vegetables that are round can be vibrated or shaken gently mechanically or manually once or thrice during packing to allow them to settle in unfilled spaces inside the container. Fragile vegetables should be arranged one by one manually in the container. Do not overfill containers.

  When economic considerations allow the use of wrapping materials, wrap delicate, costly vegetables individually with suitable wrapper, provided such wrapped vegetables are handled at low temperature. A wrapper traps the heat of respiration within it as the vegetables are transported or kept at high temperature so wrapped vegetable might deteriorate fast instead. Asparagus should be packed upright with a space above the vegetable as it still elongates during handling. When packed horizontally, the ends will curve upwards.

Transportation. Vegetables should be brought to the market, processing plant, or cold storage within the shortest possible time after harvest. Prompt transport and proper transport conditions are necessary. Heat increases inside a vegetable container when transport is done during the hot time of the day and no mechanically cooled truck is available. The increase in heat promotes faster deterioration. Transport then must be done during the coolest part of the day.

When stacking containers in trucks, spaces should be provided in-between containers for ventilation purposes. Containers that slope towards the bottom permits air to circulate freely at the bottom. It is important that the vegetable container does not move during transport. Braces may be necessary to secure the load.

Ripening. During early, late or off-season, growers and traders usually want to speed up the natural ripening process of fruit vegetables especially tomatoes to take advantage of the high price and to have a uniform rate of ripening. The standard method is to use ethylene gas. This method requires a specially-constructed ripening room which is air tight, insulated, with a refrigerating system, and good air circulation and ventilation. In the absence of a ripening room and ethylene gas, the following are the alternatives:

1. Use Ethephon (sold as Ethrel) dip at 2500-5000 ppm. Ethephon, chemically known as chloroethyl phosphonic acid, liberates ethylene when it comes in contact with the plant cells.

2. Insert paper-wrapped small pieces of calcium carbide in between green mature tomatoes inside a container or room for two to three days. One hundred sixty-two grams of calcium carbide give off 2 cu ft of acetylene. Tomatoes ripened with calcium carbide are pale yellow-orange because the heat generated by calcium carbide plus the heat of respiration of the vegetable result in high temperature in the pack. The enzyme responsible for the production of the red color does not function at high temperature.

3. Put ripening fruits together with unripe fruits and allow them to stay for about two days — Purple passion fruit gives a high amount of ethylene. Banana and even ripening tomatoes can also be used.

4. For small volumes, the smoke from joss sticks or other slow-burning material can be used.

5. Leaves that give off high ethylene can be inserted among the tomatoes in an enclosed container *Gliricidia sepium* leaves give relatively high level of ethylene with low amount of CO_2.

Storage. The vegetables should be stored when they are not brought to the market after harvest or not consumed immediately. Storage extends the usefulness and availability of the vegetables since deterioration of the freshness is minimized. It also increases the profit of the producers during the time of the year when availability is scarce.

Storage can be done by refrigerated and common (unrefrigerated) methods.

Refrigerated storage. This is undoubtedly the most effective method of prolonging the storage life of fresh fruits and vegetables. When this method is to be used on a commercial scale, the total value of the commodity should be considered. It may keep the commodity fresh for a long period but if it is not profitable to put up a refrigerated store or even to rent a refrigerated room, then other methods of storage should be used.

Since commodities have their optimum temperature and relative humidity at which they keep fresh for the longest possible time as discussed earlier, the cold room should have the desired temperature and relative humidity (Table 12.7). The commodities should be cooled as soon as possible. Root and bulb crops should be cured before storing for better protection against microorganisms.

Avoid mixing different commodities. Most fruits emit ethylene when they ripen, hence should not be mixed with leafy vegetables, root and bulb crops, and green fruit vegetables. Store only good quality produce. Use of a cold room for poor quality produce might not be profitable in the long run.

The faster the temperature of the vegetable is brought down to the optimum, the longer is the storage life of the commodity. Cooling vegetables immediately and quickly after harvest before storage at the optimum temperature is an effective way to remove the heat carried over from the field and, therefore, to slow down deterioration. Fast cooling is called ***precooling*** and can be achieved by cooling in special precooling rooms or equipment with air (room cooling), iced water (hydrocooler), ice (package icing) or vacuum (vacuum cooler).

A ***room cooler*** is a cold room with a much higher capacity to cool (refrigerating capacity) than a usual cold room. In a ***hydrocooler,*** the vegetable is showered with or immersed in iced water. The time of cooling is determined by the temperature difference

Table 12.7. Recommended cold storage conditions for vegetables.[a]

Vegetables	Temperature (°F)	Relative Humidity (%)	Storage Life (wk)
Ampalaya	42-45	85-90	3
Asparagus	32	95	3-4
Beans			
Bush sitao, yard-long	42	88-92	4
Lima in pods	40-45	90-95	1.5-2
Dolichos lablab, in pods	32-35	90	3
Snap	38-42	88	2-3
Winged	50	90	4
Beet, bunched	32	90	1.5
Beet, topped	32-35	90-95	8-14
Bitter gourd	33-35	85-90	4
Brussels sprout	32-35	90-95	4-6
Cabbage, wet season	32-35	92-95	4-6
Cabbage, dry season	32-35	92-95	12
Carrot, bunched	32	90-95	4
Carrot, topped	32	95	20-24
Cauliflower, 'Snowball'	32-35	85-95	7
Celery	31 32	92-95	8
Chayote	45	85-90	4-6
Colocasia, Taro	52-55	85-90	21
Condol (Wax gourd)	45	85	8
Coriander leaves	32-35	90	5
Corn, sweet	33-35	90-95	1
Corn, green	32	90-95	1.5
Cucumber	50-53	92	2
Eggplant	50-55	92	2-3
Garlic (bulbs), dry	32	65	28-36
Ginger	45-50	75	16-24
Gourd, bottle	45	85-90	4-6
Gourd, snake	65-70	85-90	2
Leek	32	90-95	4-12
Lettuce, head	32	90-95	3
Lettuce, leaf	32	95	1
Mushroom	32	95	1.5
Muskmelon, cantaloupe	35-38	85-90	1.5
Muskmelon, Honeydew	45	85	4-5
Okra	48	90	2
Onion, white	34	70-75	16-20
Onion, red	32	70-75	20-24
Onion, green (immature)	32	90-95	2
Bottle gourd *(Lagenaria)*	42-45	85-90	3
Pea, green	32	88-92	2-3
Pepper, sweet (green)	45	85-90	3-5
Pepper, sweet (ripe)	42-45	90-95	2
Petsai	32	95	1.5-2.5

Table 12.7. Continued.

Vegetables	Temperature (°F)	Relative Humidity (%)	Storage Life (wk)
Potato, Irish			
(8 varieties)	38-40	85	34
Pumpkin	35-60	70-75	24-36
Radish, topped	32	88-92	3-5
Squash	55-60	70-75	8-24
Sweet potato	50-55	80-90	13-20
Tomato			
'VC-lines', mature green	48-50	85-90	4-5
'VC-lines', ripe	45	90	1
'Oxheart', 'Hybrid-6'			
'Marathi', all green	35-38	85-90	6
'Ponderosa', yellow	42-45	85-90	3
'Sioux', red	32-35	85-90	2
Turnip	32	90-95	8-16
Watermelon	45-60	80-90	2

[a]Pantastico, Er.B., 1975.

between the water and the vegetable, the nature of the vegetable, and type of container used. Only vegetables and containers which are resistant to prolonged contact with water can be hydrocooled. Vegetables that can be hydrocooled are leafy vegetables, asparagus, sweet corn, celery, carrot, radish, and muskmelon. Packaged icing is a modification of hydrocooling. Put crushed ice in between layers of vegetables.

Vacuum cooling is based on the principle that evaporation of water requires heat and that evaporation is very fast at low atmospheric pressure. A vacuum cooler is a special air-tight chamber with powerful pumps to create a vacuum within the chamber to decrease pressure inside the cooler.

