Soybean Production

TRAINING MANUAL

MANUAL No. 10



International Institute of Tropical Agriculture

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TABLE OF CONTENTS

Foreword		(ii)
Chapter 1:	Soybean	1
Chapter 2:	Nutritive Quality and Use	6
Chapter 3:	Botany	26
Chapter 4:	Soybean Physiology	45
Chapter 5:	Land Preparation and Planting	60
Chapter 6:	Nutritive Requirements and Mineral Nutrition of soybean	81
Chapter 7:	Weeds and Their Control	132
Chapter 8:	Soybean Breeding	166
Chapter 9:	Seed Production and Handling	185
Chapter 10:	Disease of Soybeans	190
Chapter 11:	Insect Pests and Their Control	235
Chapter 12:	Nematodes as Pests of Economic Plants	262
Chapter 13:	Harvesting and Seed Storage.	308

Foreword

This manual has been compiled to provide information and guidelines relating to all aspects of soybean production in the humid and sub-humid tropics. It is designed to serve as a basic reference document for participants in IITA's soybean training courses.

Our sincere thanks go to the following scientists who have contributed or reviewed the materials that are included in the manual (by alphabetical order).

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Mention in the text of trade names of certain products does not constitute approval by IITA to the exclusion of other products that may also be suitable. It is our sincere hope that this manual will be of assistance to the many research workers and extension supervisors who come to IITA for further training in soybean production.

WADE H. REEVES

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Head of Training.

CHAPTER ONE

SOYBEAN

1.1 Origin.

Soybean originated in Manchuria and is recognized as one of the oldest species cultivated by man. The first recorded evidence of its existence is thought to be in Chinese literature in 2838 B.C., but the crop is considered to have been extensively cultivated in China long before this (Leakey, 1970). The first records of the introduction of soybeans into the Western Hemisphere date back to about 1700 A.D., while the first published account of the plant in the United States of America appeared in 1804 (Roberts, 1970). The first large-scale introduction of numerous varieties into the United States was done by the U.S. Department of Agriculture beginning in 1898.

1.2 Production trends.

Before the 1939-45 World War, China and Manchuria were the most important soybean producing countries. During the war, however, cultivation in North America increased very rapidly, and by 1946 the USA was the largest producer of soybeans, providing about 38 percent of the total world output. The crop is now grown throughout much of the world with the largest production in the United States, Brazil, People's Republic of China, Mexico, Indonesia and Argentina (Fehr, 1980). Soybeans are also cultivated on a large scale in Canada, Eastern Europe and the USSR.

In Africa, soybeans have only been grown on a comparatively limited acreage. Introductions were made into Tanzania as early as 1907 and into

Uganda in 1913, but the crop did not really become established until the early 1940s (Auckland, 1970). Production in Uganda increased from about 1000 tonnes to more than 8000 tonnes by 1968 (Leakey, 1970); and in Nigeria it has increased from 4000 tonnes in 1948-52 to 77000 tonnes by 1980 (FAO 1981). Production of soybeans has increased very rapidly in Zimbabwe and Zambia in recent years. Soybean production is expanding in Rwanda; it frequently replaces *Phaseolus* bean in environments where *Phaseolus* production is marginal. There are several regions in Zaire where soybeans have been successfully introduced. Cameroon has recently initiated a soybean pilot project with involvement of French development banks. Small farmers in Benue State of Nigeria have been growing soybeans for about 50 years. The crop was originally promoted as an export crop, but most of the crop is currently used for direct human consumption as a fermented paste called 'local maggi' or 'Dawadawa'. The opportunity for expansion is very great in Nigeria due to a massive increase in poultry production requiring protein concentrates. Ivory Coast has initiated an ambitious soybean project in recent years with technical assistance from Brazil. Senegal has done rather extensive research on soybean production and a processing plant is being established.

Results of the FAO Agro-ecological Zones study for Africa for rainfed production potential for soybeans are shown in Table 1.1. The low input potential approximates to a low technological level and involves hand cultivation. It can be compared to traditional systems of shifting cultivation

or bush fallow rotation. The high input level involves mechanical cultivation under capital intensive management practices.

Table 1.1:Land suitability assessment for Africa.

Extent ('000 ha) of land variously suited to production of rainfed soybeans 1/

Major climatic division	High inputs				Low Inputs			
	Very suitable	Suitable	Marginally suitable	Not suitable	Very suitable	Suitable	Marginally suitable	Not suitable
1. Warm tropical lowlands	65149	200266	160402	1604158	14334	127778	228130	1659733
2. Warm subtropics (Summer rainfall)	1751	1813	3707	284623	784	2141	3931	285038

1/ FAO (1978). World Soil Resources Report - Report on the Agro-ecological Zones Project. Vol. 1: Methodology and results for Africa. FAO, Rome Italy.

Despite the high potential for rainfed production of soybean in Africa less than half a million hectares are now being grown (Table 1.2). The low production is due to the inability of the crop to nodulate and fix the essential nitrogen without inoculation, low storability of the seeds, general lack of investment and lack of extension in popularizing the crop.

Table 1.2: Soybean Production Trends in Africa 1/.

Country	Area harvested (1000 ha)				Total Production (1000 mt)			
	1969-71	1978	1979	1980	1969-71	1978	1979	1980
Egypt	-	35	42	34	-	79	106	91
Liberia	4	5	5	5	1	2	2	2
Nigeria	162	190	195	197	61	70	75	77
Rwanda	1	6	6	6	1	5	5	5
S. Africa	12	25	26	28	5	37	28	39
Tanzania	2	5	5	5	1	1	1	1
Uganda	4	5	5	5	4	3	3	3
Zaire	2	9	5	10	2	8	8	9
Zambia	-	2	9	2	-	3	3	3
Zimbabwe	6	25	33	35	6	44	70	81

1/ FAO, (1981): FAO Production Yearbook for 1980, FAO Rome Italy.

Asian soybean lines have been identified that nodulate freely with native rhizobia. Some progress has been made in developing soybean lines that nodulate with native rhizobia and with improved seed storability. Priority has been given to finding ways of enhancing nitrogen fixation which minimizes the need for nitrogen application to legumes or crops grown in sequence with legumes (Table 1.3).

Table 1.3: Yield response (tons/ha) to inoculation of two types of soybeans, (Okigbo, 1981).

Treatment	Highly responsive (U.S.)	Poorly responsive (Indonesia)
Uninoculated	1.08	2.12
N Fertilizer 150kg/ha	2.68	2.67
Rhizobial inoculation	3.15	2.53
LSD 05	0.62	

Genetic crosses have been made to incorporate the promiscuous nodulation characteristics into high yielding varieties with improved seed storability.

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CHAPTER TWO

2.1 Nutritive quality and use.

The soybean seed provides primarily protein and oil. Varieties commonly grown average approximately 40-41 percent protein and about 20 percent oil on a dry matter basis. The protein is well balanced in the essential amino acids but is somewhat low in methionine and cystine. The distribution of the amino acids in soybean meal (44 percent protein) and maize is given in Table 2.1 (Hinson and Hartwing 1977).

Table 2.1: Amino acid analyses of soybean and maize (g of amino acids;16g N)

Amino Acid	Soybean Meal	Maize
Arginine	7.4	3.7
Histidine	2.5	2.4
Lysine	6.2	2.6
Tyrosine	3.5	3.6
Tryptophan	1.4	0.6
Phenylalanine	4.7	4.1
Threonine	3.8	3.0
Methionine	1.2	1.6
Cystine	0.8	1.3
Leucine	7.2	11.2
Valine	4.9	3.9
Glycine	4.0	2.9
Glutamic Acid	17.1	14.1
Protein percent	45.2	9.3

2.2 Composition.

Commercial soybeans constitute approximately 8% cotyledon, and 2% hypocotyl and plumule. Proximate compositions for whole beans and fractions are given in Table 2.2 (Wolf and Cowan, 1977).

Table 2.2: Proximate composition for soybeans and seed parts.

Fraction	Protein (N xx6.25) (%)	Fat	Carbohydrate (%)	Ash (%)
Whole bean	40	21	34	4.9
Cotyledon	43	23	29	5.0
Hull	8.8	1	86	4.3
Hypocotyl	41	11	43	4.4

The constituents of major interest-oil and protein-make up about 60% of the bean, but about one third consists of carbohydrates including polysaccharides, stachyose (3.8%, raffinose (1.1%), and sucrose (5.0%) Wold and Cowan). Phosphatides, sterols, ash and other minor constituents are also present. Oil and protein contents depend on variety, soil fertility, and weather conditions.

2.3 Use of soybean as food in Africa.

The main staple food items in Africa are the grains - rice, sorghum millet and maize - and the tubers - cassava, yams and sweet potato. The protein content of these are low and in the face of insufficient animal protein in the diet a good plant protein substitute is imperative. Cowpeas have largely served this need especially in the diets of the people of West Africa. However, soybeans are by far superior to cowpeas in nutritive value in so far as protein content and amino acid composition are concerned.

Soybeans are used in the preparation of many traditional foods in African countries. In Ethiopia, the Ethiopian Nutrition Institute uses soybeans in two of the products that it makes: Faffa, a weaning food, and SWF, an enriched wheat flour and both products have been used extensively (Hiwot, 1975). There have been many suggested methods of utilizing soybeans for human consumption in Nigeria. Onochie (1965) suggested that the use of soybean in the Nigerian menu can be improved by mixing it with the more desirable cowpea paste for 'Olele' and 'Akara' by using it to fortify wheat flour for bread, or by making it into soybean milk.

This soybean milk can then be processed into traditional foods such as kosai, panke, and wara in the Northern States of Nigeria or akara ball, moyinmoyin and puff-puff in the Southern States of Nigeria, with acceptable taste (Ashaye *et al* 1975). More recently, Faryna (1978) has prepared a book on "Soybeans in the Nigerian Diet" which contains recipes for using soybeans in most of the traditional dishes in Nigeria. Recently, protein-enriched pap (Soy-Ogi) has been developed by the Federal Institute of Industrial Research. This is made by mixing soybean flour with maize flour and adding sugar for taste. Soy-Ogi is meant for cheap baby food and so replaces costly dried skim milk.

In Zambia soybean flour has been used successfully as a constituent for making bread. The present cost of frying oil and protein meal for livestock and poultry in Africa points to the great potential for industrial uses of this crop when grown in large quantities.

2.4 Processing soybeans into oil and meal.

Processing soybeans removes the oil which is used by the edible fat industry and converts the defatted meal into feeds and food products. Soybean meal contains factors that must be inactivated by moist heat before optimum growth rates are obtained with young animals when the meal is used as a feed. For food uses the processing may consist of merely heating and grinding the defatted material as in the preparation of flours and grits, or of further fractionation to increase protein content as in the production of concentrates and isolates.

Soybeans are processed into meal by either of two processes, the older mechanical processes or the newer chemical solvent process. The mechanical methods include the hydraulic press and the continuous expeller or screw press. At present, in developing countries nearly all soybeans are processed by the chemical solvent method. The solvent method removes more oil from the meal than can be removed by the expeller or hydraulic press. Normally meal prepared by the expeller method contains approximately 4 percent oil, while solvent extracted meal contains less than 0.5 percent oil. Commercial hexane is the most widely used solvent. A high percentage of the hexane may be recovered and used again, but solvent plants should be run almost continuously.

2.5 Soybean oil products.

Soybean oil is made up of approximately 12-14 percent saturated oils and the balance is unsaturated oils. The saturated fraction is made up primarily of palmitic and stearic acids. The unsaturated fraction includes approximately 30-35 percent oleic acid, 45-55 percent linoleic acid, and 5 to 10 percent linolenic acid. The oil is used primarily for food purposes - margarine, cooking oils, and salad oils.

2.6 Kinds of soybean products.

Edible soybean proteins are classified according to protein content:

Product	Protein content (%)
Flours and grits	40 - 50
Concentrates	70
Isolates	90 - 95

Edible soy flours and grits are made from dehulled beans and are classfied according to particle sizes:

Product	Mesh size (U.S. standard screen)
Grits:	
Coarse	10 - 20
Medium	20 - 50
Fine	50 - 80
Flour:	100 or finer

Grits are prepared by coarse grinding and screening, compared to flours that are ground until 97% of the material passes through a 100 mesh screen. Many soy flours are ground to 200 mesh size and especially flours of 300 mesh size are also available. The term flours as applied to soy refers only to particle size, and has no similarity to wheat or maize flour. In addition to varying in particle size, available flours and grits also differ in fat content.

2.6.1 Full-fat products.

In commerical preparation of full-fat flours and grits, the beans are cleaned, cooked, dried, cracked, dehulled, ground and screened. Alternatively, the beans may be cracked and dehulled before heating. Full-fat flours are the least refined commercial soybean protein products, because only the hulls are removed. Hulls consist mainly of indigestible carbohydrates cellulose and hemicelluloses. Cooking is used to inactivate enzymes, such as lipoxygenase, that if permitted to remain active, are believed to catalyse oxidation of linoleic and linolenic acids in the oil and in turn lead to the development of off-flavours.

2.6.2 Defatted products.

Defatted flours and grits are made by the following sequence of steps: cleaning, cracking, dehulling, conditioning, flaking, extracting, desolventizing, grinding and screening. The oil as well as the seedcoat is removed during this processing. The oil is extracted with hexane, and as a result, defatted grits and flours contain a minimum of 50 percent protein.

Defatted grits and flours are the major soybean protein form produced at present and are also the starting material for further processing into protein concentrates and isolates.

2.6.3 Protein concentrates.

Concentrates are made from defatted flours or grits by removing the oil soluble, sugar (sucrose, raffinose, and stachyose), along with some ash and minor constituents.

2.6.4 Protein isolates.

Isolates are the most refined form of soybean proteins available commercially, By definition they must contain a minimum of 90% protein. Like concentrates, isolates are made from defatted flakes or flours.

2.6.5 Functional properties.

A functional property is one that imparts desirable changes to a food during processing or in the finished product. Examples of functional properties are water absorption, viscosity, emulsification, fat absorption, and texture. In many applications, the functional effects are obtained with only a few percent of soy proteim ; hence, the contribution to dietary protein may be minor. A given functional property does not always ensure use of soy protein in certain foods. For example, when isolates are washed with aqueous alcohols, their solutions can be whipped to form very stable foams, but these foams do not have the additional functional property of heat-setting that is characteristic of egg white proteins. Consequently, alcohol -washed soy proteins are not suitable as replacements for egg whites in angel food cakes.

Often it is necessary to make adjustments in the formulation before soy proteins can be added to a given food. Use of soy flour in bread frequently leads to a decrease in loaf volume but this can be overcome by adding oxidizing agent such as potassium bromate or dough conditioners such as sodium stearoyl lactylate. Tests for evaluating the functional properties of soy proteins are largely empirical and hence not very reliable for predicting the performance of the proteins when they are added to a given food. The only reliable way to evaluate effectiveness of soy proteins for this purpose is to incorporate them into the formulation and prepare the finished food product.

2.6.6 Dietary protein.

Use of soy proteins at high levels as a dietary source of protein is a recent development. The best examples of this application are the textured soy proteins that serve as extenders or complete replacements for meat. Functional properties, however, are also important in these uses. In fact, success of soy proteins as meat extenders and meat analogs depends largely on their ability to assume a meat-like texture and to retain it during cooking.

The characteristic beany and bitter flavours of raw soybeans are difficult to remove completely by processing. Consequently, flavor has been a factor limiting the use of soy protein in some foods, especially those with bland flavors. Concentrates and isolates were developed to overcome the flavor of flours and grits, but the problem has not been completely solved for some potential applications such as dairy-type food.

Flavor may therefore be a barrier to extensive use of soy proteins for dietary purposes; that is, at levels high enough to be a significant source of protein in the diet. Table 2.3 is a listing of food uses for the different soy protein forms currently marketed in the developed countries (Wolf, 1976).

2.6.7 Flours and Grits.

A major application of flours and grits is in bakery products. Rapid rises in the price of non-fat dry milk solids in recent years have nearly priced this commodity out of the market as a normal bread ingredient. However, in developing countries where wheat flour and milk solids are imported, soybean provides an excellent opportunity to enhance the nutritional quality of bread and reduce importation of goods.

Table 2.3: Food uses of soy proteins (Wolf, 1976)

Protein form	Uses
Flours and grits	Bakery products:
	Bread, rolls, and buns
	Doughnuts
	Sweet goods
	Cakes and cake mixes
	Pancakes, crackers and cookies
	Meat products:
	Sausages
	Luncheon loaves
	Patties
	Canned meats in sauces
	Breakfast cereals
	Infant and junior foods
	Confectionary items
	Dietary foods
Textured flours	Ground meat extenders
	Meat analogs (bacon-like bits, etc.)
Concentrates	Bakery products:
	Bread, biscuits, and buns
	Cakes and cake mixes
	Meat products:
	Sausages
	Luncheon loaves
	Poultry rolls
	Patties
	Meat loaves
	Canned meats in sauses
	Breakfast cereals
	Infant foods
	Dietary foods
Isolates	Meat products:
	Sausages
	Luncheon loaves
	Poultry rolls
	Dairy-type foods:
	Whipped toppings
	Coffee whiteners
	Frozen desserts
	Beverage powders
	Infant foods
	Dietary foods

Table 2.3 (continued)

Protein form	Uses
Spun isolates	Meat analogs Bacon-like bits Simulated sausages Simulated ham chunks Simulated chicken chunks Simulated bacon slices
	Meat extenders

The added soy flour-whey blend increases the protein content of the bread and improves the amino acid balance of the wheat proteins by supplying lysine. In other bakery applications, soy flours often are employed primarily for their functional properties. For example, addition of soy flour to doughnuts helps reduce absorption of fat during frying; in pancake and waffle mixes it contributes to desirable browning in the fried products. Soy proteins have good water-holding capacities; hence, help maintain freshness of bread. Some bakers add about 1 percent of a raw soy flour preparation (soy flour plus corn flour) to white breads for bleaching purposes. Raw Soy flour contain the enzyme lipoxgenase which catalyzes reactions with polyunsaturated fatty acids that in turn cause bleaching of the yellow pigments in wheat. It is also claimed that bread flavor is improved as a result of action by the enzyme.

Soy flours are added to processed meats largely for functional purposes binding emulsion stabilization, and fat absorption. Textured soy flours are utilized extensively as extenders for ground beef. Smaller amounts of textured flours serve as replacements for meat-pizza toppings, simulated fried bacon bits, and related items.

Soy flour is also blended with cereals such as oats for infant and adult breakfast cereals. Some canned infant foods and infant cookies contain soy flour. Dietetic cookies and candy likewise have soy flour added to them. Protein concentrates find some of the same uses as flours. A major outlet for concentrates is in processed meat - sausages, meat balls, meat loaves, salisbury steak, and poultry rolls - for functional characteristics such as moisture absorption and fat-binding. Concentrates are blander and higher in protein content than flours. Certain ready-to-eat breakfast cereals and infant foods likewise contain protein concentrates.

2.6.8 Protein isolates.

Isolates are added to many kinds of products as flours and concentrates such as processed meats, infant foods and dietary foods. Isolates are often used to replace the higher priced sodium caseinate in dairy-type items such as whipped toppings, liquid coffee whiteners, and frozen desserts. Instant cocoa mixes, instant breakfast preparations, and milk replacers are examples of beverage powder products containing protein isolates. Several milk-like formulas designed for infants who are allergic to cow's milk are based on soy protein isolates. Methionine is also added to these products to raise the nutritive value of soy protein to that of casein.

The ability to convert soy protein isolates into fibers has led to development of a variety of meat analogs. In these products, spun fiber provides some of the chewiness that is characteristic of meats and can also supply a significant amount of dietary protein.

2.7 Amino acid balance.

The essential amino acid contents of soy protein types are given in Table 2.4 (Wolf and Cowan 1971). Also included is the amino acid pattern for hen's egg protein recommended as a reference protein of good nutritional quality by the FAO - WHO Expert Group. Most of the amino acid levels in the soy protein are equal to or exceed the levels in egg proteins with one exception. The sulphur amino acids are low, and as a result the protein scores for soy proteins are low as compared to egg proteins.

Table 2.4: Essential amino acid patterns for soy and hen's egg proteins.

	(mg/g total essential amino acids)			
Amino Acid	Flour*	Concentrate**	Isolates**	Egg Proteins*
Isoleucine	119	115	121	129
Leucine	181	188	194	172
Lysine	161	151	152	125
Total "Aromatic" A.A.	209	229	227	195
Phenylalanine	117	125	134	114
Tyrosine	91	95	93	81
Total Sulphur A.A.	74	73	60	107
Cystine	37	40	34	46
Methonine	37	33	27	61
Threonine	101	100	93	99
Tryptophan	30	36	34	31
Valine	126	118	120	141
Protein score	68	68	56	100

* From FAO-WHO Expert Group Report

** Based on total sulphur-containing amono acids.

The lower score for isolate as compared to flour and concentrate results from loss of amino acids in the whey proteins during isolation. It is therefore necessary to supplement with methionine when isolates are the sole source of protein as is being done with infant formulas. Alternatively, soy protein can be blended with other proteins to provide a good balance of essential amino acids. For example, cereal proteins which are low in lysine can be blended with soy proteins to make mixtures which are better than either protein source by itself.

2.8 Soybean Meal.

The protein meal is used largely as a high protein supplement with the cereal grains for the production of poultry, swine, dairy and beaf animals. The composition of soybean meals is given in Table 2.5. Soybean meal is very uniform in protein quality, though protein content may vary depending on the processor and geographical area of growth of the soyben. The amino acid composition of soybean meal is given in Table 2.6 while the vitamin and mineral content is given in Tables 2.7 and 2.8 respectively (Cravens and Herder, 1976).

Table 2.5: Composition of Soybean Meal

Composition	Soybean meal 44 percent	Soybean meal dehulled
% Protein (minimum)	44.0	49.0
% Fat (minimum)	0.5	0.5
Fiber, percent, (maximum)	7.0	3.3
Moisture, percent (maximum)	12.0	12.0
Metabolizable energy, Cal./kg	2240	2530

Table 2.6: Amino acid composition of soybean meal.

Amino Acids	Soybean Meal 44 percent	Soybean Meal dehulled
	Amino acid content (Percent of soybean meals)	
Arginine	3.20	3.80
Cystine	0.67	0.80
Glycine	2.10	2.30
Histidine	1.10	1.20
Isoleucine	2.50	2.60
Leucine	3.40	3.80
Lysine	2.90	3.20
Methionine	0.65	0.73
Phenylalanine	2.30	2.70
Threonine	1.80	2.00
Tyrosine	0.70	2.00
Tryptophan	0.60	0.65
Valine	2.30	2.70

Table 2.7: Vitamin content of soybean meal.

Vitamins	44 Percent	Dehulled
Riboflavin, mg/kg	3.3	3.1
Nicotinic acid, mg/kg	27.0	22.0
Pantothenic acid, mg/ kg	14.5	14.5
Choline, gm/kg	2.7	2.7
Pyridoxine, mg/kg	8.0	8.0
Biotin, mcg/kg	0.32	0.32
Folic acid, mg/kg	3.6	3.6
Alpha tocopherol, I.U./kg	3.0	3.3

Table 2.8: Mineral content of soybean meal.

Minerals	44 Percent	Dehulled
Calcium, %	0.32	0.26
Phosphorus %	0.67	0.62
Sodium, %	0.01	0.01
Potassium, %	2.0	2.0
Manganese, mg/kg	35	40
Zinc, mg/kg.	27	45
Selenium, mg/kg	(0.075-0.15)[a]	

a. Varies with soil in which grown.

The protein of properly processed soybean meal is extremely well utilized by all species and may be used as the sole source of protein when combined with the protein of cereal grains and synthetic amino acids. Methionine is the chief limiting amino acid of soybean protein and fortunately is available in commercial volumes.

2.9 World soybean Product Trade.

World soybean oil and soybean meal production is shared by a large number of countries than is world soybean production. This arises, however,

only because soybean importers become soybean product producers as the imported soybeans are processed. These soybean importers have, in general, played only a small role in world soybean product trade during the last decade. The major exception to this is trade among Western European countries. Large quantities of both soybean oil and soybean meal are traded among these countries on a regular basis with smaller, though substantial, quantities also exported to a number of Eastern European countries from Western Europe. This trade between Western Europe and Eastern Europe is more important with respect to soybean meal than it is with respect to soybean oil (Frahn, 1976). Table 2.9 show trends in world trade in soybean meal and soybean oil.

Table 2.9: World Soybean Product Trade (FAO, 1981). Soybean oil

	Imports (Mt)			Exports (Mt)		
	1978	1979	1980	1978	1979	1980
N. America	34550	22240	12175	915868	1109711	1081237
W. Europe	559441	579986	679162	1098603	1208206	1200448
Oceania	28965	26067	31538		14	23
Other developed countries	8796	20025	18024	3680	4757	18334
Africa	292780	339990	332106	1964	690	
Latin America	343341	376154	428054	570268	613986	845082
Near East	365976	364157	479455	7	168	3202
Far East	583329	841079	902838	6507	6374	28854
Asian centrally planned economies	136500	142625	137500	5800	4304	2000
E. Europe USSR	103346	122461	166918	6882	8880	18179

Table 2.9 (Continued) Soybean meal

	Imports (Mt)			Exports (Mt)		
	1978	1979	1980	1978	1979	1980
N. America	412659	46455	403650	6009417	6109302	7102808
W. Europe	9253432	9672563	10467163	2571774	2983317	3355281
Oceania	28085	7207	11610			
Other developed countries	339939	282932	325544	25522	39955	42027
Africa	79337	109467	118810	2261	29868	27000
Latin America	483022	492566	838579	5794436	5578473	7130625
Near East	321431	301818	405563		25000	40000
Far East	558224	697681	763803	156468	155941	194128
Asian centrally Planned economies	39251	380	10500	7100	11700	20000
E. Europe USSR	3228161	3531383	4407211	1800	12500	3900

The United States of America is the major supplier of soybean oil entering world trade from net exporting countries. In 1980, the United States exported about 1.1 million metric tons of soybean oil (FAO, 1981). Other countries such as Brazil and Argentina have emerged as net exporters of soybean oil in the last few years. Brazil was up and down as a world soybean oil supplier during the early 1970's having exported 92,000 metric tons in 1973 and none in 1974 (Frahn, 1976), but became a substantial exporter of soybean oil during the late 1970's reaching a record high of 744,000 metric tons in 1980 (FAO, 1981). Argentina is another country that shows signs of becoming a regular net exporter of soybean oil, having exported 80,786 metric tons in 1979 and approximately 100,000 metric tons in 1980 (FAO, 1981). The increased level of soybean processing which has developed in Western Europe has also increased the probability that excess soybean oil which could be exported to countries outside the European continent, will exist from time to time.

Major soybean oil importers in the world are a very diverse group. Many though certainly not all, would be classified among the less developed or developing countries of the world. Another trend which emerged during the 1970's was the increased importation of soybean oil and other vegetable oils by several of the petroleum-rich countries who have rapidly upgraded the dietary levels of their people.

World trade in soybean meal, like soybean oil trade, is greatly dominated by the United States which exported 7 million metric tons in 1980 and is followed closely by Brazil which exported 6.6 million metric tons in 1980 (FAO, 1981). Unlike soybean oil, however, much of the soybean meal entering world trade is imported by more developed countries. These countries have large commercial livestock and poultry industries which require large quantities of protein meal for incorporation into animal rations. Many less developed countries are also improving their livestock and poultry industries and, as a result, import substantial quantities of soybean meal as well as other protein meals.

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CHAPTER THREE

BOTANY

3.1 Taxonomy

The soybean is a member of the family *Leguminosae* and the subfamily *Papilionoideae*. Cultivated soybeans have been known by several botanical names but in 1948, Ricker and Morse presented evidence that the correct botanical name should be *Glycine max* (L.), Merril (Ricker and Morse, 1948). Their conclusion has been generally accepted, and *Glycine max* has been used almost exclusively in scientific literature since 1948.

The genus Glycine is subdivided into three subgenera: *Glycine*, *Bracteata*, and *Soja*. *G. max* has not been found growing wild. It probably originated from *G. soja*, which gorws wild in the Yangtze River Valley, the northern and northeastern provinces of China and adjacent areas of the USSR, and in Korea and Japan (Hinson and Hartwig, 1977).

G. max and *G. soja* have diploid chromosome numbers of 40. Crosses between them are easily made, and F_1 hybrids are fertile. However, *G. soja* has a twining growth habit, small hard seed, and low productivity. These traits make *G. soja* an undesirable parent in breeding programmes, unless the breeder identifies some specific trait in *G. soja* that he wishes to transfer into the more productive species, *G. max*.

The subgenus *Bracteata* contains only one species - *G. wightii* which is subdivided into five subspecies. They are viny perennials that are used as tropical forages, and have diploid chromosome numbers of 22 and 44. They have not been hybridized with *G. max*.

Species within the subgenus *Glycine* are perennials. They appear to have limited value in intensive agriculture. Diploid chromosome numbers for four species are either 40 or 80. However, none has been hybridized with *G. max* (Hinson and Hartwig, 1977).

3.2 The seed.

Seed shape varies from almost spherical to flattened and elongated. Seeds of cultivated types are generally oval in outline (Fig. 3.1). Seed size varies from about 20 to 400 mg per seed, but almost all cultivated varieties produce seed that weigh between 120 and 200 mg.

The seed coat is marked with a hilum or seed scar that varies in shape from linear to oval. At one end of the hilum is the micropyle, a tiny hole formed by the integuments during seed development. The tip of the hypocotyl - radicle - axis, often visible through the seedcoat is located just below the micropyle.

3.2.1 Seed coat.

The seed coat proper has three distinct layers: epidermis, hypodermis and inner parenchyma layer. The epidermal layer consists of closely packed palisade cells. The hypodermis consists of a single layer of cells which have the shape of an hourglass. The inner parenchyma tissue consists of six to eight layers of thin-walled, flattened cells that lack contents. This parenchyma is essentially uniform throughout the entire seed coat except at the hilum, where it forms three distinct layers.

3.2.2 Embryo.

The embryo consists of two large fleshy cotyledons, a plumule with two well developed primary leaves, and a hypocotyl - radicle axis that rests in a shallow depression formed by the cotyledons.

In cross section the cotyledon is semicircular in shape and bounded by an epidermis of cuboidal cells that contain aleurone grains. The plumule is about 2mm long and has two opposite simple leaves each with a pair of stipules at the base. The vascular system of the primary leaves is pinnate and consists of protoxylem initials, metaxylem initials, and some

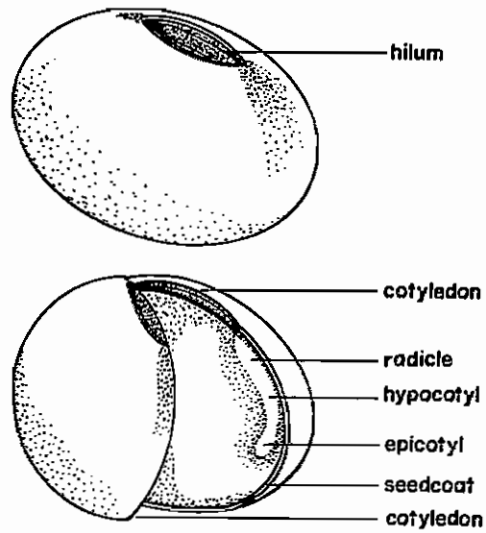


Fig. 3.1: Diagramatic illustration of a soybean seed (adapted from Scott and Aldrich, 1970).

mature protophloem elements. The hypocotyl - radicle - axis is about 5mm long and somewhat flattened both on the outer surface, which is in contact with the seed coat, and on the inner surface, which is tightly appressed to the cotyledons.

The radicle located at the tip of the embryo axis consists of the stelar initials that produce the stele and a group of common initials that give rise to the root cap, epidermis and cortex. The transition from root to hypocotyl is not marked by any clear anatomical change in the dormant embryo.

3.2.3 Seed colour.

Soybean seeds vary in colour from yellow, green, brown or black and may be solid coloured, bicoloured, or variegated. The pigmentation of the seed coat is located mainly in the palisade layer and consists of anthocyanin in the vacuole, chlorophyll in the plastids, and various combinations of breakdowns products of these pigments.

The cotyledons of the mature embryo are either green, yellow or chalky yellow, but in most genotypes are yellow.

3.2.4 Germination and seedling development.

When placed in an environment that is optimum for germination, some seeds imbibe enough water to double their weight within about three hours. Other seeds imbibe water less rapidly, but only rarely does seed of a cultivated variety require scarification for rapid germination. Variation in the rate of water imbibition is influenced by the genotype of parent plant and the environment in which seeds are produced.