At low pressure, water on the surface of the vegetable plus some of the vegetable's own water is evaporated faster taking with it the heat of the vegetable. It is very fast, but it is also the most expensive, so its use is limited to vegetables which have a high surface area, such as leafy vegetables. Water loss can be offset by vacuum-cooling moistened vegetables.

In the absence of precooling facilities, fast cooling can be achieved by filling an ordinary cold room to half of its capacity or making a forced-air precooler with canvas or tarpaulin and a floor exhaust fan. Vinyl or plastic film could be used instead of canvas. Place two parallel rows of containers leaving an aisle in the middle. In front of the aisle is an exhaust fan and the other end of the aisle is open to air. The rows of boxes are covered, including the aisle but not the open back end. Cold air is sucked by the fan through the open end of the aisle and forced through the rows of containers. Several of such contraptions could be made in a room.

If temporary, short-term storage is desired in order to slow down deterioration and the vegetables will have to be brought out to high temperature later for disposal, it would be better to store the vegetables at about 20°C in order to minimize condensation problems later. Such is the case for vegetables not sold after market hours in the morning and will be sold again the following morning.

When storing commodities, allow spaces for ventilation so as not to trap the heat given off during respiration and to provide passageway for gases. Use sturdy containers to avoid damage when the containers are piled on top of the other.

Store only until it is profitable to do so and before the vegetables deteriorate. Usually, the entire contents of a cold room has to be sold when the amount of deteriorated produce reaches 20%-30%. Beyond this level, the rate of deterioration increases rapidly and cost of labor to sort or trim the vegetables is likely to be high. When bringing out vegetables from the cold room, make sure they will reach the market before they lose their good quality.

When bringing out produce to a temperature higher than the storage temperature, it is best to do so early in the morning or at night so the rise in temperature of the commodities will be gradual. Abrupt transfer from a cold to a warm environment results in sweating (condensation) of water on the surface of the commodity. Sweating should be avoided as this favors the growth of microorganisms and promotes sprouting in the case of root and bulb crops. Otherwise, use blowers or fans to remove the surface moisture.

Potatoes stored at 10°C or below for a long period accumulate sugars during storage and are reconditioned by keeping them at 15°-20°C for two to three weeks before processing. High sugar content in potatoes that are processed results in darkened products. Keeping them at 15°-20°C reduces the sugar content.

Other treatments that will enhance the effectiveness of cold storage such as sprout inhibitors for roots and tubers and (See Chapter 7) modified or controlled atmosphere and waxing should also be used.

Controlled/modified atmosphere storage is based on the fact that high CO_2 and/or low O_2 slow down respiration. When there is a very good control of the gases, the method is more appropriately called ***controlled atmosphere***. Automatic generators are used to produce and regulate the gases.

When the respiration of the commodity is allowed to reach a desirable low level of O_2 and high level of CO_2 inside a closed container, plastic bag, or plastic tent; and gases are maintained at those levels, then the system is called ***modified atmosphere.*** Both systems are best used with refrigerated storage.

Controlled atmosphere is seldom used commercially for vegetables. On the other hand, the use of plastic bags to line containers or as retail packages is an example of modified atmosphere. To prevent accumulation of too much CO_2 and decrease of too much O_2, a few holes could be made.

Waxing. Since the waxy coating of vegetables is removed by repeated handling, application of a thin layer of food grade wax will retard transpiration and add gloss to the vegetable. A fungicide and sprout inhibitor can also be incorporated with the wax. In developed countries, the following vegetables are waxed: cucumbers, peppers, sweet potato, muskmelons, squash, and to a limited extent eggplant, tomato, and carrot.

Only mature clean fruits of good quality should be waxed. The wax should not be applied too thickly or too thinly. It should be thin enough for gas exchange and thick enough to minimize transpiration.

Unrefrigerated storage. In areas where refrigeration is not feasible, alternatives that are simple, cheap, readily available, and effective should be considered. Most of these methods are traditionally used to prolong storage life. In countries with low temperature, cabbage, Chinese cabbage, and the root and tuber crops can be kept in basements or underground cellars since cold air tends to sink and temperature in such rooms is lower. Other techniques for both tropics and subtropics are as follows:

1. In-ground storage for potatoes and sweet potatoes – This means intentionally leaving the crop on the ground after the crop has attained the size (for sweet potato and taro) and characteristics of a mature vegetable (for potato). Sweet potato continues to increase in size after it has attained the size for the market while the shoots of potato die. Harvest can be delayed for several months for sweet potato, and three to six months for potato.

   A variation of the method for sweet potato and taro is selective harvesting. Harvest only bigger-sized tubers and allow the rest to develop.

2. Evaporative cooling in hot and dry areas — Evaporative cooling utilizes the evaporation of water using heat of respiration of the vegetables. Water should be near or around the vegetable. Hot, dry air is thus cooled when it flows through a wet surface. The temperature may drop by 1°-5°C and relative humidity increase by 20%-30%, depending on the prevailing temperature and relative humidity.

   The hotter and drier it is, the greater the decrease in temperature and the higher the increase in relative humidity. Evaporative cooling is especially useful for vegetables which easily wilt, shrivel, or soften because of low relative humidity. Some applications of evaporative cooling are:

   a. Sprinkling vegetables with water.
   b. Keeping vegetables in moist earthen jars.
   c. Keeping vegetables inside drip coolers — These are structures with sides which could absorb water to be evaporated like jute sacks or charcoal held on two sides by wire netting. Water is allowed to continuously drip on the walls.
   d. Clamp storage for low temperature areas — Clamp storage is putting vegetables in piles or pits (holes that are deep but narrow) or trenches (holes that are long and shallow), then covering them with dried straw or similar materials and sometimes soil on top. This is useful for potato, cabbage, and sweet potato.

      The efficiency of the storage method could be improved by inserting air ducts (ventilators) to serve as passageway of air and gases through the top (open to the atmosphere) and through the sides to the stored vegetables. Ventilators could be made of wood slats or bamboo splits tied or nailed together in a circular, triangular, or rectangular form with spaces between the slats.

3. Ventilated storage — This is done to provide the vegetables with proper ventilation. Hanging onions and garlic is the simplest form of ventilated storage. In low temperature areas, storage houses for potatoes have air inlets at the sides near the floor level and outlets near the ceiling. Such storage houses could be forced-ventilated. The entry and exit of air is mechanically controlled by thermostats which measure temperature inside and outside the room. Air is allowed to enter when it is cold and kept out when it is hot.

4. Diffused light storage for seed potatoes — This is popularized by the International Potato Center (CIP). This is any structure that allows light to diffuse through its walls; so the sides are made of transparent material, such as plastic. Diffused light results in many vigorous, green sprouts compared to a few thin and long pale sprouts when stored without light.

   Good ventilation is provided by having inlets at the bottom and outlet at the top. Potatoes for food should be stored in the dark to prevent greening, since the green color is associated with the formation of glycoalkaloids which are toxic at high concentrations to human beings.

5. Modified atmosphere storage — Some vegetables may be stored in plastic bags at high temperatures for a few days up to a week. At lower temperatures, as in the highlands, this might prove to be a good method of storing or transporting vegetables without refrigeration.

6. Irradiation to prevent sprouting of onions, garlic and potatoes at 0.05-0.15 kilogray (KGy).

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CHAPTER 13

Economics of Vegetable Production

As the objective of vegetable production shifts from providing the family with vegetables to supplying a market or processing plant, there arises a need to become more aware of the costs and profits involved. Moreover, the use of improved production techniques requires bigger investment; so that a farmer should first evaluate the economic feasibility of these improved techniques before he decides to adapt them. Estimation of costs and profits and evaluation of the economic feasibility of production techniques are aspects of the management of a farm as a business enterprise.

Given the same environmental factors and the same amount of investment, different farms will not necessarily obtain the same yield and realize the same profit. The farmer who can manage and operate his farm more efficiently will have the edge.

Most farmers are concerned with minimizing expenses to produce a given yield or maximizing yield with a given level of expenses. The budget will show whether he is succeeding or not.