Genetic and environmental influences on water imbibition probably are associated with intensity of a compacted region in palisade cell walls (outer cell layer) of the seedcoat. The upper part of palisade cell walls of hard seeded legumes, including "wild" soybeans, have a very

compacted region that reflects light more strongly than the rest of the cell wall. A strong expression of this "light line" is associated with impermeable seedcoats. The light line is not prominent in cultivated soybean varieties (Carlson 1973).

A genetic tendency towards hard seed has some advantages and some potential disadvantages. Potential disadvantages are that slightly higher soil moisture may be required for rapid germination, and occasionally seeds may imbibe water too slowly. Advantages are that mature unharvested seeds absorb less moisture from light rains or heavy dews. Thus, mature unharvested seeds that tend to have hard coats undergo less swelling and shrinking. The swelling and shrinking reduces quality and viability by causing internal mechanical damage and increasing respiration. Further, stored seeds that tend to have hard coats respond less to fluctuations in atmospheric humidity. High moisture content of stored seed or changes in seed moisture increase respiration and reduce viability.

When soil moisture, soil temperature, and planting depth are optimum, soybean seedlings emerge four to five days after seeds are planted. Excessive soil moisture hinders germination. However, in order to germinate, soybean seeds must imbibe more water, relative to their weight, than seeds of most other crop species. In one study summarized by Howell (1963), a moisture content of about 50 percent was required for germination of soybean seeds; whereas corn, rice, and sugar beet seeds germinated at 30, 26, and 31 percent moisture, respectively.

Optimum soil temperature for germination is between 25 and 35°C. Soybean seeds did not germinate at temperatures above 42°C in one study (Howell, 1963) and at 40°C in another (Hatfield and Egli, 1974). However, the ability of seeds to germinate at high temperatures may vary with genotype and seed quality. Optimum planting depth is between 2 and a half and five centimeters, and depends on soil type, soil moisture, and other factors.

The sequence of events from planting in a favourable medium to seedling emergence follows the following general pattern. Seeds imbibe water rapidly over their entire surface. Seed weight doubles within a few hours, and seeds become kidney shaped. The radicle extends downwards through a break in the seedcoat in one to two days. In three to four days the hypocotyl arch or "crook" extends upward to near the soil surface (Fig. 3.2). During this time the cotyledons remain near their original position. Then, the hypocotyl arch straightens, lifting the cotyledons above the soil surface. The seedcoat usually remains in the soil.

The cotyledonary leaves become green almost immediately after they are exposed to light. They carry on some photosynthesis, but they are primarily food storage organs. They supply nutrients to the young seedling until other leaves are formed and the root system is established. When food reserves are depleted, the cotyledons turn yellow and drop.

3.3 Stem.

The small plumule is elevated above the soil surface with the cotyledons. It is between the two cotyledons, and probably is protected by them. Stem and leaf tissue are formed from further growth and development of the plumule.

The two primary (unifoliolate) leaves, which are well differentiated in mature seed, expand at the second node. Only one leaf forms at the third node, and it is trifoliolate as are all subsequent leaves. The time between the initiation of any one trifoliolate leaf and the next on the opposite side of the stem apex is about two days.

The number of nodes and internodes that ultimately make up the main stem depends on the reaction of the genotype to the photoperiod in which it is grown and whether the growth type is determinate or indeterminate.

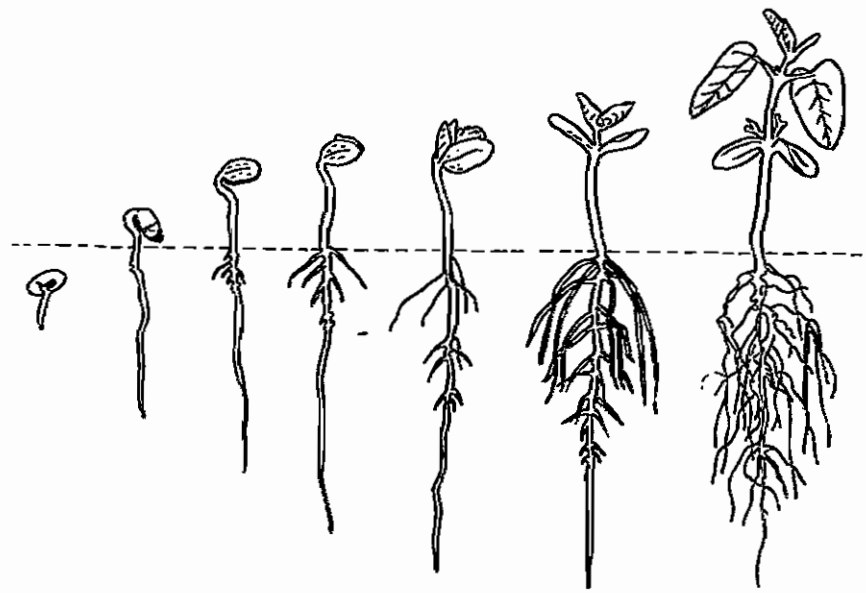


Fig. 3.2: Stages in germination and early seedling growth. Dotted line indicates soil level. (Modified from Carlson, 1973).

When determinate genotypes that are adapted to long days are grown in short photoperiods, plants may form as few as six nodes and stem lengths may be as short as 15cm. When indeterminate genotypes that are adapted to short days are grown in long photoperiods, plants tend to be viny and stems may be as long as four meters.

Stems of determinate plants stop growing about the time flowering starts. Stems of indeterminate plants continue growth throughout much of the seed development period and usually about double their length after flowering starts. Stem diameter becomes progressively less and is very small near the tip, whereas stems of determinate plants differ much lessin diameter near the base and near the tip (Fig. 3.3).

In the U.S.A. primarily indeterminate varieties are grown above about 36°latitude, and determinate varieties are grown at lower latitudes. This association of growth type with latitude provides each major production area with the plant type that researchers and farmers in the two areas now consider most desirable for efficient management and high productivity. A similar association of growth type with latitude may be best for mechanized production at similar latitudes outside the U.S.A. However, management techniques determine the ease with which each growth type can be managed, and they also influence relative productivity.

The growth type best suited to most tropical and subtropical locations has not been determined. It is likely that determinate varieties will perform best where long growing seasons are used.

However, many factors other than growth type influence relative performance. Plant breeders should develop and test varieties that have both growth types. It appears that they should develop determinate types that require a relatively long period from emergence to flowering for regions where soil fertility is low and the growing season is long.

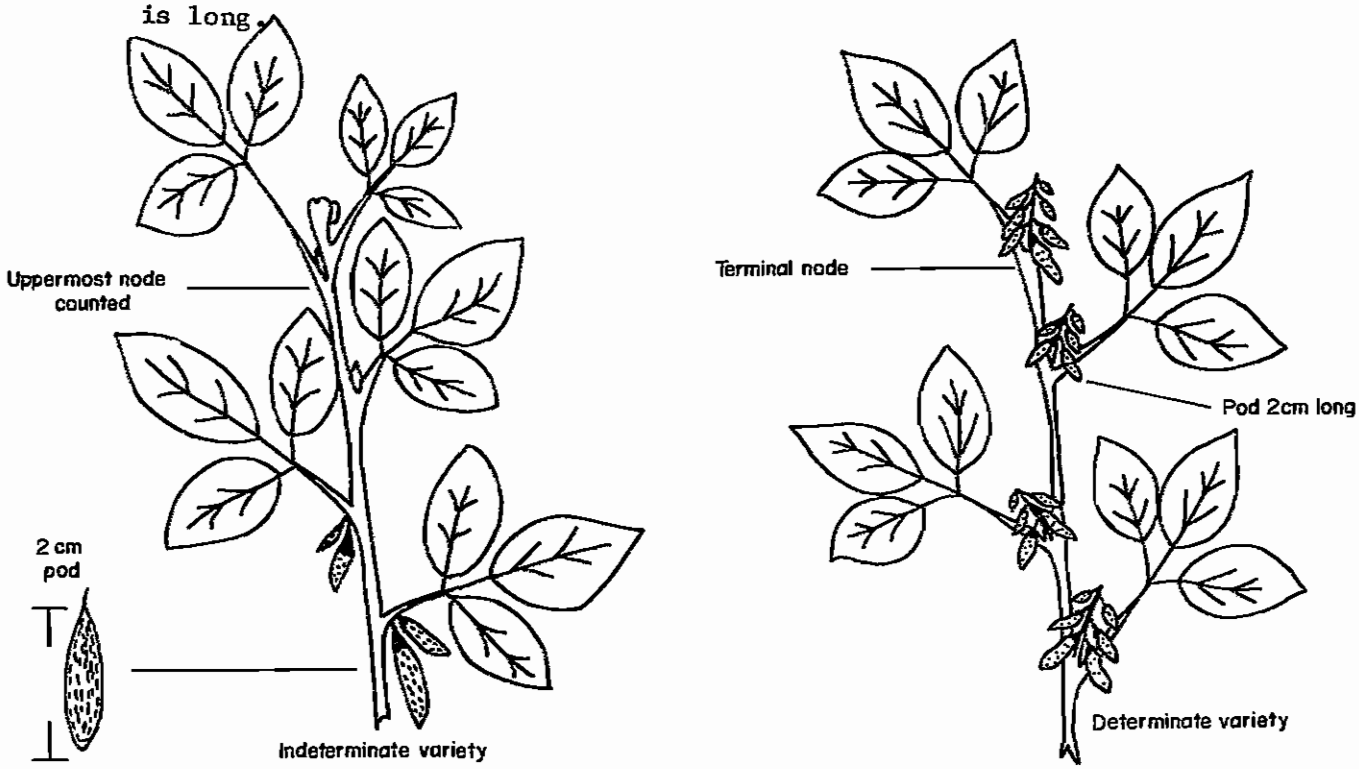


Fig. 3.3: Digramatic presentation of an indeterminate and determinate soybean plant. (Modified from Fehr and Caviness, 1977)

3.4. Leaves, branches, and flowers.

Nearly all leaves above the second (unifoliolate) node are trifoliolate, but occasional leaves have four or five leaflets (Fig. 3.4). Leaflet shape ranges from oval to lanceolate, and is controlled genetically. For practical purposes, the various leaflet shapes can be classed as "broad" or "narrow".

Nearly all commercial varieties have broad leaflets. In most production environments, varieties that have broad leaflets yield more, apparently because they intercept more sunlight. Narrow leaflets permit sunlight to penetrate deeper into the plant canopy. Deeper light penetration appeals to some researchers, because of theoretical considerations.

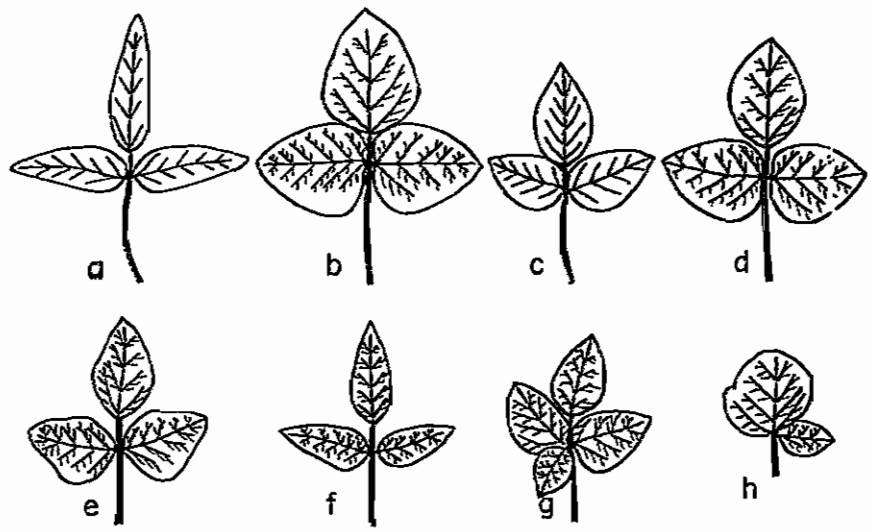


Fig. 3.4: Leaves of soybean plant (a) Lanceolate leaf; (b) and (c) Ovoide leaf; (d) Oval leaf; ;(e) Rhomboid leaf; (f) Rhomboid-Lanceolate; (g) Leaf with four leaflets; (h) Fused leaflets. (Modified from Carlson, 1973).

Leaf axils contain axillary buds. Nearly all axillary buds on the upper part of the stem develop into flowering structures. Lower axillary buds may produce late flowers, or remain undeveloped. Axillary buds have their own axillary buds in various stages of development. When these secondary buds develop, most of them form flowers, but some lower ones form additional branches.

Good growing conditions and low-density plant populations favour early branch development from axillary buds on the lower stem. Branches are morphologically similar to the main stem.

Flowering structures vary from compact clusters to spaced flowers on long recemes. In some cases only two secondary axillary buds develop at a node to form one pair of flowers. Flowers on most determinate varieties grown in the U.S.A. are borne on rather long racemes, and flowers on indeterminate varieties tend to be more clustered.

Soybean flowers are structurally similar to those of beans, peas and other species within the subfamily *Papilionoidaea*. The soybean flower has a tubular calyx, a five-parted corolla, ten stamens (nine fused and one separate), and one ovary, usually two to five ovules. The stamens surround the pistil. Patals extend beyond the sepals the afternoon before flower parts are completely expanded, thus there is little opportunity for natural cross pollination (Fig. 3.5).

Flowers may be purple, white, or white with purple throat. The small flower parts make artificial cross pollination rather tedious, but an experienced technician has no difficulty in making enough crosses for breeding programmes.

3.5 Roots.

The radicle, which is present in mature seed, begins to extend downward during the first or second day of germination. It is the beginning of the root system and forms the taproot. Four rows of secondary roots arise from the taproot and several orders of branch roots arise from secondary roots. Adventitious roots emerge from the lower part of the hypocotyl.

The taproot may reach a depth of two metres. However, under some field conditions taproots do not extend below the tilled layer. Thus, soybean plants probably are best described as being weakly taprooted.

Root development patterns are influenced by fertilizer application methods, tillage methods, soil texture, physical and chemical properties of the subsoil, and other factors. Fertilizer application methods include band vs. broadcast applications or shallow vs. deep placement.

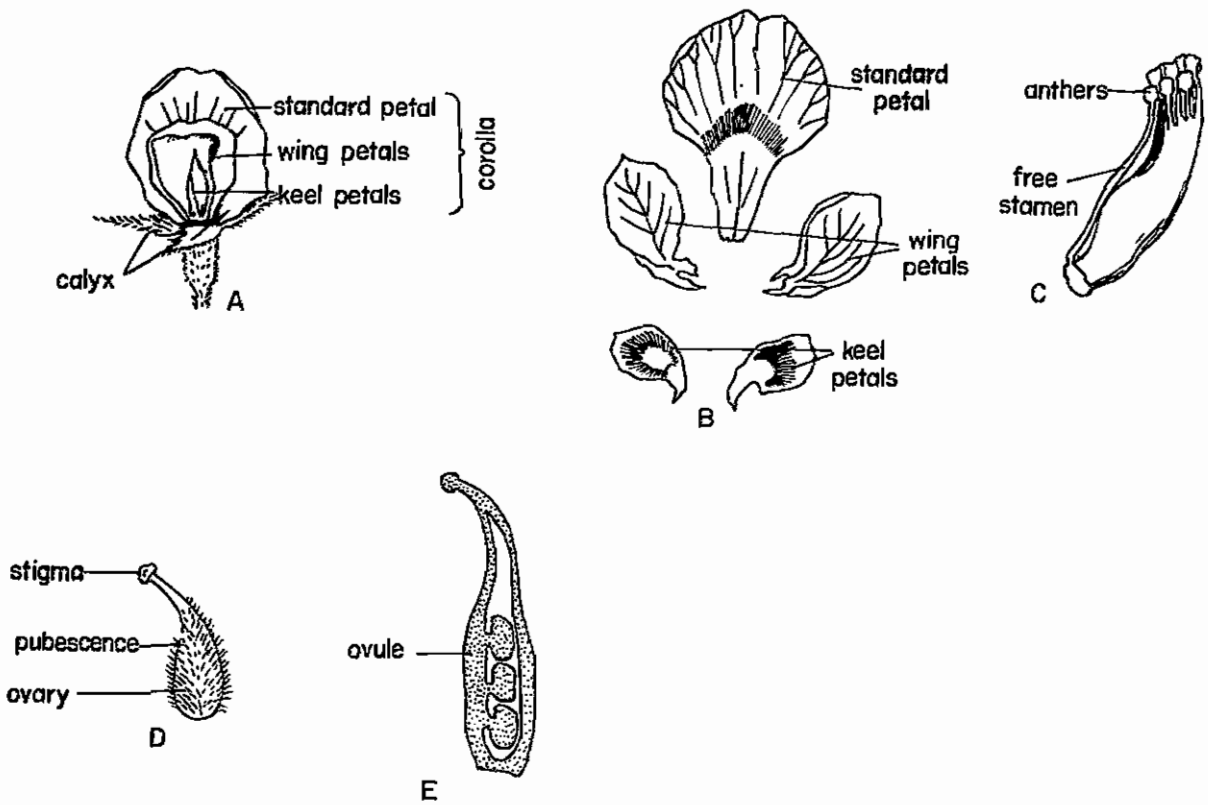


Fig. 3.5: Flower of soybean (A) Single open flower showing the corolla and calyx, (B) Corolla dismembered to show the standard, two wing, and two keel petals, (C) Nine stamens develop in a tube around the pistil. One stamen remains free (D) Pistil covered with small hairs, (E) Section through the pistil of a mature flower showing three ovules (Adapted from Poehlman, 1959).