A small farm is relatively simple to manage, as resources are limited and labor is generally confined to the family, and especially if the farmer raises only one kind of vegetable as a secondary crop after a main crop. He usually plans and budgets by rough estimation; and as he becomes more experienced in it, he is able to manage his farm successfully. In contrast, one with a big or specialized farm must have more extensive plans; as he has to see to it that land, labor, and capital are properly coordinated for maximum profit. The bigger the farm enterprise, the more important the plan. The farmer has to make decisions about a lot of variables, such as determining:

- positions and responsibilities of personnel to attain a set of objectives
- the right people for the job
- daily activities
- requirements and allocating resources for various activities.

Before he starts producing, a grower should first have a sure market with acceptable prices. If he does not have a sure market, he will have to make sure that he sells at a price that will give him the most profit. A common mistake of small farmers is to plan what crops to grow and how to raise them but forget to plan where and how to market them.

Steps in Planning

Planning is the process of choosing alternative courses of action for the future. Determining farm requirements, allocating resources to different activities, and estimating the results or returns is called ***budgeting.*** The plan provides the basis for the budget. A budget cannot be made, therefore, without a plan although a plan can be made without a budget. The budget evaluates a plan. An alternative plan may, therefore, be made and subsequently budgeted again. Two or more of such plans and budgets will enable the farmer to choose wisely.

Plans are made first, then a budget is set up based on the plan. When a farm is still to be started, the plans and budgets established are called a ***feasibility study, project study,*** or ***project feasibility.***

It is not too sophisticated for farmers to learn and use a budget with ease. By careful budgeting, a farmer can set down the combination of crops to plant in a multiple cropping system, or the production techniques to be used to get a reasonable profit from his vegetable production enterprise.

Inventory of Resources

The first step in planning is to make a list of resources. The land, labor, goods, money, building, and equipment available for use by the grower or farm manager are collectively called ***resources.*** They could be owned by the farmer or be acquired by borrowing, renting, or hiring. Assets are the resources owned by the farmer. Inputs include everything utilized or put into the production of vegetables such as land, labor, and capital. The inventory should include:

- Land — area that could be used including type of soil, topography, availability of water, drainage, and land tenure arrangement
- Labor — amount and availability of labor who can be tapped easily, like family members
- Capital — land and farm value; condition and uses of buildings; kind, number and value, condition, and use of tools and equipment; cash, and amount of money that the farmer may borrow (credit)

A list like this will enable the grower to see to it that all available resources are utilized to the fullest.

Survey of Farm Conditions

This is the second step in planning. Assistance in getting information can be obtained from extension agents, agricultural agencies, or other pertinent offices. Information is needed on the following:

- Weather conditions — can be obtained from a weather bureau, a meteorological station, an experiment station, or agricultural college.
- Soil conditions — assistance can be obtained from a soils bureau, a soil-testing laboratory, experiment stations, or the soils unit of agricultural universities.
- Technology conditions — include amount of additional labor needed for each farm operation and improved techniques that can be employed, their requirements, and expected results. Extension agents, agricultural officers, agricultural schools, and sales agents of farm chemicals can provide the information on improved technology.
- Socioeconomic conditions — include sources and conditions (including interest rates) of credit; prevailing market prices; cost of fertilizer, chemicals, and others; availability and conditions of hiring labor; marketing facilities; means and cost of transport; availability of price information services.

Review of the Present Management System

If vegetable production is an ongoing enterprise; the performance of the farm in the previous season has to be examined to determine where improvements can be made. Were all available resources fully and efficiently utilized? Were there opportunities missed? What were the resources for the lower-than-average yields? If the vegetable production enterprise is still to be started, the experiences of other farmers are to be studied instead and the system that best suits the farmers' resources and objectives selected.

Data from demonstrations or experimental trials of research agencies can also be studied. Analysis of the whole production system has to be based on knowledge of the principles of vegetable production discussed in the previous chapters, as well as from the financial point of view.

At this point, the grower as a manager, has to rely on farm records — the records that he has kept of his expenses, activities, inputs, etc. He also employs budgeting at this stage. These aspects are discussed later in this chapter.

Preparation of Plans

In a feasibility study, the plan is made based on the experiences of other farmers. Experimental results can also be used. In an ongoing vegetable production enterprise, the weak points of the business have to be identified, and remedied or made the basis of alternative plans. For example, if too much labor was involved in a small farm, an alternative would be to resort to mechanization on a small scale.

It is easier to make the second and subsequent budgets since these require less work and preparation than the first. Much of the same data can be used; so the second and succeeding budgets are often only modifications of the first.

When the farmer raises several kinds of vegetables or crops other than vegetables, or sells the harvest to different outlets, it will be useful to prepare plans and budgets for each kind of vegetable for each outlet (partial budgeting), and prepare one for the entire farm (complete budgeting). Partial budgeting is used when there is a change in a technology used, for example, a change in the method of weeding. Only the expenses and receipts that change with crop or technology will be considered.

A partial budget considers a) added costs, b) added returns, c) reduced costs, and d) reduced returns. These elements may be grouped into two in terms of their effect on net returns and computations. The total of the added returns and/or reduced cost is subtracted from the total of the added costs and/or reduced returns in order to get the profit or loss as follows:

$$B - A = P$$

Where: B = added returns + reduced cost
A = added cost + reduced returns
P = profit if the answer is positive (+) or loss if the answer is negative (–)

The above equation may be set into a form which allows detailed itemization as follows:

A	B
Added cost	Added returns
$ _______	$ _______
$ _______	$ _______
Reduced returns	Reduced cost
$ _______	$ _______
$ _______	$ _______
Total A $ _______	Total B $ _______

Estimated change = B — A

The format of a complete plan and budget is less standardized than the partial budget. It, however, contains the following parts: a) inventory; b) personnel organization; c) calendar of operations; d) schedule of labor requirements; e) schedule of supplies required; f) schedule of expected production and income; g) summary budget; and h) tests of success like costs-and-return analysis.

Farm Record-Keeping

It is easy to keep track of expenses if a grower hardly incurs any cash expense. However, as the enterprise expands and decision making as well as production management become complicated, it is harder to keep track of costs and returns. The bigger the farm, the more important record-keeping becomes.

Farmers perform functions that are similar to those of physicians. Before giving a diagnosis and prescription, a doctor has to know his patient's daily activities and possibly all the symptoms from his ailment. In planning his farm business, a farmer must base his decisions on the information he gets from his farm records. It can furnish him valuable information about past performances in specific areas of the farming operations. When kept for an adequate period of time, it can provide a basis for determining the yield increases due to additional fertilizers, for example.

If he applies for a loan, he can also use his records to prove that his enterprise is on a sound footing and that, he has the capacity to pay. If there is no record of costs and receipts for a given crop, it is impossible for a farmer to calculate profit, family earnings, and other related information.

For specialized farms, the computer is an important management tool. It can minimize record keeping for the farmer and facilitate budgeting and analysis. It permits testing of more alternative plans within a given time.

Inventory of Resources

During a given cropping season, the amount of resources changes. The farmer should have an updated record that show these changes. A sample format of a resource inventory at the beginning of the year is shown in Fig. 13.1.

Resources	Cost ($)
A. Farm Assets	
Farm land (if there are several areas, include all areas used for vegetables that are not adjacent to one another). The value of the land is the market price.	
1. Sweet corn area: area x cost/hectare =	
2. Cabbage area: area x cost/hectare =	
3. Multi-cropped area: area x cost/hectare =	
Total land area (hectare)	
B. Farm Building	
1. Barn	
2. Shed	
3.	
4.	
Total	
C. Tools and Machinery	
1. Tractor	
2. Power tiller	
3. Irrigation system	
4. Spraying system	
5.	
6.	
Total	
D. Pesticide, Fertilizer and Other Supplies	
1. Pesticide	
2. Fertilizer	
N — kg	
P — kg	
K — kg	
3. Sacks	
4 Seeds	
5. Stored crop	
Total	

Fig. 13.1. Sample format of an inventory of resources.