Thus, a relatively shallow, fibrous root system appears to be the rule, particularly where a compacted layer is present and where chemical properties of the subsoil are unfavourable for root development.

Root hairs first appear near the tip of the primary root about four days after germination. As the root system branches and extends through the soil, root hairs develop on other young roots. All epidermal cells probably are capable of forming root hairs. Root hairs greatly increase the absorbing surface of roots. Some are lost when secondary growth causes epidermal cells to slough off.

3.6 Nodules.

Nodules develop on roots following a series of interactions between nodulating bacteria (*Rhizobium japonicum*) and the soybean plant. Nodule initiation can occur as soon as root hairs develop on primary or secondary roots. Small nodules may be observed within ten days after seeds are planted.

The entire infection process in the soybean is not as well documented as it is for some other legumes. Apparently, roots secrete substances that cause nodulating bacteria to multiply rapidly. The bacteria in turn secrete substances that directly or indirectly result in softened cell walls. Then the flagellated bacterial cells enter epidermal cells through the softened areas. Root hairs probably are the most frequent point of entry. However,, in the soybean, bacteria apparently infect epidermal cells that do not have root hairs or they may invade through cracks in epidermal cells.

Most infections do not induce nodule formation. Bacterial cells that induce nodule formation move two to five cell layers into the cortex through infection threads formed by host cells. Bacteria eventually reach cortical cells that are (or become) nodule primordium cells; then they multiply rapidly. Nodule primordium cells and the surrounding noninfected cells divide, differentiate, and grow to form the exterior nodule. In the process, xylem and phloem elements of nodules become continuous with those of the roots.

Nodules with pink centres (form the presence of leghemoglobin) are considered active in symbiotic nitrogen fixation. Those with green centres are considered inactive. Many factors influence the length of time each nodule remains active. Nodules are not formed uniformly, and they do not degenerate uniformly unless the soil becomes waterlogged or some other environmental factor destroys them.

3.6.1 Varietal difference in strain recognition

Recent research at IITA and elsewhere has revealed that a few soybean varieties have the capacity to nodulate with a wider range of rhizobia including many strains of the cowpea cross-inoculant group. These varieties can nodulate with the bacteria that already exist in the soil. This characteristic has been called 'Promiscuous nodulation' and new, high-yielding varieties are being developed that can be grown by farmers without application of rhizobium inoculants.

3.7 Genetic traits of agronomic importance.

Several genetic traits are important in the production, management, or use of the soybean. Many are simply inherited. Other important genetic traits are:

3.7.1 Pubescence type.

The leaves, stems, and pods of most soybeans are covered with fine hairs or pubescence. The normal pubescence is round and hair-like, but may vary in erectness or density. Dense pubescent types have three to four times as many hairs as the normal types. Sparse pubescent types have one-fourth the number of hairs as normal types. Pubescence on most of the commonly grown varieties is nearly erect, but types exist which have appressed pubescence. Curly pubescent types have flat, wool-like pubescence. They become dry and brittle at maturity and shed easily. In addition, there are types which have no pubescence. These are termed glabrous. The hairs are either brown or silver. Leaf pubescence conditions resistance to leaf hopper damage. Glaborous varieties are susceptible.

3.7.2 Seed holding.

Environmental conditions at time of maturity influence pod dehiscence. A considerable range exists among available varieties and strains in their ability to hold seed after they reach maturity. Many types will shatter before the seeds reach 13 percent moisture. Some varieties will hold seed for at least six weeks after reaching 13 percent moisture. Seed holding is of greater economic importance where large land areas are harvested by machines than where the crop is harvested with hand labour. Shattering resistance appears to be quantitatively inherited.

3.7.3 Seed color.

Soybean seeds can vary greatly in seed color. The most commonly observed colors are yellow and black. The yellow seeded types can be used for nearly all processing proceedures while black seeds have a slightly more limited utilization. Black pigments or other compounds produced in the pigment synthesis may provide some benefit in seed storability. However, not all black seeded varieties store well.

3.7.4 Seed storability.

Most of the large seeded varieties introduced from the USA do not store well when kept in humid tropical environments. Seed deterioration is greatly accelerated by high temperatures and high relative humidity. Poor stand establishment is a common problem in the tropics. Some varieties from Indonesia were identified at IITA to have superior seed keeping quality and improved varieties are being developed that store better than materials from the USA.

3.7.5 Seed size.

While most varieties grown in the U.S. range in 100-seed weight from 12 to 18g, a wider range is available. Hartwig and Edwards (1970) transferred several genetic seed sizes to a common background (by backcrossing), to study the effect of seed size on yield. In types which had 100-seed weights of 9, 14, and 25g, no differences in seed yield were measured. However, the small seed required less moisture for germination (Edwards and Hartwig, 1971). In general large seeds are more readily damaged by mechanical handling.

Small seeds are associated with high protein and lower oil, more seed coat.

3.7.6 Leaf shape and seeds per pod.

Most commonly grown soybean varieties have ovoid leaves and produce pods having two or three seeds per pod. Narrow or lanceolate leafed types produce pods having three or four-seeded pods. Oval leafed types produce pods having one or two-seeded pod. The variety Lee averages 2.6 seeds per pod. Hartwig and Edwards (1970) transferred the narrow (3.6 seeds per pod) and oval (1.6 seeds per pod) leaf character to a Lee background and were unable to measure any differences in seed yield.

3.7.7 Time of Maturity.

Garner and Allard (1920) recognized the significance of length of day in determining the flowering behaviour of soybeans and termed the response "photoperiodism". As interest in soybeans in the U.S. developed, it became evident that days to maturity was not adequate for describing the various types planted. Neither was it adequate to describe types as early or late, because a type may be early at 33^{o} latitude and very late at 40^{o} latitude. Because of the rather precise response to latitude, a system of classifying varieties according to maturity groups was developed. Groups 00, 0 and 1 are adapted to the longer day regions of the U.S. and Canada, and higher numbered groups are adapted further south. Varieties classified as Group VIII are the latest grown in the continental U.S. Introductions are available which flower and mature later than Group VIII varieties; they are classed in Maturity Groups IX and X.

A maturity range of ten to 15 days normally occurs within a maturity group. A standard variety is usually used as a basis for comparisons within a maturity group, and other varieties within the group are rated according to the number of days earlier or later than the standard variety.

3.7.8 Chemical composition of seed.

Soybean seeds contain protein and oil. These components have high negative correlations with each other. Environmental conditions influence chemical composition to some extent, but varieties may be classified as high protein-low oil or high oil-low protein.

3.7.9 Lodging resistance.

If the plants fall to the ground (lodge) before pod-filling, yields can be greatly reduced. Varieties should be selected for strong, rigid stems and good root systems. Late-maturing, indeterminate varieties are often prone to lodging when grown on fields with high soil fertility. Varieties from Zimbabwe such as 'Sable' have excellent resistance to lodging.

3.7.10 Uniform pod maturation.

It is important that all pods mature at nearly the same time otherwise pods that mature early will suffer from field weathering or shattering. Determinate varieties are generally better than indeterminate varieties for uniformity of pod set under tropical conditions.

3.7.11 Height.

If varieties are selected that are too short difficulties occur at harvest time, especially if plants are to be harvested mechanically. Short plants often have pods set very close to the ground and rain splash can cause losses in seed quality. Plants that are too tall often lodge.

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CHAPTER FOUR

SOYBEAN PHYSIOLOGY

4.1 Germination and seedling establishment.

The radicle is the first part of the embryo to penetrate the seed-coat. It develops rapidly into a root which must become firmly anchored for the seedling to develop enough leverage to force its way to the soil surface.

Lateral roots are formed soon after the radicle begins to elongate. And often within four or five days after planting, root hairs appear on the laterals. Hairs are very small and short lived, and might be described as tubular extensions of single epidermal cells. They are formed in the actively growing part of the root just behind the growing point.

The taproot of the soybean plant is less pronounced than the tap-root of some other legumes, such as alfalfa. Soybean roots branch and re-branch, and within five to six weeks after planting, they generally reach the center of the conventionally spaced row. By the end of the growing season the roots will penetrate to a depth of 150cm or more in a well-drained, good soil. However, the bulk of the roots will be found in the upper 30cm of soil, with a surprisingly extensive growth in the topmost 15cm.

Most of the soybean plant's nitrogen requirements are supplied by nitrogen-fixing bacteria which live in nodules on its roots. The first nodules appear within a week after seedling emergence. Ten to 14 days later, the nodule bacteria are able to supply the plant's full nitrogen requirements. Active nodules have an internal pink color, and new nodules are formed during most of the life of the plant.

After the radicle emerges, the hypocotyl begins to elongate. It forms an arch which is pushed upward through the soil. As the arch breaks the soil surface, it pulls the cotyledons and epicotyl upward. The uppermost cells of the hypocotyl stop growing as cells on its underside continue to grow until the arch is straightened. This process lifts the cotyledons into an upright position.

The epicotyl is exposed to the sunlight when the cotyledons assume a more or less horizontal position. At this stage, the plant is prepared for growth from the shoot tip.

The first three leaves begin expanding from the epicotyl by the time the cotyledons and epicotyl reach the soil surface. These unfold and develop rapidly following exposure to the sunlight. The first two leaves are unifoliate (only one leaf blade), They are opposite each other and located at the same node. The next leaf and all those that follow are trifoliate (three leaf blades). The trifoliate leaves are located only one at a node and are alternate in position on the stem.

Soon after exposure to sunlight the cotyledons and other plant parts develop chlorophyll and turn green. However, the food stored in the cotyledons remains the main source of nourishment for about a week after emergence. The cotyledons drop after the seedling is capable of supporting itself. Some photosynthesis occurs in the cotyledons, but this contributes very little to the needs of the seedling.

A good supply of soil moisture during the germination period is

critically important. The seed must reach a moisture content of 50 percent before the germination process starts. A corn seed, on the other hand, must absorb only 30 percent of its weight in water before germination begins. Because the hypocotyl arch is easily broken when pushed against a solid crust, soil crusting is a serious threat to the germinating soybean, because if the cotyledon cannot emerge the hypocotyl swells and breaks.

After emergence, the seedling is tough to kill. This is surprising when it is considered that the meristem (main growing point) is above the soil surface in contrast to that of corn, which is protected underground until the plant is about knee high.

4.2 Vegetative period.

Most crop plants have two major growth states - the vegetative stage and the flowering or reproductive stage. In the case of the soybean plant, the period between emergence and the appearance of the first flower - usually six to eight weeks - is the vegetative period. The ultimate size of the plant and the total number of flower positions largely depend on its length and the environmental conditions prevailing during this period.

The soybean plant is photoperiod sensitive, which means that it makes the transition from vegetative to flowering stages in direct response to day length. The key to its flowering mechanism is the length of darkness during a 24-hour period.

The size attained by a soybean plant before flowering depends on the variety and the environment. The amount of vegetative growth occurring

after the initiation of flowering depends not only on environmental factors but also the growth habit. Some varieties are indeterminate in growth habit, while some others are determinate. Indeterminate varieties may increase their height by two to four times after flowering begins. Determinate varieties increase their height very little, if at all, after flowering.

4.3 Flowering period.

Flowers are produced where leaf petioles join the main stem or branches of the main stem. The junction of these plant parts is an axil. The flower branch originating at the axil is called a raceme.

The number of flowers that may be produced in a single leaf axil varies greatly among varieties and between locations on the plant. Environmental factors such as temperature and moisture supply during the flowering period also affect the number of flowers on each raceme. The flowering period is relatively long for soybeans. There are reports of as much as six weeks between the appearance of the first and the last flowers. Three to four weeks is considered normal for most varieties.

Flowering characteristics of determinate and indeterminate plants are somewhat different. An indeterminate plant usually blooms first at the fourth or fifth node. Flowering progresses upward. Many new leaves and leaf axils are developed after the first flowers appear on this type of plant. Pods are formed near the base of the plant before the last flower appears at the top. A determinate plant starts blooming at the eight or tenth node. Flowering progresses both downward and upward from this point.

Since all, or nearly all, of the axillary buds are in existence when the first flower appears, the progression of flowering from the bottom to the top of the plant is rapid. On this type of plant the racemes terminating the main stem and its branches are frequently quite long. These commonly produce more flowers than racemes located elsewhere on the plant. The plant blooms for a prolonged period because flowering progresses relatively slowly from the base to the tip of each raceme. Frequently terminal flowers and pods of a raceme abort.

The soybean flower is only six to seven millimeters in length. It is self-pollinated (the pollen produced within a flower fertilizes the ovary of the same flower). The soybean plant does not form a pod for each flower it sets. Up to 75 percent of the flowers produced by a plant may fall to the ground. The tendency to abort perfectly healthy flowers is a major concern of the soybean scientist. The key reason for, and prevention of this loss are unknown. The plant loses more blossoms during periods of hot, dry weather than under more favourable conditions. However, weather and fertility conditions that might be considered ideal do not prevent blossom drop.

The ability to produce more flowers than pods, and to do this over an extended period of time, makes the soybean less susceptible than some other crops, such as corn, to short periods of adverse weather during flowering

4.4 Pod and seed formation.

There is no sharply defined transition from flowering to the pod and seed-formation stage. Pods, withered flowers, and newly opened buds

may be found at one time on the same plant, often at the same node. This is particularly true of indeterminate varieties. Both flowering and pod set tend to be more intense and more uniform in the determinate types, but there is still some variation on a single plant.

Few pods are set by the earliest flowers. The first pods appear ten days to two weeks after the first flowers appear. Pod set, once started, proceeds at about the same speed as flowering. Under normal conditions it will be essentially complete in three weeks. The rate of pod growth and seed enlargement is relatively slow at first, but picks up rapidly as flowering comes to a halt. Dry matter accumulates in the seed at a relatively rapid and constant rate for the next 30 to 40 days. There is little difference between varieties in the rate of dry matter accumulation. The seed filling period is the most critical time in the life of the soybean plant. Anything that interfers with plant functions during this time can reduce yield. For example, if a hailstorm causes a 100 percent leaf loss when the beans are beginning to fill, there can be more than an 80 percent reduction in yield. While the maximum number and size of seed is controlled genetically, the actual number and size produced is largely determined by conditions prevailing during the seed filling period. Moisture stress is especially serious. Dry weather during seed filling will not only reduce seed size, but may also reduce the number of seed per pod. If the stress is serious, small pods may even abort. Adequate moisture during the seed filling period may completely overcome the effects of moisture stress during the flowering period.

The plant actively accumulates nutrients from the soil during most of the pod and seed formation period. The plant draws about 30 percent of its potassium and 40 percent of its phosphorus and nitrogen from the soil after the seed filling stage begins. In contrast, corn at the same stage has satisfied all of its potassium needs and 70 percent of its phosphorus and nitrogen requirements.

4.5 Maturity.

A newly formed soybean seed contains nearly 90 percent moisture. Early in the bean filling period, and again as the bean matures, the moisture content declines rapidly. The initial reduction takes the moisture content to 65 to 70 percent. From this point moisture content decreases slowly to 60 to 65 percent, while the seed accumulated dry matter and grows in size. As dry matter accumulation is concluded, moisture content declines to 10 to 15 percent in a matter of one to two weeks. This sharp, rapid drop in moisture can sometimes cause the crop to become too dry for optimum harvesting, and results in heavy shattering loss shortly before, or at, combining.