The value of equipment and buildings decreases (depreciates) as they get older. The depreciation cost is included in the production cost. This depreciation cost represents the diminished value due to wear and tear or the process of becoming obsolete. A simple way of computing the depreciation cost is shown below.

$$D = \frac{OV - SV}{UL}$$

Where: D = depreciation cost
OV = original value, or cost when building was established or equipment was acquired
SV = salvage value, or the value of the building or equipment at the end of its useful life
UL = useful life or the length of time the equipment or building is expected to last before it becomes useless or can no longer be repaired.

In developed countries, equipment is junked after a few years of use to avoid costly maintenance. Its salvage value, therefore, is considered zero. However, when maintenance cost is cheap and repair service is readily available and efficient, salvage value may be high.

For example, a power tiller costing US$192 has been used for four years. With proper maintenance (care and repair), it will last for ten years. If that tiller were to be sold after years, it will sell for US$115. Its depreciation cost is:

$$D = \frac{US\$192 - 115}{10} = \frac{27}{10} = US\$7.7/year$$

Buildings, tools, and machinery that were bought or constructed a few years before inventory, may be valued at construction cost or at acquisition minus depreciation cost. Those which were constructed or bought many years back should be valued by computing replacement cost minus depreciation cost.

Preparing the Cost Record

Cost is incurred in every operation. It is to get the value to identify inputs that are bought or paid for, unlike family labor or manure obtained from the farm. These also have some value when used in alternative enterprises, and therefore must be taken into account. The cost of family labor is estimated by the current wage rate.

A record of farm expenses is called a ***cost record.*** The purpose of this record is to keep data of farm operations and associated expenses in order to evaluate the performance of farm management and to help in sound farm planning. The data of farm expenses and receipts should be recorded whenever an operation takes place.

Generally, the same brand of pesticide or fungicide should not be used continuously to enhance the effectiveness of these inputs. Therefore, a farmer needs to know what brand was previously used. The answer can be found in a well-kept farm cost record. In determining what price to charge for vegetables harvested, the costs of all the inputs in a cost record should be used as a basis.

Every crop should have its own cost record. An effective farm record should be simple and easy to keep. When making recommendations, extension workers should remember that farmers are always very busy in farm jobs, being both manager and accountant/bookkeeper. A sample format of a cost record is given in Fig. 13.2.

Record every operation related to farm management. The data should include the date, description of operation, kind, amount, and unit price of inputs or receipts.

In addition to operation cost, it is important to record the kind and attribute of each input used. Attributes are such things as brand name and formulation or concentration of the inputs used. This information is useful in planning. The cash and noncash inputs, hired or

							Material Inputs							
		Labor					Fertilizer		Pesticide		Others		Revenue	
Date	Description of Operation	M/F[a]	H/F[a]	Man-days	$/Man-days	Cost	Q (kg)	Cost ($)	Q	Cost ($)	Q	Cost ($)	Q (kg)	Value ($)

[a]M/F = male/female; H/F = hired/family.

Fig. 13.2. A sample form for recording farm expenses and receipts for a crop.

family labor (male or female labor), and the unit of each input (such as kilograms, liters, etc.) should also appear in the cost record.

Costs may be variable or fixed. Variable costs vary from season to season and these include the cost of labor, fertilizers and pesticides, and other material inputs. Fixed costs are attributed to fixed investments such as machinery, barns, and sheds. These refer to depreciation cost of fixed investment items, land rental, and interest on capital.

Each item of expense is assigned a column. A cash expense transaction is recorded under its appropriate column heading. Should the expense be on credit, the same procedure is followed; but this is recorded under deferred account or in a separate form for credit transactions. Once paid, it is marked paid and transferred to the appropriate column heading.

Problems in Keeping Farm Cost-Records

Farmers frequently miss recording some important information like the units of input, figures, and the contents of mixed pesticides or fertilizer. Farmers also tend to forget to record events immediately as they happen because they are busy with farm work. Then, after a busy period, he simply forgets that record-keeping has not been done. So, an extension worker who helps farmers use modern farm-management techniques should frequently visit farmers, check what he has not done, and help him recollect and record the costs of the operations that have already taken place.

Farm Receipt Record

Total revenue or receipts or income is the sum of money from the sale of products (of different grades) and the implied (implicit) or approximate value of family-consumed product. The value of family-consumed product should also be estimated by the market value at the time of consumption. It should be placed under farm receipts, since this is part of the farm produce which could have been added to the sales proceeds had it been sold.

When a page in a farm receipt record is filled up, the entries should be summed and entered in the first line of the following page with the explanation, "Balance forwarded".

Cost-and-Return Analysis

Farm records are used in analyzing the profitability of the farm with a cost-and-return analysis. If noncash inputs are assigned money value and these are added to the cash expenses incurred in the production of vegetables, the summation is called ***production cost.*** The income that the grower gets from his vegetables is his ***returns.***

To help decide whether or not a plan like intercropping cabbage and onion is worth undertaking, or which among alternative plans (for example, what varieties to grow, whether to use a rototiller or not, what level of N to apply) has an acceptable profit, an analysis of the costs and return of the given plans is made. If there are benefits to be considered other than income, the term "benefit" is more appropriate than "return". Thus, a cost-benefit ratio is computed. A percentage return on investment is computed when the farmer desires to see how much he got for the capital (investment) he used. The estimate of the costs and expenses constitutes the budget.

The technique of analyzing the budget to determine profitability is called ***cost-and-return analysis.*** In general, if the cost of production is subtracted from the returns, the difference is the net income or the profit. The higher the difference, the better the plan.

The price of the vegetable used in analyzing the production system is usually the cost of the vegetable if bought at the farm (farmgate price). If the vegetables are sold ungraded, only one price is used. If quality or large-size vegetables have a higher price (a premium), then each grade or size has a separate price. In general, the price should be the average price expected of the quality produced.

The analysis could be stated in a simple equation:

$$P = TVV - TCP$$

Where: P = profit
TVV = total value of vegetables
TCP = total cost of production

The cost-and-return ratio is computed by dividing the receipts or gross income by the cost of production.

Sample Planning and Budgeting

A hypothetical example is given here to illustrate the above discussion. A farmer, Mr. Lee, has a one-hectare farm. During the summer season, he plants rice, then tomatoes, and then corn. Only the plan and budget for his tomato operations will be examined. For this crop, he uses a power tiller to prepare the land. He has an irrigation system and provides his own seeds. He fertilizes his field with 100 kg N, 100 kg phosphorus, and 50 kg potash. The family provides most of the labor. He uses stakes to prop his tomatoes, Malathion to control insects, and Dithane to control diseases. He sells his produce to a buyer who comes to his farm. He has a capital of US$400.

The description of the operations are shown below.