The seeds continue to accumulate dry matter after the leaves of the plant begin to loose their green pigment and turn yellow. The seed crop finally reaches its maximum dry weight when all the leaves are yellow and half of them have fallen from the plant.

4.6 Water requirements.

Water is often the primary limiting factor in soybean production and is therefore an important management concern. In areas of low rainfall,

irrigation may be a necessary and often profitable practice. Growth of the soybean from germination to maturity is, in general, proportional to the available moisture supply. The period of germination is critical for soybean; at this time, excess moisture or prolonged drought may be injurious. A moisture content of 50 percent is required for germination of soybean seed.

The long flowering period and extensive root system of soybean enables the plant to escape or survive short periods of drought stress. Failure due to water stress, of early flowers to set pods may be compensated for by excellent pod set of late flowers if moisture becomes available. A shortage of moisture during the pod-filling stage reduces yields more than during earlier stages, including the flowering stage. A moisture deficit for two to four weeks immediately after flower-bud differentiation reduces growth and causes heavy flower and pod dropping. Nevertheless, deficiency of soil moisture between germination and flowering retards vegetative growth; irrigation before flowering may increase yields if rainfall is deficient. Irrigation at different times during the flowering period may result in differences in yield.

Under conditions of optimum soil moisture, the difference in yield among varieties is largely relative to the difference in yield produced under dificient moisture conditions. Some varietal differences to drought exist. In addition to having the ability to withstand short periods of

drought, soybeans can tolerate short periods of waterlogged soils relatively better than maize and cowpea. Nevertheless, short periods of excessive moisture after the period of bud differentiation will result in very poor yields.

In the bimodal rainfall region of West Africa, soybeans generally produce higher yields but poorer seed quality in the first season than in the second season (Nangju, 1977). The second season is short and unreliable unless supplemental irrigation is available. In monomodal rainfall regions medium and long duration varieties are more suitable than short duration variaties.

4.7.1 Water stress and photosynthesis.

Boyer (1970) has shown how moisture stress markedly influences leaf enlargement and rate of photosynthesis. At soil tensions higher than 4 bars, leaf enlargement declined rapidly and approached zero at 12 bars, as did photosynthesis. Plant water deficits probably decrease assimilation of carbon dioxide as well. However, while rewatering results in a rapid recovery of plant water content, CO_2 assimilation recovers slowly. This slow recovery of assimilation suggests that under field conditions the relief of high internal water stress following irrigation may not result in immediate resumption of maximum photosynthetic activity (Pallas *et al.*, 1967).

4.7.2 Water stress and nitrogen fixation

Perhaps no physiological process affecting soybean yield is more sensitive to moisture stress than is N fixation. Spent (1972) studied the

effects of water stress on nitrogen-fixing root nodules and the effects on whole plants of *Vicia faba* L. and *Glycine max* (L.) Merrill. Slow, natural drying of the soil over a 6-week period resulted in progressive reduction in N-fixing activity. Irrigation restored activity, and maximum N fixation occurred at about field capacity; above that level, activity was reduced because of water logging. It was suggested that water stress affected nodule activity directly, but the effect might be aggravated by reduced supplies of photosynthate from wilted leaves.

In an experiment designed to evaluate the effect of soil temperature and soil water stress on the ability of soybeans to fix nitrogen, Kuo and Boersma (1971) showed that both parameters are important and do not work independently of one another. Activity of nodule bacteria was very sensitive to water tension and root temperature. Relative rate of nitrogen fixation of 3-week-old soybean plants relative to soil temperature and soil water tension is presented in Table 4.1.

Table 4.1: Effect of soil moisture and temperature on relative N fixation in soybeans.

Soil temperature (°C)	Relative rate of nitrogen fixation at different values of soil water suction (bars)			
	0.35	0.70	1.50	2.50
10.0	43.2	30.7	17.0	13.1
23.9	100.0	83.5	76.1	58.5
32.2	88.1	76.1	72.7	55.7

Rates of nitrogen fixation decrease with increase in water suction, particularly at lower temperatures. It is interesting to note that the relatively large decrease in nodule N fixation occurred long before the soil tension approached wilting point. The nitrogen content of the 3-week-old soybean plant also decreased as the soil tension increased from 0.35 to 2.50 bars.

Sinclair and de Wit (1975) have studies the mobilization and transfer of nitrogen from soybean leaves during seed formation. The pool of nitrogen and protein in vegetative tissues eventually loses physiological activity as the nitrogen levels decrease. They hypothesize that the plant becomes self-destructive, leaves drop, and photosynthates to fuel the nitrogen fixation process disappear. The period of seed development depends on a readily available nitrogen supply to offset the self-destructive process. This N supply is terminated as N fixation is depressed during periods of soil moisture stress. Other scientists believe that such senescence events are primarily under hormonal control.

4.8 Light requirements.

The light saturation curve of soybean photosynthesis has been determined by a number of researchers. For canopies it was reported as 5.918×10^4 lux to 6.994×10^4 lux. Two peaks of photosynthesis activity occur during the growing season, one at the time of flowering and the other at the time of pod filling. Varietal differences as large as 100 percent occur in soybean photosynthesis.

It has been shown that high-yielding varieties tend to have high leaf photosynthesis rates. Seed yield is not always correlated with dry matter production, indicating that a stimulation of the conversion of photosynthate to seed instead of vegetative growth would be agronomically useful.

Since soybean flowers in the field only when the days are shortened below a critical value for a particular variety, it is called a short-day plant. This photoperiodic response is an important factor in soybean production. Soybean will remain vegetative almost indefinitely if the days are long enough, and some varieties will flower in less than a month if the days are short. One well-known example of photoperiodic effect on soybean is the delay in date of blooming and maturity of soybean as it is moved north in the northern hemisphere. This delay in maturity illustrates why soybean is said to be adapted to rather narrow belts of latitude. Some varieties have been identified that are relatively insensitive to photoperiod. This has been recognized by agronomists as the principal factor in determining the area of adaptation and time of maturity of varieties. Responses to day-length are modified by temperature which, during the dark period, is more important than that during the light period.

The soybean is a short-day plant, but there is considerable genetic variation for sensitivity to photoperiod. The critical day length for flowering ranges from about 13 hours for genotypes adapted to tropical latitudes to 24 hours for photoperiod-insensitive genotypes grown at

higher latitudes (Fehr, 1980). Flowering of soybeans seems to be insensitive to day length for 9 days after emergence (Fehr, 1980). Photoperiods shorter than the critical day length are required for 7 to 26 days to complete flower induction.

Sensitivity to day length is an important consideration when genotypes are grown outside of their area of adaptation. When genotypes adapted to tropical latitudes are grown in the field at higher latitudes, they may not mature before frost occurs. They can be induced to flower and mature earlier by creating artificially short days or by grafting.

When varieties adapted to temperate regions are grown in the tropics the short day lengths and warm temperatures encourage early flowering and seed maturation, and genotypes can produce a seed crop in 90 days or fewer after planting.

Temperature can also play a significant role in the flowering and development of soybeans (Major *et al.*, 1975). It can influence the time of flowering and suitability of flowers for hybridization. Temperatures below 21°C or above 32°C can reduce floral initiation or seed set (Hammer, 1969). Artificial hybridization is most successful between 26°C and 32°C because cooler temperatures reduce pollen shed and result in flowers that self-pollinate before they are large enough to manipulate. Warmer temperatures frequently are associated with increased flower abortion caused by moisture stress; However, successful crosses are possible at about 35°C if soil moisture is adequate (Fehr, 1980).

Information from the tropics on the periods from sowing to first

flowering and to maturity, branching habit, mean seed weight, and percent protein on 104 introduced varieties and selections from Uganda land-races has been published by Rubaihayo and Leakey (1970). This work revealed that, for the maturity classification system used for cultivars in the United States, based on the response of genotypes to the changing photoperiod from North to South, does not hold when the same cultivars are grown at Kabanyolo, which is on the equator and at an elevation of approximately 1,219 meters above sea level. Leakey and Rubaihayo (1970) discussed this further and put forward a hypothesis concerning soybean adaptation at the equator that implicates temperature rather more than photoperiodism. Recently it has been shown that night temperatures, in particular, influence the length of the juvenile period and the time to maturity. It would seem likely that this response of a genotype to night temperatures, as well as to photoperiod, will determine its suitability for any given location.

Rubaihayo and Leakey (1970) established that most of the material from the United States and Japan mature in 85 to 100 days, whereas the local selections took rather longer - between 100 and 130 days. Lines introduced from low elevation areas in Tanzania required much more than 130 days to complete their growth and were deemed unsuitable for Uganda, as their growth period would exceed the length of the biennial rainy seasons in most years.

4.9 Temperature requirements.

The effects of temperature on soybeans are noticed right from the germination period, with the optimum temperature being around 30°C. The

rate of growth, the time required for the plants to shade the ground and blooming dates are all affected by temperature. For most growth processes, the optimum minimum temperature is 30°C. High temperatures (over 38°C) early in the season have adverse effects and during seed development are a cause of poor seed quality. Increased pod and flower shedding occur at high temperatures.

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CHAPTER FIVE

LAND PREPARATION AND PLANTING

5.1 Growing season.

In tropical and subtropical regions, growing seasons are determined largely by rainfall patterns rather than by temperature, as they are in the higher latitude temperate regions. The soybean evolved in a temperate region and vegetative growth took place during long days while seed development took place during decreasing day lengths. At subtropical latitudes, changes in day length may be sufficiently large to greatly influence days to flower, days to maturity, and amount of vegetative growth. In such situations soybeans normally perform best if they grow vegetatively when day lengths are longest and develop seed during periods of decreasing day length. However, in many areas, periods of optimum soil moisture do not coincide with optimum photo-periods. Where such conflicts exist and irrigation is not feasible, the period when soil moisture is adequate should be chosen. A growing season with little or no moisture stress for about 120 days usually produces near maximum yield. It is important that soybeans ripen under dry conditions at the end of the rainy season. If for example, the rainy season lasts for 150 days and if the variety matures in 120 days, one would delay planting for 30 to 40 days after the onset of the rainy season. Seed quality is best when the last rain coincides with physiological maturity.

5.2 Varieties.

In tropical and subtropical regions, some effective seasons are less than 110 days and some are more than 130 days.

At locations which have growing seasons of less than 110 days, one should choose a variety that will utilize all of the growing season. A variety that matures near the beginning of the drought-stress period usually produces more than a variety that matures several days before stress occurs. But yield and seed quality are reduced if drought stress causes plants to "dry up" rather than mature normally. For these short season conditions, researchers (or producers) should test varieties that have a range of growth-period requirements to determine which is best adapted to their particular situation.

At locations which have growing seasons of more than 130 days, varieties with long growing seasons should be used, unless soybean production utilizes only a part of the growing season. Plants should mature after rains cease so that seeds can be harvested before they loose viability. Indeterminate plants that require more than 120 days to reach maturity may produce excessive vegetative growth if the soil fertility is good. In most situations, determinate plants that mature in 120 to 130 days produce near optimum vegetative growth.

Disease resistance is another important varietal trait. Some diseases reduce yields drastically. Some others, that detract from the appearance of the foliage, may only reduce yields slightly. In general, foliage diseases that cause leaves to drop prematurely reduce yield more than those that only produce necrotic spots in leaf tissue. One should identify diseases that are capable of causing serious yield reductions and select resistant varieties.

In assessing disease losses, do not overlook root diseases, and take care not to underestimate losses from defoliating foliar diseases.

5.3 Seedbed preparation.

Seedbed preparation or tillage is defined as physical, chemical or biological soil manipulation to optimize conditions for seed germination, emergence and seedling establishment. The short-term objectives of seedbed preparation are: to optimize soil temperature and moisture conditions, to minimize weed competition, to stimulate root system proliferation and development, and to decrease the energy input. The long-term objectives, however, must keep in view maintenance of soil productivity over long periods of time through adequate soil and water conservation, by maintaining soil organic matter content at a high level, and by preserving soil structure and pore stability (Lal, 1979).

In the traditional methods of farming in the tropics, based on bush fallow and related systems of replenishing soil fertility, a wide range of land preparation systems are used in different agro-ecological regions of tropical Africa. After slashing the weeds and bush regrowths farmers commonly use fire to dispose of the excess vegetation and perhaps to supply some nutrient elements. In many regions of West Africa, particularly in the region of Alfisols with gravel layers at shallow depths, farmers plant on small hillocks which are mounds prepared by heaping the surface layer soil to increase effective soil depth (Lal, 1979). In the semi-arid regions, bullock-driven implements are sometimes used for mechanical seedbed preparation. Elsewhere in tropical Africa conventional tillage

operation is normally used and includes ploughing and harrowing one or more times with a disc, a spring tooth harrow, or some similar implement. Where large quantities of plant residues are incorporated, or where the soil breaks up in large aggregates, the initial ploughing should precede planting by several weeks. This will enhance the decay of plant residues, and natural processes will aid in breaking large soil aggregates.

5.4 Zero tillage.

5.4.1 Definition:

Zero tillage is a system of seedbed preparation without primary or secondary cultivation where mechanical soil disturbance and manipulation is limited to seedling and fertilizer placement. A continuous cover of mulch with crop residue or dead weeds is an essential component of this concept.

5.4.2 Relevance to shifting agriculture:

Shifting agriculture is a system of land management under which food is produced by reliance on nature rather than on the use of modern technology to restore soil productivity. According to this system, land is cultivated until the yield can no longer sustain the farm family. The area is then abandoned, temporarily, and another piece of land is cleared for cultivation. Approximately 5 to 6 billion hectares of land in the tropics are cultivated with this system of subsistence farming. With the increasing pressure of population and awareness to improve the standard of living, this system has to be replaced by a viable and stable system of land management. The essential components of soil management in the tropics include: (i) a minimum disturbance of the soil surface,

(ii) continuous ground cover of dead crop residue, (iii) a mechanism for replenishing nitrogen by leguminous cover crops, and (iv) maintenance of soil structure through natural agencies such as earthworms and termites. The zero tillage system of soil management appears to meet most of these requirements (IITA, 1979).

5.4.3 Form of zero tillage:

Though the possibilities of zero tillage are promising, its adaptation to specific soil conditions depends on the soil types, nature of the crop to be grown and financial resources of the farmer. Under shifting cultivation, where farm sizes are less than two hectares, chemical or manual weed control and planting, directly through mulch, is all that is required. For commercial large scale farms, however, the zero tillage concept may be applied with one of the following modifications:

(i) Zero till or no till is a system whereby a crop is planted directly into a seedbed untilled since the harvest of a previous crop. This system is also referred to as sod plant, slot plant or slit plant.

(ii) Till planting is a strip tillage system in which a small strip is cut through the stubble ahead of the surface planters in one operation.

(iii) Minimum tillage is the minimum soil manipulation necessary for crop production under given soil and climatic conditions.

(iv) Stubble mulching or mulch tillage involves soil preparation in such a way that plant residues and other materials are left to cover the soil surface before and after crop establishment.

5.4.4 Historical background.

Zero tillage techniques have been extensively used since the last decade by some farmers in the U.S., U.K. and European countries. Realization of zero tillage became feasible with the availability of herbicides in the 1950's. With the aid of herbicides, a number of researchers worked on a reduced tillage system for corn production in the U.S.A. A no-till plant system was developed in the 1960's for row crops to prevent soil erosion and minimize energy input. Herbicides became an essential input in this system. Because of the serious weed problems with reduced tillage, a satisfactory herbicide should kill existing vegetation and prevent weed germination and establishment without harmful effects on crops. As a result, the total acreage cropped with various forms of zero tillage methods in the U.S. in 1972 reached nearly one million hectares. The acreage of cereals under direct drilling in the U.K. in 1971 was about 4000 hectares. Even though the development of the zero tillage concept took place in temperate regions, those techniques have not been widely adapted because of delayed soil warming under mulch in the spring. This disadvantage, however, is a natural advantage in the tropics where soil temperature can be supra-optimal in the early stages of crop growth. Because soil erosion hazards and drought susceptibility of tropical soils are greater than in temperate regions, zero tillage is more applicable to the tropics. Further reference here to zero tillage will be confined to tropical environments.

5.4.5 Soil conditions under zero tillage and conventional tillage:

(i) Soil structure. Soil structure, the pore size distribution as reflected in the infiltration rate and moisture retention characteristics,

is adversely affected by mechanical manipulation of tropical soils. Zero tillage with mulch stimulates biological activity of earthworms which keep the soil porous and in good physical condition. The activity of earthworms is drastically reduced by soil exposure and lack of surface residue.

On an Alfisol in Nigeria, for example, earthworms produced an equivalent of nine tons of casts per hectare per month as compared to only one ton in the conventionally ploughed plots (Table 5.1). Worm casts are soil particles cemented together and are quite resistant to raindrop impact. The worm channels also facilitate root penetration in the deeper layers. As a result of very high biological activity, soil under zero tillage remains porous with low bulk density and high porosity. The bulk density of surface soil, 40 days after seeding, under zero tillage was 1.3 g/cm^3 as compared to 1.4 g/cm^3 with conventional seedbed preparation.

Table 5.1: Effects of tillage treatments on earthworm activity under different crop rotations as measured 70 days after planting during the first season 1973 (After Lal, R. 1976).

	Number of casts/m^2		Equivalent weight metric tons/ha	
Cropping sequence	Not ploughed	Ploughed	Not ploughed	Ploughed
Maize - Maize	1,060	90	41.34	3.51
Maize - Cowpeas	1,220	372	47.58	14.50
Pigeon peas - Maize	464	100	18.09	3.90
Soybeans - Soybeans	42	3	1.64	0.12
Cowpeas - Cowpeas	28	36	1.09	1.40
Average	563	120	21.96	4.68

(ii) Infiltration rate. As a result of good soil structure with high porosity and minimal crustation, the infiltration rate of soil with zero tillage can be maintained at a very high rate. For example, four year after forest clearing in Nigeria, the infiltration rate of soil with zero tillage

declined from 315 to 1.1 cm min^{-1} and 3.5 to less than 0.1 cm min^{-1} for a ploughed bare ground surface. The zero tillage treatments without adequate crop residue will have a serious decline in the infiltration rate since the protective effects on the soil surface by mulch will be negligible. The infiltration rate of zero tillage plots without mulch was 0.5 cm min^{-1} as compared with that of 0.8 cm min^{-1} for zero tillage with mulch.

(iii) Soil erosion. Because zero tillage prevents soil erosion, conventional control measures are usually not required. The high infiltration rate, better soil structure and pore space relationship minimizes runoff and soil loss with zero tillage. Mechanical cultivation of soil reduces the water stability of aggregates through puddling and sealing of the surface, thereby lessening the infiltration capacity and increasing runoff. The runoff and erosion loss from conventionallly ploughed and zero till soybeans at various slopes is shown in Table 5.2. Soil loss from zero tillage was negligible even on a 15 percent slope. Mean soil loss from ploughed plots was 2000 times greater than that from zero till soybeans. The runoff from ploughed plots was nine times higher than zero till plots.

Table 5.2: Soil and water loss from zero till and ploughed soybeans (modified from Research and Training activities at IITA, 1979)

Slope	Runoff (% of Rainfall)		Soil loss (kg/ha)	
	Zero till	Ploughed	Zero till	Ploughed
1	0.9	8.8	0.2	40.0
5	2.1	24.5	5.0	620.0
10	2.4	13.6	1.0	7620.0
15	2.4	21.4	1.0	6910.0
Mean	1.9	17.1	1.8	3800.0

The significant implication of the zero till technique for tropical soils thus lies in its ability to prevent erosion on otherwise highly erodible soils.

(iv) Soil moisture regime. Zero till plots are less susceptible to drought than conventionally ploughed land. Soil moisture storage is greater in zero till plots because of minimal water runoff and because of changes in the moisture release characteristics of the soil, and to lesser evaporation losses due to the insulating effect of a mulch layer. Plants grown with a zero till system can, in general, withstand a short dry spell much better than conventionally ploughed unmulched plots. The lesser drought susceptibility of zero till plots may be attributed to differences in the rooting pattern and changes in pore size distribution and hydrological characteristics of the soil.

(v) Soil temperature. Supra-optimal soil temperature conditions in some tropical soils can seriously affect plant growth with an unmulched, conventionally ploughed system of soil management. The optimum soil temperature for maize and soybeans is 25 to 30°C. Soil temperature higher than 35°C can be injurious to crop yield. The maximum soil temperature

measured at 5cm depth with conventional ploughing has been observed as high as 45, 43 and 41°C respectively, under maize, soybeans and cowpeas. The maximum soil temperature under similar conditions with zero till system was 34°C under all of the crops. The soil temperature difference even at 20cm depth can be as much as 4 to 5°C between two tillage systems. In addition to the differences in the absolute maximum soil temperature, there are also phase differences in the propagation of temperature waves. The maxima in the surface layer of zero till plots can be two to three hours later than the conventionally tilled piece of land.

(vi) Nutrient status and availability. The organic matter content of the surface soil is maintained at a higher level with zero tillage techniques than with conventional ploughing. For the surface 0 - 10cm layer, the organic carbon content and total nitrogen in the zero tillage plots five years after forest clearing was 1.30 and 0.103 percent, respectively. Because of the differences in organic matter content due to tillage systems, there can be significant differences in the cartion exchange capacity of the surface soil and the nature of the cations on the exchange complex. There is strong evidence that phosphorus availability is enhanced in the mulched layer of zero till soil. There may, however, be greater nitrogen requirements for zero till system, particularly in the first few seasons of crop growth.

5.4.6 Crop response to zero tillage.

Mulch farming techniques applied to Alfisols in Sri Lanka indicate that cotton yields can be improved by 32%. The plants were, however, less

vigorous in the early stages of growth during wet years. Thick mulch during heavy rains acted as a sponge and cotton seedlings were adversely affected. In Ghana, it was reported that zero till techniques using *Pueraria phaseoloides* as a sod crop produced a satisfactory maize crop. Nigerian experience indicates that maize grown with zero tillage can produce grain yields equivalent to those with conventional ploughing in good season and better yields in seasons with frequent drought stress

(i) Germination and seedling establishments. Under tropical conditions with well drained soil, germination and seedling establishment with a zero tillage system may be better than conventional ploughing, provided seeding is done with equipment capable of planting through crop residue or cover crop. Soybean emergence in zero till plots at IITA was, for example, significantly better than with conventional ploughing, probably because of better soil moisture and temperature regime and lack of surface crust formation. The time required for soybean emergence in conventionally ploughed plots was longer. No difficulties have been experienced with seedling establishment of maize, soybean, cowpeas, pigeon-peas and cassava with zero till techniques.

(ii) Root growth. Restricted root growth in zero till plots during the seedling stage could be related to the compacted surface layer, the inadequate amount of c rop residue mulch, or to excessive wetness. Experiments conducted on Alfisols in Nigeria indicate that although root growth and development is restricted in the seedling stage, root proliferation

in zero tillage plots is superior in terms of depth of penetration at later stages of growth. Thus, the superior yield potential of a zero till system during drought stress is attributed to a deeper root system.

(iii) Plant growth and yield. Crop response to tillage systems depends on various factors such as soil type and climatic conditions. If the initial soil conditions are favourable, zero tillage can provide a yield equal to that with conventional tillage. Under adverse conditions such as drought, zero tillage may actually outyield conventional ploughing.

Even though the initial crop growth under zero tillage is sometimes suppressed, it usually improves during the later stages of porosity. The annual grain yield obtained with zero tillage at IITA in 1973 was, for example, 27% higher for maize-maize rotation, 59% higher for maize-cowpea, 3% higher for pegion-peas-maize, 22% lower for soybean-soybean and 27% higher for cowpea-cowpea rotation than with conventional ploughing. The maize yield record with zero tillage has shown higher yields in three out of four years.

(iv) Weed competition. Weeds can be a serious problem with zero tillage, particularly for the first year or two. However, if carefully controlled in the initial stages of land development, weeds under zero tillage may be less of a problem than with conventional ploughing. A thick mulch layer in zero tillage helps suppress weed growth. Rhizomatus weeds such as *Imperata cylindrica* and *Talinum triangulare* may pose a more serious problem with zero tillage than with ploughed plots.

Systematic herbicides can help eradicate such weeds. Weeds of graminae family have been observed to be more prevalent in conventionally ploughed land. With time, some weeds resistant to herbicides, may dominate the zero till plots. Adequate crop rotation may help solve this problem.

(v) Insects, pests and disease. The incidence of insects, pests and disease depends on many factors. Limited experiments conducted at IITA indicate that population of parasitic nematodes in maize is five times greater in ploughed plots. Similarly, the insect infestation, i.e. stalk borer damage in maize, has been shown to be much higher with conventional ploughing. The parasitic insects and pests may be greater under mulch, but so will be the population of predators.

6.4.7 Desired improvements.

If soil and water conservation is the objective, as in the humid tropics, zero tillage is one of the most desirable approaches. Under many circumstances, zero tillage is the only possible approach. Presently, however, the zero tillage technique is not perfected as it is still soil and crop specific. Its specificity calls for improvement towards versatility.

5.5 Planting.

Planting dates should be determined by rainfall patterns and photoperiod. Seeds should be planted about three centimeters deep in fine-textured soil and about four centimeters deep in coarse-textured soil. The deeper planting in coarse-textured soil is to help ensure that the soil around the seed does not dry before the primary root begins to absorb water.

When seeds are planted deeper than about four centimeters, seedling emergence is reduced, as illustrated by the data in Table 5.3 (Hinson and Hartwig, 1977).

Table 5.3: Effect of planting depth on seedling emergence on two varieties of soybeans.

Planting depth (cm)	Percentage emergence	
	Bragg variety	Hardee variety
2.5	63	72
5.0	38	55
7.5	27	13
10.0	4	2

Where soil temperatures are high and conditions favour rapid drying of the soil, one should take special precautions in planting. Scudder (1975) measured soil temperatures of 42°C four centimeters below the surface during mid-afternoons. This is near the critical temperature for seed germination and is particularly serious on sandy soils which dry rapidly. If seeds swell then shrink because soil moisture becomes deficient, the high temperatures kill the seed. Lightly compacting moist soil around seeds at planting helps to provide adequate moisture for completing germination and emergence. Also, where soil temperature at seed depth is near the critical level for germination, evaporation of water from the soil surface may reduce soil temperature enough to improve germination. This emphasizes the importance of adequate soil moisture at planting.

Planting seed should be harvested, handled, and stored in ways that will maintain viability. Rough handling of seeds during harvesting or handling causes mechanical damage.

Seeds stored under high temperature, high moisture conditions loose viability very rapidly, from physiological changes and from the growth of organisms in and on the seed. Seedlots should be tested for germination a few days before the intended planting date, even if they have been tested earlier.

Growth of organisms in and on seed can be reduced by treating seeds with fungicides. Nearly all soybean seed produced at low latitudes are likely to contain micro-organisms. For best results, planting seed should be treated soon after they are harvested. However, before seeds are treated one should know that they are viable, because treated seed should not be used as food or feed. Seed treatment with some fungicides are also detrimental to seed-borne *Rhizobium japonicum*. Thiram is generally considered safe.

The first requirement in soybean production is a good stand. This means that one must plant every 3 to 4cm in rows 50 to 70cm apart. One of the major problems in growing soybeans in the humid tropics is seedling emergence. Poor seedling emergence may be due to the fact that soybean seed quickly lose their viability in storage, that the soil surface crusts up easily and it is difficult for the cotyledons to penetrate the surface, that soil temperatures are so high that they inhibit hypocotyl elongation, or that soil moisture is limiting.

The problem of seed germination in Nigeria was studied by Wein (1973) who found that if seeds experienced 42^{o}C temperature even for two hours per day with a base temperature of 30^{o}C, the hypocotyl growth was reduced.

Longer hours at 42°C reduced hypocotyl length by more than 50% (Table 5.4).

Table 5.4: Effect of the deviation of high temperature on the hypocotyl length in soybean and cowpea (Wein, 1973).

Daily period of 42°C temp. (hours)	Kent soybean		280-3 soybean		Prima cowpea	
	Hypocotyl length (mm)	± SD	Hypocotyl length (mm)	± SD	Hypocotyl length (mm)	± SD
0	85	18.6	91	25.2	118	23.7
2	23	7.0	45	17.6	71	13.6
4	17	7.9	28	10.9	62	18.6
6	11	4.6	14	7.2	58	18.2
8	14	4.2	10	2.8	63	13.4

By using a grass mulch, soil temperature, surface crusting and erosion can be reduced and soil moisture conserved, thereby ensuring a better seedling emergence as shown in Table 5.5 (Dadson and Boateng, 1975).

For some varieties application of fresh *Rhizobium japonicum* is essential in most African soils where soybeans have not been successfully grown in the recent past. Because inoculum loses its viability quickly at high temperatures, it should be stored under refrigeration and the seeds treated immediately before planting. Some varieties nodulate with 'cowpea' type Rhyzobia which exists in most African soils even if cowpeas are not grown in the area. If one plants such varieties inoculant application is not imperative.

Table 5.5: Effect of mulching on emergence, growth, and yield of three soybean varieties grown during the major rainy season, Legon, Ghana,1973

Variety	Treatment	Initial stand (plants/m^2 a/)	Days to flower	Plant height at first flower (cm)	Stand at maturity (plants/m^2 a/)	Plant height at maturity (cm)	Days to maturity	Grain Yield (kg/ha) (13% moisture)
Hill	Control	12.9	27.0	23.1	10.0	25.2	90	1,026
	Mulched	19.4	27.0	25.2	15.8	26.6	91	1,914
Kent	Control	3.7	23.8	21.1	2.3	38.6	103	641
	Mulched	8.0	23.3	23.6	5.7	44.6	100	1,334
CES 486	Control	5.8	41.0	36.8	3.9	82.4	120	1,840
	Mulched	11.9	40.8	41.8	7.7	90.3	120	2,551
Varieties (V)		**b/	**b/	**b/	**b/	**b/	**b/	**b/
Mulching (M)		**b/		**b/	** b/	**b/		**b/
CV (%)		31.2	1.8	5.4	34.3	4.0	2.4	27.9

a/ Significant at P = 0.05

b/ Significant at P = 0.01

5.6 Date of planting and population density.

The choice of planting dates is determined by four factors: (a) maturation time of variety, (b) the need to plant when the soil conditions are favourable for good seedling emergence, (c) the need to provide adequate soil moisture throughout crop growth to obtain high yields, and (d) the need to have dry periods during crop maturation to obtain high seed quality and to facilitate harvesting and drying.

In the bimodal region of West Africa soybeans planted in the major rainy season (April-August) have higher yields but is of poorer quality

than those planted in the minor season (September-November) (Nangju, 1977). In the major season soybeans often ripen during the rains, and thus suffer greatly from weathering even though harvesting is done promptly. Seed quality is poor because most seeds are purple stained and discoloured. Germination declines rapidly if the seed is not properly dried immediately after harvest. In this bimodal region seed production needs to be done in another environment. In the monomodal region of the West African savannah, planting date can be carefully chosen on the basis of growth duration and rainfall data so that the crop matures just after the rains cease . In this way high seed yields and quality can be obtained.

Data illustrating the effect of planting date of soybeans at Samaru, Northern Nigeria is shown in Table 5.6. The study compared 3 varieties at 3 times of planting and 3 plant population spacing (Fisher, 1980). In this study there was no significant effect of spacing on yield (Table 5.6), although there was a tendency for the higher population (109,000 plants/ha) to have the highest yield. Early planting also gave the highest yield irrespective of spacing used.

More recently, (Fisher, 1980) has examined the possibility of closer row spacings for soybeans grown on the flat at 3 populations. There were worthwhile responses to higher population, and closer row spacings gave some yield advantage (Table 5.7). Noticeable in these studies was the considerable difficulty of hand weeding the close-spaced rows, where very good weed suppression was achieved later on. Close row-spacing would seem to be worthwhile for farmers able to use a herbicide.

Table 5.6: The effect of planting date and plant spacing on the yield of soybeans at Samaru, 1976.

Spacing in (cm)	Mean yield of 3 varieties (kg/ha)			Mean
	Planting date			
	31 May	21 June	12 July	
10.2	1836	1695	1545	1692
15.2	1815	1551	1562	1643
33.0	1895	1589	1301	1595
Mean	1849	1612	1469	

Table 5.7: The effect of population and row spacing on the yields of soybeans at Mokwa, sown 4 July, 1979.