Farm Operations and Input

Date	Description of Operation and Associate Inputs
1/3-2/3	Land preparation by family power-tiller, 20 liters gasoline, at US$0.77/liter, 10 man-hours family labor
3/3	Irrigation: 3 man-hours of family labor
3/3-3/3	Planting: 5 man-hours family labor, 15 woman-hours family labor Fertilization: N = 20 kg at US$0.10/kg, P = 20 kg at US$0.12/kg, K = 10 kg at US$0.12/kg, 10 woman-hours family labor
20/3-25/3	Weed control: 10 woman-hours hired labor, 20 woman-hours family labor
30/3	Pesticide spraying: 8 man-hours family labor; Malathion, 2 bottles (500 cc) at US$11.54/bottle
10/4-15/4	Staking or propping: 15 woman-hours hired labor, 25 woman-hours family labor, bamboo US$38.46

Date	Description of Operation and Associate Inputs
20/4	Fungicide spraying: 8 man-hours family labor, Dithane Z-78 2 kg at US$19.23
22/4	Irrigation: 5 man-hours family labor
30/4-5/5	Pruning/tying: 15 woman-hours hired labor, 25 woman-hours family labor
10/5-15/5	Fertilization: N = 80 kg at US$0.10/kg, P = 80 kg at US$0.12/kg, K = 40 kg at US$0.12/kg, 15 woman-hours hired labor, 25 woman-hours family labor
20/5	Fungicide spraying: 8 man-hours hired labor, Dithane Z-78 2 kg at US$19.23
10/6	Harvesting: 500 kg at US$0.21/kg, 10 woman-hours family labor, 20 crates at US$0.58/pc
15/6	Harvesting: 500 kg at US$0.19/kg ten woman-hours family labor, ten crates at US$0.58/pc
20/6	Harvesting: 1,200 kg at US$0.18/kg, 20 woman-hours family labor, 24 crates at US$0.58/pc.
25/6	Harvesting: 1,500 kg at US$0.18/kg,20 woman-hours family labor, 5 man-hours family labor, 30 crates at US$0.58/pc.
15/7	Harvesting: 1,000 kg at US$0.15/kg, 20 woman-hours family labor, 20 crates at US$0.58/pc.
25/7	Harvesting: 800 kg at US$0.13/kg 15 woman-hours family labor, 16 packing receptacles at US$0.58/pc

Personnel Organization

The manpower on his farm consists of the following:

- the farmer
- the members of his family
- other laborers, hired when needed

Farm Inventory

The value of physical assets on the farm as of January 1990 was US$4,453.46 (Table 13.1).

Calendar of Operations

His tomato production activities starts on March 1 and ends on July 25 (Table 13.2).

Table 13.1. Farm inventory, Lee's farm, January 2, 1990.

Item	Cost (US$)
Land, 1 ha	3,846.15
Farm house	384.62
Power tiller	192.31
Knapsack sprayer, 2 units	19.23
Shovel, 3 units	1.15
Hoe, 3 units	1.15
Machete (bolo), 4 units	1.15
Crates, 100 units (disposable)	7.69
Total	4,453.46

Table 13.2. Calendar of operations for Lee's farm, 1990.

Operation	Date
Land preparation	Mar. 1-2
Irrigation	Mar 3
Planting/fertilization	Mar. 3
Weed control	Mar. 20-25
Spray of insecticide	Mar. 30
Staking (propping)	Apr. 10-15
Spray of fungicide	Apr. 20
Irrigation	Apr. 22
Pruning/tying	Apr. 30-May 5
Fertilization	May 10-May 15
Spray of fungicide	May 20
Harvesting	June 10, 15, 20 July 15 & 25

Labor Requirement

Laborers are to be hired only when necessary (Table 13.3).

Supplies

The supplies required include gasoline, fertilizer, insecticide, bamboo stakes, fungicide, and crates (Table 13.4).

Farm Record

His farm record is shown in Table 13.5.

Table 13.3. Labor requirements in Lee's farm, 1990.

Operation	Type of Labor	Man-Days	Rate ($/man-days)	Value ($)
Land preparation	family-man	10	1.92	19.23
Planting	family-woman	15	1.92	28.85
	family-man	5	2.31	11.54
Irrigation	family-man	8	2.31	18.46
Fertilizing	family-woman	35	1.92	67.31
	hired-woman	15	1.92	28.85
Weed control	hired-woman	10	1.92	19.23
	family-woman	20	1.92	38.46
Pruning/tying	hired-woman	15	1.92	28.85
	family-woman	25	1.92	48.08
Spraying	family-man	8	2.69	21.54
	hired-man	16	2.69	43.08
Staking	hired-woman	15	1.92	28.85
	family-woman	25	1.92	48.08
Harvesting	family-woman	95	1.92	182.69
	family-man	5	2.31	11.54
Total		322		644.62

Table 13.4. Supplies required in Lee's farm.

Material	Unit Price (US$)	Rate/ha	Total Requirement	Value (US$)
Gasoline	0.77/liter	20 liters	20 liters	15.38
Fertilizer				
N	0.10/kg	100 kg	100 kg	9.62
P	0.12/kg	100 kg	100 kg	11.54
K	0.12/kg	50 kg	50 kg	5.77
Pesticides				
Malathion	11.54/bottle	2 bottles	2 bottles	23.08
Dithane Z-78-2	9.62/kg	4 kg	4 kg	38.46
Bamboo Stakes	—	—	—	38.46
Crates	0.58/piece	110	110	63.46
Total				205.77

Estimates of Production and Gross Income

His gross income from the sale of tomatoes amounted to US$944.62 (Table 13.6).

Summary Budget

Although his gross income is high, his net income is only US$46.94 (Table 13.7)

For a small vegetable farm (such as Mr. Lee's), considering the family labor, the self-provided expenses of seeds, capital interest, and value of the crop consumed by the family

Table 13.5. Lee's record of farm expenses and receipts.

Date	Description of Operation	Labor: M/F[a]	Labor: H/F[a]	Labor: Man-hours	Labor: Man-Hours	Labor: Cost (US$)	Material Inputs: Fertilizer Q (kg)	Material Inputs: Fertilizer Cost (US$)	Material Inputs: Pesticide Q	Material Inputs: Pesticide Cost (US$)	Material Inputs: Others Q	Material Inputs: Others Cost (US$)	Revenue: Q (kg)	Revenue: Value (US$)
1-2/3	Land preparation (power tiller)	M	F	10	1.92	19.23					20 liters	15.38		
3/3	Irrigation	M	F	3	2.31	6.92								
3/3	Planting	M	F	5	2.31	11.54								
3/3	- do -	F	F	15	1.92	28.85								
3/3	Fertilizing N 20 x 0.10 P 20 x 0.12	F	F	5	1.92	9.62	N 20 P 20	1.92 2.31						
3/3	Fertilizing K 10 x 0.12	F	F	5	1.92	9.62	K 10	1.15						
20/3	Weed control	F	H	10	1.92	19.23								
25/3	- do -	F	F	20	1.92	38.46								
30/3	Spray insecticide Malathion @ 11.54	M	F	8	2.69	21.54			2 bt.	23.08				
10/4	Propping: bamboo stick	F	H	15	1.92	28.85						38.46		
15/4	- do -	F	F	25	1.92	48.08								
20/4	Spray fungicide Dithane 2 kg	M	H	8	2.69	21.54			2 kg	19.23				
22/4	Irrigation	M	F	5	2.31	11.54								
30/4	Pruning/tying	F	H	15	1.92	28.85								
5/5	- do -	F	F	25	1.92	48.08								
10/5	Fertilizing N 80 x 0.10 P 80 x 0.12	F	H	15	1.92	28.85	N 80 P 80	7.69 9.23						
15/5	K 40 x 0.12	F	F	25	1.92	48.08	K 40	4.62						
20/5	Spray fungicide Dithane 2 kg	M	H	8	2.69	21.54			2 kg	19.23				
10/6	Harvesting	F	F	10	1.92	19.23					20 crates	5.77	500	105.77
15/6	- do -	F	F	10	1.92	19.23					10 "	5.77	500	96.15
20/6	- do -	F	F	20	1.92	38.46					24 "	13.85	1200	221.54
25/6	- do -	F	F	20	1.92	38.46					30 "	17.31	1500	259.62
		M	F	5	2.31	11.54								
15/7	- do -	F	F	20	1.92	38.46					20 "	11.54	1000	153.85
25/7	- do -	F	F	15	1.92	28.85					16[b]	9.23	800	107.69
	TOTAL			322		644.62		26.92		61.54		117.31	5500	944.62

[a]M/F = male/female; H/F = hired/family.

[b]packing receptacle.

Table 13.6. Estimates of production and gross income, Lee's farm, 1990.

Yield per hectare (kg)	5,500
Total production (kg)	5,500
Ave. price per kg (US$)	0.17
Gross income (US$)	944.62

(if any) as part of the income would be a better indicator of the profitability of his tomato production than his net income.

Farm family earning = returns on family labor + self-provided expenses of seeds, organic fertilizer, animal labor, mechanical labor, land rent, and capital interest

Table 13.7. Summary budget of Lee's farm, 1990.

Budget Item	Cost (US$)
Receipts	944.62
Cash Expenses	
Gasoline	15.38
Fertilizer	26.92
Pesticides	61.54
Crates	63.46
Hired labor	148.85
Irrigation fee[d]	7.69
Repairs[d]	1.92
Bamboo	38.46
Subtotal	364.22
Noncash Cost	
Seeds[d]	3.85
Depreciation[d]	8.92
Family labor	495.77
Land rent[ad]	0.77
Interest on capital[bd]	24.15
Subtotal	533.46
Total Expenses	897.68
Net Farm Income (Loss)	46.94
Return per Dollar Invested[c]	1.05

[a]US$1.92/annum ÷ 365 days x 147 days = 0.77.
[b]interest or capital for 147 days @ 15% per year.
[c]$\frac{\text{Receipts}}{\text{Total expenses}} = \frac{944.62}{897.68} = 1.05.$
[d]Not reflected in Table 13.5.

Returns on family labor = net revenue + value of family labor

In the case of Mr. Lee:

Returns on family labor = US$46.94 (Table 13.7) + US$495.77 = US$542.71

The value of his seeds is US$3.85. His capital is US$400; if he borrowed it, he would have been charged 15% which is US$60.00 per year. If he rented his land he would have been charged US$1.92/year. It is assumed that the family consumed only a negligible amount of tomatoes, so family consumption is equivalent to zero. So:

Family earnings = US$542.71 + 3.85 (seeds) + 0.77 (land rent) + 25.15 (capital interest) = US$571.48

Kind and Amount of Vegetables to Produce

Mr. Lee now wants to know if he should replace tomatoes with another crop to get more profit. What vegetables should he plant? To be able to answer this, he has to consider one of the basic and most known laws in economics — the law of supply and demand. The law implies that Mr. Lee will have to determine what the buyers want to buy and produce it, if he wants to get the most from his vegetables. He has to know the amount and quality of the vegetables that could possibly be sold. He can ask potential buyer-traders, restaurant operators, housewives, and processing plants. Otherwise, he will have to agree on a lower price; or in an extreme case, his crops may not sell.

If the vegetables are for a processing plant, it is easier to determine the kind, amount, and quality that the processors want since they have specific requirements and their processing operations are programmed.

In a market where many sellers and buyers come together, the higher the demand for a certain vegetable relative to the supply, the more willing are the buyers to bid among themselves for the available supply. Thus, prices are high during periods of low supply, such as during the early or late season for seasonal vegetables, or after natural calamities, such as typhoons.

Demand for vegetables, however, is generally inelastic; that is, if the price is reduced, people will not buy more than what they usually buy.

Mr. Lee also has to consider the principle of opportunity cost. The principle states that profits will be greatest if each unit of land, labor, and capital is used where it will add the most to returns. ***Opportunity cost*** is the amount or value which a given factor of production (for example, capital) could have earned had it been used somewhere else or invested in a different way. Although growing tomatoes was profitable for Mr. Lee, he could have invested his $10,400 in another crop and got more profit.

Each vegetable will give different gross returns, costs, and profits. Will his money earn more if he invests it in carrots than in potatoes or tomatoes? To be able to answer this question, a tool which he can use is the simple cost-and-return analysis (Table 13.8). He got the costs of production and returns on carrots and potato from his neighbors. Analysis of the data shows that for every dollar he invests, he gets $1.05 for tomatoes, $1.20 for carrots and $1.50 for potatoes. He thinks that the increase in returns is not big enough to consider raising a new crop. Therefore, he will still plant tomatoes after rice.

Table 13.8. Cost-and-return analysis for 1 ha of carrot, potato, or tomato.

Crop	Gross Returns (US$)	Costs (US$)	Net Returns (US$)	Return per Dollar Invested
Carrot	1153.85	961.54	192.31	1.20
Potato	1346.15	846.15	500.00	1.59
Tomato	944.62	897.68	46.94	1.05

Kind and Amount of Input to Use

One of the decisions that Mr. Lee will make is to determine what and how much of what input or combination of inputs to use in order to maximize his profits. He has to base his decisions on his cost records for the past years, also using the cost-and-return analysis, or he can rely on the data of others or farms with similar characteristics as his farm. Two principles of economics are useful here.

Principle of Diminishing Returns

The principle states that as you add more inputs, the additional output decreases for every unit of input until total product diminishes. The volume of production tends to increase when one or more factors of production are increased. However, the increases are not uniform. As an input is increased, yield may increase at a fast rate, level off, and then decrease. From this principle is derived the rule that it pays to increase production up to a point where the additional cost of the inputs is equal or less than the added profit that a grower gets.

Consider the following yields obtained as Mr. Lee applied more N to his tomatoes.

Amount of Fertilizer Kg N/ha	Yields (t)	Increase in Yield (in kg) per kg Change in Fertilizer*
60	4.9	-
90	7.6	90.0
120	12.1	150.0
150	13.4	43.3
180	13.9	16.7
210	12.7	-40.0

*Computed by dividing change in yield by change in fertilizer.

For 90 kg N/ha:

$$\frac{(7.6 - 4.9)\ t}{(90 - 60)\ kg} = \frac{2.7\ t}{30\ kg} = \frac{.09 \text{ tons or } 90 \text{ kg}}{\text{kg of fertilizer}}$$

The yield continues to increase with the addition of fertilizer up to 180 kg N/ha. However, as N is increased from 120 kg to 150 kg, the increase in yield for each kilogram of N decreases. This trend follows the principle of diminishing returns. Hence, the optimum amount of nitrogen is 120 kg/ha.

Principle of Substitution

In growing vegetables, several choices may be made to achieve the same results. The principle of substitution states that it is economical to substitute one production factor for another if the cost of the first is less than the cost of the second, provided that the two factors are equal in effect. For example, if 120 kg of N is recommended, Mr. Lee will have to decide which form of N should be applied: ammonium sulfate, or urea, or any other source. Only the two major sources will be considered in the example. Assuming there are no technological conditions that will influence the effectiveness of the N from the different sources (pH of the soil is one), Mr. Lee should select one that gives the same result at the least expense. So, if both ammonium sulfate and urea cost the same per 50-kg bag, urea would be a cheaper source since it contains more N as shown in the example below:

	Cost per 50-kg Bag	% N	Amount of N per Bag (kg)	Cost/kg N (US$)
Ammonium sulfate	US$16	21	10.5[a]	1.52[b]
Urea	US$16	45	22.5	0.71

[a]50 x 0.21 = 10.5
[b]16 ÷ 10.5 = 1.52

Mr. Lee wants to determine next whether he should direct-seed or transplant his tomatoes. Using partial budgeting, he can compare the change in income as a result of the shift from transplanting to direct seeding, assuming the following:

- Fertilizer cost increases from US$26.92 to US$34.62.
- Herbicide cost is incurred (US$11.54) since direct-seeded tomatoes cannot compete with weeds.
- Total labor cost decreases from US$644.62 to US$500.00 as a result of the elimination of some farm practices, such as nursery bed preparation, pulling of seedlings, and transplanting.
- Seed cost increases from US$3.85 to US$7.69.
- Yield increases from 5,500 to 6,000 kg at an average of US$0.17.
- Harvesting cost increases by one-sixth of increase in returns.

Computations:

- Increase in fertilizer cost = US$34.6 — 26.92 = US$7.70
- Herbicide cost = US$11.54
- Decrease in labor cost = US$644.62 — 500.00 = US$144.62
- Increase in seed cost = US$7.69 — 3.85 = US$3.84

- Increase in yield = 6,000 — 5,500 = 500 kg
- Increase in return = 500 x US$0.17/kg = US$85.00
- Increase in harvesting cost = 1/6 (US$85.00) = US$14.17

The analysis in Table 13.9 shows that Mr. Lee will gain US$192.37 if he were to direct-seed his tomatoes instead of transplanting them.

Table 13.9. Cost-and-return analysis of shifting from transplanting to direct seeding.