Row spacing in (cm)	Mean yield of 3 varieties (kg/ha)			Mean
	Population, thousand per ha.			
	330	220	110	
75	1661	1392	1090	1381
50	1492	1573	1289	1451
30	1553	1862	1344	1586
21	1981	1833	1358	1725
Mean	1672	1666	1270	

Considerable variation can occur between genotype x density x spatial arrangement as illustrated by data on Tables 5.8 and 5.9 recorded from Uganda (Rubaihayo *et al*, 1973). These data show clearly the interaction between genotype and plant spacing and also serve to demonstrate the very large difference that exists between genotypes with respect to the efficiency with which assimilate is channeled into the economic part of the plant,

namely the seed. Thus, although Bukalasa 4, with its longer growing period, accumulated rather more dry matter than Clark 63, the much higher Crop Index of the latter was responsible for its exceeding Bukalasa 4 in terms of seed yield.

Table 5.8: Main effects of density (mean for three spatial arrangements) on the seed-yield performance (kg/ha) of four contrasting genotypes, second-rains season, 1971.

Plant density (Number of Plants/ha)	Bukalasa 4	Willett 1	Clark 63	Tokachinagaha
67,200	1912	2047.3	2429	1345
134,400	1886	2242.0	3052	1951
201,400	1859	2037.0	3124	1999

Table 5.9: Selected growth and development parameters for the four soybean genotypes featured in the genotypes X density X spatial arrangement experiment, second-rains season, 1971*

Parameters	Bukalasa 4	Willett 1	Clark 63	Tokachinagaha
Plant height at maturity (cm)	93.0	17.4	45.0	22.1
Main-stem node no.	17.9	16.0	13.6	9.4
Total dry matter/ plant (gms) maximum recorded during the season	30.7	28.3	24.8	14.5
Fraction of total dry matter channeled into seed	29%	32%	48%	45%
Number of days from sowing to harvest	122	166	102	87
Height from ground level of the lowest borne pods (cm)	26.4	11.7	2.8	2.5

*Figures represent the mean of nine spacing treatments and three replications.

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CHAPTER SIX

NUTRIENT REQUIREMENTS AND MINERAL NUTRITION OF SOYBEANS

6.1 Introduction.

Crop yields are a function of three major factors: (a) the soil upon which the crop is grown, (b) climatic conditions, and (c) the management practices followed. Each of these factors has several variables which must be considered in evaluating that factor.

Soil fertility is a very important phase of the soil in crop production. In fact it is one of the four minimum and essential conditions which must be provided by nature or man in order for production to occur. The other minimum and essential conditions are varieties adapted to the environment, adequate moisture in the rooting zone, and protection against diseases and pests.

6.1.1 Essential nutrients.

If a soil is to produce crops successfully, it must have, among other things, an adequate supply of all the necessary nutrients which plants take from the soil. If any of these elements is lacking or it is present in improper proportions, normal plant growth will not occur. There are 16 elements required for plant growth. The first nine elements are required in relatively large amounts and are called macronutrients. Of these, carbon, hydrogen and oxygen are supplied by air and water, and are therefore not dealt with as nutrients by the fertilizer industry. The other macronutrients are subdivided into primary and secondary elements (Table 6.1).

The remaining seven elements are required in much smaller amounts and are known as micronutrients or trace elements.

Table 6.1: Elements essential for plant growth and forms taken up by plant:

Macronutrients		Forms taken up	Micronutrients	Forms taken up
	Carbon	CO_2	Boron	$B_4O_7^{2-}$, $H_2BO_3^-$, HBO_3^-
	Hydrogen	H_2O	Chlorine	Cl^-
	Oxygen	O_2	Copper	Cu^{2+}
Primary nutrients	Nitrogen	NO_3^-, NH_4^+	Iron	Fe^{2+}, Fe^{3+}
	Phosphorus	$H_2PO_4^-$, HPO_4^{2-}	Manganese	Mn^{2+}
	Potassium	K^+	Molybdenum	MoO_4^{2-}
Secondary nutrients	Calcium	Ca^{2+}	Zinc	Zn^{2+}
	Magnesium	Mg^{2+}		
	Sulphur	SO_4^{2-}, SO_2		

6.1.2 Roles of essential elements in plant nutrition.

Carbon, Hydrogen, and Oxygen serve largely in the synthesis of carbohydrates, proteins and fats, which are major constituents in most plant compounds.

Nitrogen is a constituent of every living cell. It is a part of many proteins which serve as enzymes and also is a part of the chlorophyl molecule. It is abundant in the leaves, seeds and young growing parts of the plant.

Phosphorus is a constituent of every living cell, phospholipids, nucleo-proteins and phytin. It is present in seeds in larger amounts than in any other parts of plants.

It plays an important role in energy transformation in the cells of plants, and is necessary for transformation of carbohydrates and assimilation of fats. Phosphorus hastens plant maturity and enhances vegetative growth. Soybeans have a very high P requirement

Potassium is essential in all cell metabolic processes and has a specific role in influencing the uptake of certain other mineral elements, in regulating the rate of respiration, and in aiding the synthesis and translocation of carbonhydrates.

Calcium in the form of calcium pectate is a part of cell walls and is necessary for the growth of meristems.

Magnesium, active in enzyme systems, is a part of the chlorophyll molecule, and aids in the translocation of phosphorus in plants.

Sulphur is a constituent of sulphur-containing amino acids (cystine, cysteine, and methionine), some vitamins and coenzyme A. It increases the oil content of oil crops.

Iron and manganese play important roles in plant enzyme systems and are required for chlorophyll synthesis.

Boron plays a role in calcium utilization and in the growth of meristem and actively growing portions.

Copper and Zinc are components of enzymes and are necessary for the formation of growth promoting substances.

Molybdenum plays a major role in the reduction of nitrates in plants.

6.1.3 Roles of nutrients in root nodulation and nitrogen fixation of food legumes.

Since food legumes are nodulated plants, and obtain some or most of

their nitrogen from the air, it is also important to consider the roles of essential nutrients in root nodulation and nitrogen fixation.

The presence of a high level of readily assimilable nitrogen in the soil depresses nitrogen fixation. If this continues for very long, degeneration of the nodule begins. The presence of combined nitrogen during the "hunger" period of crop development, however, may promote nodulation, especially on poor soil.

Phosphorus is an important element influencing symbiotic nitrogen fixation. It is important in relation to the earlier infection stages of nodulation. It also plays a most important part in maintaining the rhizobial population at a high level in the soil.

Calcium is important in both the nutrition of the legume and of the rhizobia. The calcium content of legumes is about three times that of grasses. Magnesium seems to play a closely analogous role, possibly in part because calcium is rendered more available in its presence. Boron is important in controlling the development of vascular tissue in the nodule, calcium intake and carbohydrate translocation. The boron content of legumes is very high in comparision with that of non-legumes. Molybdenum is required in small quantities for the nitrogen fixation process in the symbiotic system.

6.1.4 Types of fertilizers.

A fertilizer is any material, organic or inorganic, natural or synthetic, that furnishes to plants one or more of the chemical elements necessary for normal growth.

Large quantities of natural organic fertilizer materials (plants or animal in origin) are still used in many parts of the world. These include animal and human excreta, wood ashes, sewage, slaughter-house wastes, fish scrap, and oil-seed meals. Their advantages are to (1) supply nutrients directly, (2) stimulate desirable biological activity in the soil, and (3) improve soil structure. Their disadvantages are (1) seldom available locally in large quantities, (2) large-scale collection and distribution are uneconomical, (3) non-uniform composition, and (4) unfavourable physical condition. Some of these disadvantages can be overcome by simple processing such as drying, pelleting and enrichment with synthetic fertilizers.

6.1.5 Relative merits of different fertilizers.

Selection of higher analysis fertilizers generally results in lower costs per unit weight of nurtients. This is particularly true where transportation and handling are major items of cost. For example, if 230 kg N/ha were to be applied, only 500 kg of Urea (46% N) would be needed, while 1150kg of ammonium sulphate (20% N) would be required. Thus, between these two fertilizers, urea would be preferred if all other factors are equal.

Besides fertilizer grade, the other consideration which should be taken in buying fertilizers is the amount of other essential elements which they contain. For example, among the nitrogenous fertilizers, ammonium sulphate contains 21% N and 23% S; ammonium phosphate contains 11% N and 20% P; calcium nitrate contains 16% N, 27% CaO, 2.5% Mg O and 0.2% Cl; potassium nitrate contains 13% N and 44% K_2O. The additional nutrients may be useful

to plants depending on the fertility status of the soil in which they are grown. Among phosphatic fertilizers, ordinary superphosphate contains 8%P (18% P_2O_5), 11% S, and 20% Ca. Concentrated or triple superphosphate contains 21% P, 1% S and 13% Ca. Thus,, if sulphur is limiting in a given soil, ordinary superphosphate is better than triple superphosphate.

The effect of continuous use of fertilizers on soils should be considered in evaluating the merits of different fertilizers. In general, phosphatic and potassium fertilizers have no permanent effect on soil acidity. But some nitrogenous fertilizers, notably ammonium sulphate, will produce acidity, and hence have an undesirable effect on soil pH particularly when used in large quantities over many years.

6.1.6 Methods of determination of fertilizer needs.

Fertilizer applications should supply the nutrient or nutrients which are deficient in the specific soil involved. Crops differ not only in their nutrient requirements but also in their value.

Of the fertilizer applied to the soil only a portion is assimilated by the crop. Some nutrients are taken up by weeds, some are lost from the root zone by leaching, denitrification or volatilization, and some react with the soil to become less available. Thus, the questions are (a) what nutrient elements does a particular soil need to supplement its inherent supply in order to fulfill the need of the crop (b) how much, and (c) when should they be applied.

1. Soil analysis. Numerous extracting solutions and procedures are being used to remove nutrient elements from the soil, but none remove exactly the same amount that plant roots obtain. This means that, in order to interpret the data, the results from each analytical procedure must be correlated with the plant response obtained in field experiments from applications of that fertilizer nutrient. From these correlation studies, it is possible to prognosticate the response that is likely to be obtained from the application of fertilizers to certain crops in a given soil. A chemical soil test is rapid and can be used to determine the needs of the soil before the crop is planted.

2. Plant analyses. Plant analyses are based on the premise that the amount of a given element in a plant is an indication of the supply of that particular nutrient and as such is directly related to the quantity in the soil. Two general types of plant analysis have been used:

(a) Tissue tests. In these tests the sap from ruptured cells is tested for unassimilated nitrogen, phosphorus, and potsssium. The results are read as very low, low, medium, or high, and are usually a good indication of how well the plant is supplied at the time of testing. The part of the plant used for testing and the time of testing should be carefully considered in order to obtain accurate results.

(b) Total analysis. This is a measurement of the total nutrient uptake since the entire plant is harvested and dried at about 65°C. The dried material is finely ground and thoroughly mixed before sampling for analysis.

Stage of crop growth for sampling must be carefully selected and identified. One of the problems in the interpretation of a tissue test and total analysis is that of balance among nutrients. When a plant is low in nitrogen, phosphorus and potassium accumulate to show high values. Likewise, if calcium and magnessium in the plant is increased, potassium would tend to decrease and vice versa.

3. Biological tests. Use of growing plants understandably has much appeal in the study of fertilizer requirements, and much attention has been devoted to this method for measuring the fertility status of soils.

(a) Field experiments. This is one of the oldest and best known of the biological tests. The series of treatments selected depends on the particular question the experimenter wishes to have answered. Since crop responses to fertilizers are influenced by many factors, the field research must consider all of the various soil, climate, and management factors that have significant influences on crop yields. Furthermore, the field experimentation must be closely coordinated with the laboratory studies which provide analysis of the soil and plant samples from the field experiments. When large numbers of tests are conducted on soils that are well characterised, recommendations based on such studies can be extrapolated to other soils with similar characteristics. Field tests are expensive and time-consuming but widely used by experiment stations

(b) Greenhouse experiments. Pot tests with many modifications have been used by various investigators. These tests are usually conducted

under greenhouse or laboratory conditions and permit the control of moisture supply, temperature, and other factors that cannot be controlled in conducting field experiments. Nevertheless, the results have to be interpreted in terms of field conditions if they are to be of value to farmers. The pot tests consist of filling a number of pots with soil material and adding various fertilizer materials. The need for fertilizer is indicated by the growth of the plants, by amount of dry matter produced, and/or by analysis of the plant ash.

(c) Microbiological methods: These techniques employ different types of micro-organisms which are sensitive to the deficiency of a certain nutrient element. The growth of the micro-organisms serve to indicate the limiting mineral nutrients in the soil. These methods are rapid, simple and fairly reliable for phosphorus and potassium.

6.1.7 Fundamentals of fertilizer application.

Crops are fertilized to supply the nutrients that are not present in sufficient quantities in the soil. The purpose of an adequate fertilization program is to supply year in and year out the amounts of fertilizer that result in sustained maximum net return. However, efficient use of fertilizers depends on several factors.

(1) Crop characteristics. The amount of nutrients removed at each harvest varies with crops. Although the nutrient removal cannot be used as an accurate guide to the amount of fertilizer to apply,

they do show the differences that exist in nutrient needs among crops and an indication of the rate at which the reserve nutrients in the soil are being depleted. The amount of nutrients removed depends on yield, parts of the plant harvested and method of harvest.

(2) Root characteristics: Understanding of the characteristic rooting habits and relative activity should be helpful in developing fertilization practices in terms of the most effective fertilizer placement.

(3) Fertilizer placement: Fertilizer placement is important for at least three reasons:

(a) Efficient use of nutrients from plant emergence to maturity. Fertilizer should be placed where it will be intercepted by the roots of the young plant and to place the bulk of the nutrients deeper in the soil where they will be more likely to be in a moist zone the greater part of the year.

(b) Prevention of salt injury to the seedling. Soluble fertilizers close to the seed may be harmful

(c) Convenience to the grower. A simple, practical method is required to reduce the cost, and to increase the speed of application. Thus, commercial growers will want more of the fertilizer ploughed down in advance of planting when time is less critical, and a minimum amount of fertilizer at planting, properly placed for most efficient plant growth. There are several methods of placement:

(a) broadcasting fertilizer uniformly over the surface of the land before planting, followed by ploughing, disking or harrowing.

(b) applying fertilizer in bands about 5-10cm to the side and 2 to 5cm below the seed,

(c) placing fertilizer in the furrow with the seed. (This method is harmful to the seedlings), and

(d) topdressing or side dressing is the application of fertilizer after emergence. These applications may be made simultaneously with cultivation.

(4) Movement of fertilizer: Soluble salts are disolved in the soil solution surrounding the zone of application. The rate and distance of movement of the salts from point of application depends on the nature of the salts, the soil prpperties and the climatic condition. In general, nitrates move most readily, but ammoniacal nitrogen is adsorbed to the soil colloids and move very little until converted to the nitrate. Phosphorus moves very slowly from the point of placement. The potassium ion is positively charged and tends to attach itself to the colloidal complex and therefore is restricted in movement. The mobility of nutrients affect the efficiency of fertilizer placement.

(5) Time of application: The time at which to apply a fertilizer depends on the soil, climate, nutrients, crop and cropping system.

(a) Soil: Soils differ greatly in the speed with which water will move through them. The degree of leaching is generally higher in sandy soils than in clay soil. Soils also vary greatly in their capacity to fix nutrients.

(b) Climate: The amount of rainfall between the time of application and time of utilization by the plant will influence the efficiency of a material.

(c) The nature of crop: A perennial crop needs two to four supplements of nitrogen whereas a fast growing, early maturing crop may require only one application of nitrogen. Grain legumes require a starter nitrogen only at planting. Once fully established the plants obtain their nitrogen requirements through nitrogen fixation by the root nodules.

(d) Nutrients: Phosphorus and potassium move very little in the soil, and hence the total quantity during the season can be applied at planting without fear of loss by leaching. This method is usually more efficient than side dressing for opportunity is provided to incorporate the nutrients in the soil. In contrast, the possibility of nitrogen losses through leaching, volatilization and denitrification must be considered in selecting the time at which it may be applied. It is generally agreed that split application is most desirable particularly in sandy soil under high rainfall condition.

(e) Cropping system: In a rotation system, fertilizers are applied to the critical crops. Thus, in a maize-soybean rotation P and K are applied to the maize and nothing to the soybean.

6.1.8 Factors affecting fertilizer use.

The amount of fertilizer used in a given country is highly correlated with yield per unit area. High yields obtained in developed countries are partly

attributed to high level of fertilizer application. The low fertilizer use in developing countries is caused by one or more of the following factors:

(a) Shifting cultivation is still widely practised in some areas.

(b) Lack of improved implements which do not make possible more timely performances of key operations or facilitate the introduction of new techniques.