A		B	
Added Cost		Added returns	
Seeds	US$ 3.84	Increase in yield	US$ 85.00
Fertilizer	7.70		
Herbicide	11.54	Reduced cost	
Harvesting	14.17	Labor cost	144.62
Reduced Returns			
No reduction in yield			
Subtotal (A)	US$37.25	Subtotal (B)	US$ 229.62
Estimated change (B-A) = US$192.37			

Economies of Scale

The scale of farming or farm size can be measured in terms of hectares or acres of land or intensiveness of the operations. Highly specialized farms, such as those using hydroponics, cannot be compared with unspecialized farms in terms of size since total investment is higher in the latter. For the most part though, the cost-and-return ratio changes in relation to size.

The volume of production increases as the relative amounts of fixed and variable inputs are increased (by improved production techniques, for example). Initially, only variable factors like labor, seed, amount of irrigation water, fertilizer, and the like may be changed; while fixed items remain the same. In later years, however, even fixed inputs may eventually be changed as when farm size or area is expanded. When all production factors, fixed or variable, are increased at the same rate, and total output increases at a faster rate, there is what is referred to as economies of scale.

For example, given more capital, a vegetable grower may practice more intensive cultivation, such as relay-cropping, and use more efficient equipment so that yield may more than double or result in more than proportionate increases. Moreover, in a bigger operation, laborers do specific tasks where they are most efficient and skillful. In a small farm they perform just about any activity they may not be skilled in. Division of labor and specialization thus result in economies of scale.

Where there are many fixed investments used, the concept of economies of scale will be an important factor to consider in deciding what scale of operation to put up. The bigger the area devoted to the production of the same kind of vegetable, the lesser the cost per unit area; since fixed costs are spread over more units. A tractor, for example, depreciates whether 1 ha or 0.5 ha is farmed. Thus, over a period of time, larger farms make more money than smaller ones.

When small farmers band together and run their farms as a large competitive group, they can get higher profits than when they operate individually. Such economic organizations are called ***cooperatives.*** A producers' cooperative can buy farm supplies in bulk, obtain credit as a unit (then give loans to members in turn), process their vegetables or sell them collectively, and even pay extension workers. Together, they get more profit from the economies of scale.

Minimizing Risks and Uncertainties

Vegetable crops are subject to high risks in price, in changing consumer demands, and in production conditions. Unusual weather during production or harvesting, or a major crop disease can seriously increase risks in vegetable production.

The farmer with sufficient capital and without any farm debt can afford to assume some risks; that is, he can afford to go broke one season. He can borrow funds and operate on a large scale with improved methods which will give him the largest profit. It is when he has done his best and still feels somewhat uncertain, that he adopts measures to minimize risks. He can also withdraw reserve funds to tide him over the bad year. However, a beginning farmer with very little capital who is afraid to go broke must minimize his risks. This is especially so for the farmer whose family relies on the farm for their livelihood and education of the children.

Steps taken to minimize risk may take all these distinct forms: 1) measures to reduce the variability of income; 2) measures to prevent profit from falling below a minimum level, such as zero family living plus debt repayment; and 3) measures to increase the farmer's ability to withstand unfavorable economic outcomes. The measures are as follows:

1. Selecting several crops which together may give him lower returns over a number of years but will not break him in one year. This means crops which are sure to sell in the area even at lower prices should be selected, instead of crops that might possibly bring a high price but without sure market.

2. Selecting a more certain enterprise. In a locality, there are crops which give more certain results or outcomes than others. While returns may vary from year to year, the ups and downs are not extreme. Although these crops will not give tremendous returns, neither will they give huge losses.

3. Getting an insurance. It may be for the crop, if crop insurance is available in the country. Insurance may also be obtained to meet major risks, such as death of the operator or a family member; or sickness or accidents which are expensive and may disable the farmer; and fires or other hazards which wipe out major capital investments such as expensive buildings or equipment. In getting a crop insurance, for example, the farmer pays a small cost for the possibility of a large uncertain loss. In the event that his crop is destroyed, he is given an amount to cover his loss.

4. Entering into contracts. Processors get into contract-growing to fully utilize plant capacity and to assist in sales programs. Many large grocery stores have buyers in the major producing areas to ensure a steady source of supplies for their stores. Grower cooperatives execute marketing orders and agreements to facilitate orderly marketing of these highly perishable products. Price uncertainty can be eliminated entirely if the farmer can enter into a contract before production for the things he has to sell in the future at a specified price. He can also do this for the things he has to buy. By doing this, he protects himself from unfavorable price movements.

On the other hand, he signs away any chance for a big profit. A contract to sell may increase or decrease the uncertainty of the future. If the farmer studies the situation and feels sure that the market will fall, he makes a contract to sell. However, if he is wrong and the prices go up, he makes less profit than if he sold it in the open market.

Increasing Labor Efficiency in the Farm

Labor is the largest contributor to farm income nd must, therefore, be efficient. In small farms, labor has no price tag as the family provides it. However, labor still has a value. The real labor cost of one job is the return it makes if used for other jobs, either on or off the farm. Labor can be made more efficient by the following practices:

1. Do work that is in season. Repair machinery during off-season.
2. Lay out daily or weekly work plans or schedules. Organize the schedule in terms of the priority to be given to different jobs and assign workers different jobs. Keep the capabilities of the workers in mind when assigning jobs.
3. Be flexible in making schedules in order to adjust to the weather. Make a list of jobs for rainy days.
4. Study, analyze, and routinize jobs to reduce motion and energy.
5. Take time to teach farm helpers the most efficient way of doing assigned jobs.
6. Provide incentives. Wages, bonus, and profit-sharing arrangements are all monetary incentives applicable to family as well as farm labor. Active participation in work planning creates a sense of responsibility and prestige among farm workers.

Marketing of Vegetables

Successful production of a vegetable is not an end goal. The grower must be able to sell his product at a price that would give him the most profit.

Decisions on how the product should be marketed and in what form are usually done long before the crops are harvested by analyzing which alternatives give better returns.

Marketing of vegetables is the performance of all business activities involved in the movement of vegetables from the farm to the final consumer at a given time, place, and form the consumer desires at a price he is willing to pay. The most well-known of the marketing functions is that of exchange which includes buying and selling. The usual list of marketing functions, in addition to buying and selling, include transportation, storage, grading, price determination, financing, and assumption of risks.

Vegetables can be sold in fresh and processed forms, each varying in supply and demand, and method of marketing necessary. Fresh vegetables are marketed quite differently from the processed products.

The vegetable marketing system is influenced by 1) perishability, 2) price and quantity variations, 3) seasonality, 4) alternative product forms and markets, 5) bulkiness of product. Marketing problems are usually due to these factors.

Vegetables are highly perishable commodities. One cannot hold them for long periods to wait for better prices. A common saying in the trade is, "Sell it or smell it". There is an urgency to either sell them as quickly and efficiently as possible to maintain their farm-fresh value or to process them. The entire distribution process is aimed towards rapid marketing, and this affects every phase of vegetable marketing.

Proper postharvest handling, short marketing channels, efficient and adequate facilities and equipment, and rapid and reliable transport aid in maintaining vegetable quality — assuming that roads, communication facilities, and other support systems are good. These are often expensive operations and to choose slower and cheaper but less efficient forms means rapid deterioration of the product.

As a result, a great deal of trust and informal agreements are involved in the marketing of fresh vegetables. There is not always time to write down or negotiate everything. A grower with a surplus of carrots may send them to an agent with instructions to sell them before they spoil. He does not know the price until the carrots have been sold. This urgent, informal marketing process often leads to dispute between buyers and sellers.

Adding Value to Vegetables

Most vegetables are seasonal. They grow best during certain seasons or in certain places. Demand for certain vegetables are also higher during certain periods of the year. Thus, processing adds value to vegetables. Vegetables for processing are harvested once but their demand is year-round. The entire crop is picked and processed within a short period.

Vegetables can be canned, frozen, pickled, dried, converted into vegetable juices, sauces, or other processed products (see Chapter 1). They can be converted into semiprocessed products, such as brined vegetables (vegetables in salt solution) to preserve them before pickling or canning.

While these products provide alternatives to marketing vegetables in fresh form at the same time adding to their values, the market for such products has to be determined first. Moreover, processed products have to meet definite standards of quality; so vegetable rejects from the fresh market cannot be used. This is the reason for the need to produce processing vegetable varieties.

Since water is a major component of vegetables, they are bulky and have a low value per unit, hence are expensive to ship in fresh form. Substantial savings in transportation cost can be achieved by selling fresh vegetables near production areas or converting them to high-value products and shipping them to distant markets.

Determining the Selling Price

A farmer has to know the price below which he does not profit from his production efforts. This is his break-even price and it is the cost of producing his crop. So if it costs him $2/kg to produce his crop, he should sell above this value. The higher the selling price above this value, the higher is his profit. If he brings his vegetables to the market, he should add handling, transport, and marketing to the cost of production to get the break-even price.

To be able to determine a reasonable selling price in an open market or to a trader he should know the price of the vegetable in the market where he intends to sell his crop and in other markets where he can possibly sell his crop, if he will stand to gain more. This requires market intelligence, which a small farmer cannot get by himself. This service can be provided by a specialized agency of the government.

Without price monitoring, a farmer is at the mercy of a trader and will not know what he will ask or bargain for.

Methods of Vegetable Marketing

Basically, farmers can market vegetables individually or as a group. Individual marketing permits a maximum amount of freedom of decision making by the individual farmer. Group marketing involves decision making by the members, thereby limiting personal choice.

Individual Marketing. If the grower decides to do the marketing of his vegetables himself (individual marketing), he has full control over what, how much, where, and to whom to sell, and what part of marketing to undertake.

A farmer can sell to direct buyers (***open market***) or he can make a contract to sell to processors or organizations before harvesting the crop (***closed market channel).***

A farmer's marketing decision can be made by a very simple approach: market the output as soon as it is produced. Whether or not this is a wise strategy depends upon the commodity, market conditions in a particular year, price seasonality, and yearly trends in overall price levels. In general, the price received by a producer varies according to the mode of sale or type of outlet.

Farmers may sell directly to the following:

1. Field agents of merchants, such as order buyers and assemblers-wholesalers.

2. Traders who take direct delivery and purchase at delivery time or immediately before delivery.

   When a grower sells to a trader, the latter may or may not sell direct to the consumer but may pass it on to other traders (wholesaler, wholesaler-retailer, commission agent, trucker-trader). Such traders are known as middlemen or intermediaries. Farmers are usually forced to sell through middlemen because they have the collection and transport facilities and are familiar with the marketing channels. They also perform the necessary postharvest activities. Some traders give loans to farmers as prepayment for the farmers' produce, often valued at prices lower than what they would otherwise command. These are the contract buyers.

3. Processors who take delivery and pay at delivery.

4. Exporters or shippers who at times buy directly, especially from large producers.

5. Retailers who may go to the farmers' places and buy directly from them.

6. Consumers who buy fresh vegetables directly at farmers' markets. This is all right:

   a. if the cost of bringing the crop to the market is offset by the difference between the farm and the market price received by the grower.

   b. if the transport facilities between the farms and market are good, that is, the produce reaches the market still at the peak of its quality.

A grower can also open roadside stands or sell at farmers' markets in nearby cities.

7. Auction markets, which have the appeal of direct bidding by several buyers. They serve only as a marketing tool, since sales may be to individuals, field buyers, or merchants or processors, or even to speculators who may dictate prices among markets.

   Sales, of course, may be made through local, central, or (more recently) electronic auction markets.

8. Commission agents and brokers if the producer has a sufficient volume. These marketing agents arrange sales mostly to processors or exporters. They usually require large quantities and uniform grades which, in most instances, are available only from wholesalers. However, individual farmers can make sales in some central markets through commission agents.

9. Contract buyers, with whom the sale is negotiated before the vegetables are ready for harvest. The contract buyer estimates the total value of the vegetables by estimating the probable harvest multiplied by the expected price at harvest time. All the expenses in preparing the produce for the market are borne by the buyers. They also assume the preharvest and postharvest risks.

Crop contracts call for a specific quantity, or production at a specified area, and delivery to a buyer at a stipulated date. The price may be set or the contract may specify the means of establishing the price under a "call" price system. In many cases, a capitalist gives out loans before or at the start of production as prepayment for the farmers' produce; in which case, the price is usually lower than what the produce would otherwise command (contract-buying). The availability of loans from legitimate lending agencies minimize such a practice.

Such marketing, however, is usually restricted to small commercial producers. For producers with a relatively large quantity to market, selling to processors would be more appropriate. Vegetable producers may make a contract with frozen-food processing or canning plants. More commonly, large growers establish their own packing and shipping firms and, thus, become known as grower-shippers who do domestic and export marketing.

Group marketing strategies. Group marketing by producers is part of a general attempt to balance the power of farmers, on the one hand, and vegetable buyers and processors, on the other.

1. Voluntary bargaining associations — Voluntary bargain associations are formed by producers to make group offerings of a commodity to processors at a prenegotiated price. A group which commands at least 30% of a crop usually has a good bargaining power.

Bargaining should be done before planting, with quality and price specified. There is little potential for bargaining when vegetables are ready for harvest, since at that stage, they are subject to quick deterioration in the field.

There are limits to local bargaining: one local plant cannot afford to pay more than its competitor in the next county or the next state, and therefore it is difficult to raise market prices. This restriction can be remedied with a regional bargaining association. If the crop is a regional one, then, all processing plants are dealt with together. Theoretically, a regional bargaining association can become a national association, but this is unusual.

Processors cannot predict wholesale prices six months or one year before; hence a protection against inaccurate price expectations is included in the price negotiated between processors and bargaining associations.

The weakness of voluntary bargaining associations lie in their voluntary nature. If all or most local growers do not join an association, processors may avoid negotiating with them and turn to other supply sources instead. This deficiency prompted the creation of compulsory bargaining associations in some countries.

2. Compulsory bargaining associations — These bargaining associations are "compulsory" in two senses: growers must belong to them and processors must negotiate with them. The existence of such an association depends on enabling legislation although such legislation is difficult to obtain. As previously noted, vegetable growers are especially vulnerable to marketing pressures at harvest time; legalization of a bargaining process for them is, therefore, politically acceptable.

A benefit of compulsory associations is that contract production can be made a part of their framework, which may lead to better coordination of demand and supply. Processors benefit from assured supplies and price. Consumers also gain, assuming that better coordination of the production and marketing systems, makes possible greater efficiencies of operation, which in turn are reflected in lower prices.

3. Marketing associations — Marketing associations are another form of group marketing activity. The most common type of marketing association is the marketing cooperative. In many instances the producers' cooperative does the marketing itself, hence in effect, are acting as marketing cooperatives. Farmers generally market their crops to large, highly organized, commodity merchant firms or to large processing firms. Since these firms combine expertise and capital, farmers should be allowed to develop their own marketing firms to deal with them on an equal footing. Cooperatives can improve the bargaining positions of farmers much as corporations do for business executives.

Agricultural marketing cooperatives are voluntary membership organizations formed by groups of farmers to provide self-help in marketing, marketing services, and related needs.

A cooperative's ability to grow depends on (1) the number of commodity members committed to marketing, and (2) its ability to attract new members. Members are in no way bound to do all their business with the cooperative. Any member who sees a higher profit from marketing outlets elsewhere has an option. Thus, a cooperative must compete against outsiders for its own members' marketing business. To be successful, agricultural marketing cooperatives must either increase member returns, decrease costs, or render a service not provided by the noncooperative sector. The growth of agricultural marketing cooperatives must be encouraged by favorable government policies that are designed to help themselves. Cooperatives face challenges in the management areas of member relations, financing, leadership, control of management and competition, but in these challenges lies the opportunity for the future.

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