(c) Limited capital to invest in fertilizer,

(d) Lack of farm credits,

(e) Unfavourable relationship between the price of the product and the cost of fertilizer,

(f) Lack of fertilizer subsidy,

(g) Risk and uncertainty associated with technological change,

(h) Unfavourable land tenure system, and

(i) High cost of transportation of imported fertilizer.

6.1.9 Application of fertilizers to soybeans.

Several factors influence the application rates that should be considered. One is the amount of each element that should be used by the crop. A second factor is the amount that is likely to remain available throughout the growing season. Some elements are readily leached:Others are rendered unavailable because of chemical combinations with other soil constituents. The relative importance of leaching and chemical combination depends on soil properties, rainfall, and the chemical properties of fertilizer materials used. A third factor to consider is how other elements in rhizosphere influence the uptake of the deficient element. When one element is deficient and others are

relatively abundant, increasing some of the abundant element may reduce yield because less of the deficient element is taken up. Therefore, it follows that higher rates of a deficient element should be applied when high levels of other elements are present than only moderate levels are present.

6.2 Nitrogen.

Soybean plants can use residual soil N, fertilizer N, or atmospheric N that is converted to a usable form in root nodules through a symbiotic relationship between *Rhizobium japonicum* organisms and host plants. Soybeans, like other legumes have the ability to supply their own nitrogen needs, provided they have been inoculated or the soil contains native Rhizobia bacteria capable of forming effective nodules and other mineral nutrients in the soil are not limiting. Therefore, it is not necessary to supply nitrogen fertilizer except possibly a small amount as a starter.

Recent studies at IITA (1976) showed that both cowpeas and soybeans utilize nitrate nitrogen as a primary nitrogen source during the early vegetative period.

Its importance declines when nodule nitrogen production becomes predominant during the late pre-flowering period (Fig. 6.1)

Estimates of rates of nitrogen fixation by root nodules using amino-N content of the stem exudate were closely correlated with actual rate of accumulation of total reduced nitrogen in the plant. Although cowpeas fixed more nitrogen per plant at flowering than soybeans, the rate declined more quickly in the former.

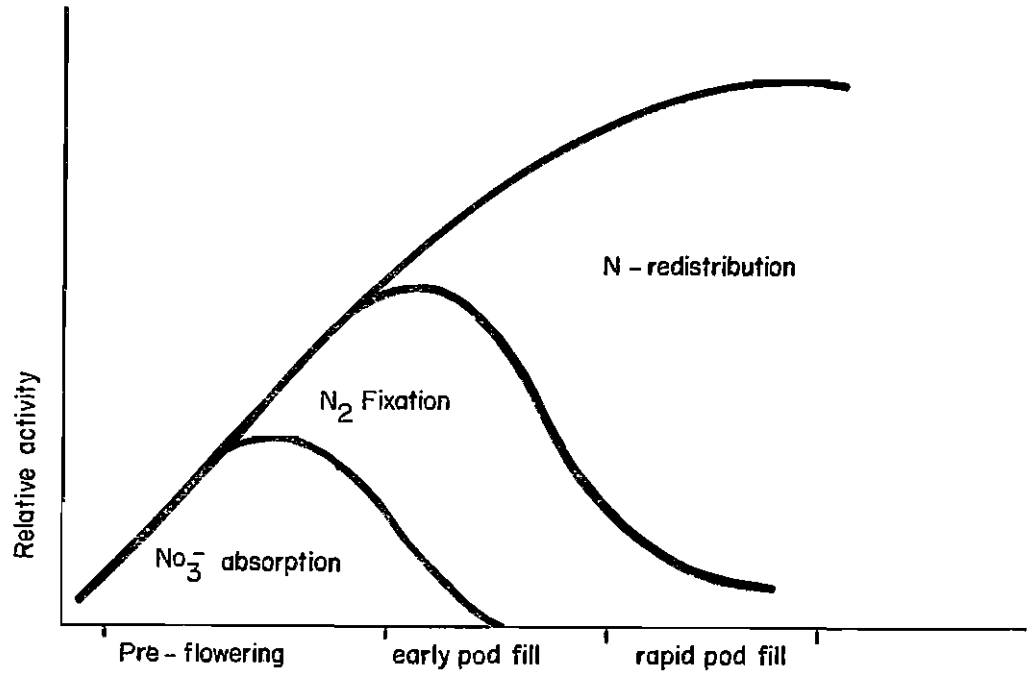


Fig. 6.1: Utilization of N by Soybean plant

In both cowpeas and soybeans, the point at which the nitrogen demand by the pods exceeded the nitrogen supply coincided with leaf senescence, indicating that the nitrogen was being fulfilled by redistributing nitrogen from other plant organs. In cowpeas, approximately 40 percent of the total reduced nitrogen in the seeds was retranslocated from tissue and 45 percent synthesized during the pod-filling period. Soybean seeds received less of their total nitrogen from the leaves, but were capable of producing a large amount of nitrogen during pod fill. However, at maturity, 40 percent of the nitrogen accumulated by the cowpeas remained in the plant whereas in soybeans, only 22 percent had not been translocated. Table 6.2 shows sources of seed nitrogen and relative amounts redistributed from other plant organs. Foliar applications of major nutrients (mainly nitrogen) after flowering delayed senescence for a short time but resulted in only slight yield increases.

6.2.1 Symbiotic nitrogen fixation.

Most soybean varieties are more specific than cowpeas in their rhizobium requirements for effective nodulation. In tropical soils not previously inoculated with *Rhizobium japonicum* the numbers of this bacteria are extremely few. This allows for the introduction of effective exotic strains without competition from less effective indigenous rhizobia, but at the same time begins with it complications arising from the need to use an inoculant.

Table 6.2: Sources of seed nitrogen at maturity and relative amount redistributed from other plant organs (IITA, 1976).

	Cowpeas				Soybeans			
	TVu 4552		TVu 3629		TGm 280-3		TGm 383	
	mg/plant	%	mg/plant	%	mg/plant	%	mg/plant	%
Total reduced nitrogen in plant	1320.7		1759.6		1057.3		1071.0	
Total reduced nitrogen in seeds	418.8	63.7**	1001.6	56.9**	797.0	75.4**	859.1	80.2**
Sources of seed nitrogen:								
redistributed from leaves	334.0	39.7*	390.0	38.7*	308.5	38.7*	175.3	20.4*
redistributed from stem	72.8	8.6*	37.2	3.7*	39.6	5.0*	66.1	7.7*
redistributed from peduncles	36.4	4.3*	136.7	13.7*	-	-	-	-
Produced during pod fill	398.7	47.4*	437.7	43.9*	448.9	56.3*	617.7	71.9*
TRN remaining in non-seed tissue	478.8	36.3**	758.0	43.1**	360.3	24.6**	211.9	19.8**

TRN - Total reduced nitrogen: * - Percent of TRN in seeds ; ** - Percent of TRN in plant.

Although many soybean varieties respond very well to inoculation, and IITA has found better nodulation and increased nitrogen fixation in inoculated plants (Table 6.3) the large-scale production, maintenance and distribution of soybean inoculants are difficult in most developing countries owing to lack of trained personnel and laboratory facilities.

Table 6.3: Effect of inoculant and fertilizer nitrogen on the yield of soybean variety Bossier at seven locations in Africa (IITA Research Highlights, 1980).

Country	No. of locations	Seed yield (t/ha)		Nitrogen fiterlizer (90 kg/ha)
		Control unino-culated	Inoculated * (Strain IRJ 2111)	
Nigeria	2	1.51	2.22	1.99
Ivory Coast	1	2.69	2.62	3.44
Kenya	3	1.74	2.34	1.94
Senegal	1	0.71	1.14	2.22
Mean		1.66	2.17	2.40

* Mean of four different inoculants.

A solution to this may lie in selecting soybean cultivars which can be nodulated by indigenous rhizobia in the soil. IITA has observed certain soybean varieties which nodulate well without inoculation with soybean-specific *Rhizobium japonicum* (Table 6.4).

Table 6.4: Inoculant response of 3 promiscuously nodulating soybean varieties of Asian origin compared to 3 US varieties.

Variety	Origin	Inoculant[1]	Nodules No/10 plants[2]	Nodules g/10 plants[2]	Shoot fresh wt[2] g.10 plants	% Increase due to inoculant
Jupiter	USA	-	101	0.86	214	-
		+	348	2.74	402	47
Bossier	USA	-	69	0.47	196	-
		+	465	3.12	349	44
TGm 294-4-2371	USA	-	105	0.70	206	-
		+	369	2.22	320	36
TGm 686	S.E. Asia	-	170	1.17	213	-
		+	281	2.23	241	12
Orba	S.E. Asia	-	416	2.55	352	-
		+	434	3.11	417	16
Malayan	S.E. Asia		421	1.75	305	-
			499	2.35	354	14
S.E.M.			44	0.25	21	

1 Soybean inoculant from Nitrogen Co. Milwaukee, Wis. USA

2 Interaction of cultivar x inoculant significant at the 1% level

Nodulation of these southeast Asian cultivars occurred even in soils with no known history of soybean cultivation. Data and observations in farmers' fields indicate that the rhizobia nodulating these particular cultivars are widely distributed, so it is suspected that these rhizobia belong to the indigenous "cowpea type" group. This is being critically examined. In contrast, improved soybean varieties of U.S. origin were found to nodulate very poorly in African soils, and to display severe nitrogen deficiency

symptoms unless inoculated with exotic (*japonicum*) rhizobia strains. The U.S. cultivars gave much higher yields than those from southeast Asia because of superior agronomic characteristics, but the Asian cultivars in turn showed better seed storage characteristics.

At IITA, a part of current research is therefore concentrating on hybridization between Asian and U.S. soybean types in order to incorporat the high yield potential of the U.S. lines with the nodulating ability and seed quality of the Asian types which may make it possible to obtain high yields of soybeans on tropical soils without the use of inoculants.

6.2.2 Mechanism of nitrogen fixation.

(i) Rhizobial multiplication in the rhizosphere

Rhizobia are present in the soil as non-sporing rod shaped bacteria. Because of their non-sporing nature they are vulnerable to environmental and moisture stresses during the seasons of the year and fluctuations in population sizes are noticed accordingly. Their frequency is also largely dependent upon the present and past cropping history. They frequent the legume rhizosphere (around the root) more commonly than the non-legume rhizosphere. In response to the root exudates from the rhizosphere compatible legume rhizobia multiply and increase in numbers, and this appears to be an essential prerequisite before recognition (infection) process.

(ii) Recognition

The legume-rhizobium symbiotic association generally speaking is specific. Thus, *Rhizobium trifolii* can infect and form nodules only on *Trifolium* and

not on soybeans (*Glycine max*) or *Rhizobium japonicum* can infect and form nodules on soybeans but not on *Trifolium*. Exceptions to this specifity do exist. For example, most cowpeas nodulate with many *R. japonicum* strains and promiscuous soybeans nodulate with many cowpea strains. A group of compounds called lectins present on the root surface are believed to be recognised by the receptor sites on the bacterial wall and as a result the binding or attachment between the bacterium and the root hair is facilitated. This hypothesis, although it has more evidence to support than others, is not universally accepted.

After binding, the bacterium produces Indoleacetic acid (IAA) and also converts tryptophan from roots to IAA through IAA oxidases. The root hair curling an important feature of host-*Rhizobium* interaction is believed to be induced by IAA. Also several wall softening and wall dissolving enzymes such as polygalacturonase, pectinmethyl esterase and celluloses are believed to be part of symbiotic interactions that result in softening of root hair cell wall.

Through a process of invagination the bacteria enter the root hair. Multiplication proceeds and the formation of infection thread is initiated, where the outer wall and the inner membrane resemble the root hair cell wall but the central matrix harbours a number of actively dividing rhizobia. The infection thread is guided into the cortex by the nucleus of the root hair. Once inside the cortex the tip of infection thread is dissolved. The bacteria along with the membrane are liberated into the host cell cytoplasm generally close to the nucleus. Cortical cells appear to begin dividing in an anticlinal fashion even prior to envasion by infection threads.

(iii) Bacteriod and leghaemoglobin formation.

The cells in the host cortex are filled with bacteria and are generally large and polyploid. The bacteria within the nodule undergo morphological and biochemical transformation and are called 'bacteriods' to distinguish them from free living bacteria. The bacteriods have an enzyme nitrogenase which is capable of fixing atmospheric nitrogen by converting it into ammonia under anaerobic conditions only. The leghaemoglobin, a pink pigment synthesized by host genes and localised in the membranes surrounding bacteriods, is responsible for regulating oxygen supply for bacteriods just enough for their respiration.

(iv) Mechanism of nitrogen fixation in nodules and transport of fixed nitrogen to aerial parts.

The conversion of atmospheric nitrogen to ammonia by nitrogenase is an energy dependent process and obviously the host plant is the source of this energy.

6e

$$N_2 \xrightarrow{\text{Nitrogenase}} NH_3$$

The fixed nitrogen is assimilated into aminoacids by enzymes such as glutamine synthetase and glutamate dehydrogenase. These amino acids are then translocated into aerial parts. However, recent work shows that ureides, allantoin and allantoic acid are very important in the translocation of N in soybeans.

(v) Methods of measuring nitrogen fixation in legumes.

(a) The difference method - In this method a comparison of the nitrogen content of a nodulating crop (soybean) with a non-nodulating legume (soybean) will give an estimate of symbiotically fixed N.

N fixed = N in nodulated crop - N in non-nodulated crop (absorbed from soil).

The presumption in this method is that both crops take in the same amount of soil nitrogen. Total nitrogen in plants can be estimated by the Kjeldahl method. Soybean varieties that do not nodulate provide a good non-nodulating crop.

(b) The acetylene reduction method - Nitrogenase present in Rhizobium bacteriods in the nodules is responsible for the fixation of atmospheric nitrogen into ammonia. Nitrogenase also reduces several other substrates including acetylene.

(1)
$$N_2 \xrightarrow[\text{Nitrogenase}]{6e} NH_3$$

(2)
$$\underset{\text{acetylene}}{C_2H_2} \xrightarrow[\text{Nitrogenase}]{2e} \underset{\text{ethylene}}{C_2H_4}$$

Ethylene production can be monitored by gas chromatogram. A conversion factor of 3:1 (C_2H_2 : N_2) is used to estimate nitrogen fixed by this method.

(c) The 'A' value technique - This technique utilizes a fertilizer labelled with a heavy isotope of nitrogen (15_N) to give separate measurements of N fixed and N absorbed from soil.

6.2.3 Soybean inoculation.

Soybeans are a high-protein crop requiring large amounts of nitrogen for satisfactory yields. Fortunately, soybeans are a legume that forms a partnership in root nodules with the bacterium, *Rhizobium japonicum*. These nodules allow the soybean plant to use elemental nitrogen (N_2) from the air. Inoculation is a way to provide adequate numbers of the proper bacteria in the soybean root zone, if they are not present, so that excellent, effective nodulation takes place.

To use nitrogen from the air successfully, both the proper soybean plant and the proper bacteria are needed. The soybean plant has genetic capabilities for accepting or resisting the formation of nodules. The selection of soybean varieties that readily form effective nodules is very important because some lines of soybeans do not nodulate in the field. Also, certain Rhizobium strains are capable of infecting only certain soybean varieties. Therefore, selection of compatible combinations is important.

The need for inoculation.

In any situation where soybeans respond to nitrogen fertilization, more effective nodulation is needed. Better nodulation can be achieved in many situations by better inoculation. Soybeans grown for the first time on a a field usually respond to inoculation because few soybean Rhizobium bacteria are present in the soil. When non-promiscuous varieties are grown on soils low in nitrogen, inoculated beans often yield 150 to 200 percent more than uninoculated beans (Fredrick, 1976). To obtain comparable yields

with fertilizer requires large amounts of nitrogen per hectare. In fields where nodulated soybeans have been grown previously, soybean Rhizobium bacteria are often present, but their numbers may be high or low, and the Rhizobium present may form nodules of unknown effectiveness (Hahn *et al.*, 1971; Weaver *et al.*, 1972).

Nodulation effectiveness can vary from one area of the field to another. Yield increases for soybeans are often small (5 to 10 percent) on fields where nodulated soybeans were previously grown. Some farmers, aiming for top yields, inoculate all soybeans planted because the cost of inoculation is usually less than the value of planted soybean seeds. More research is needed to determine the survival patterns of Rhizobium bacteria in different soils and cropping sequences, especially in acid or flood soils. The failure to use good inoculants can cost many kilograms of seeds because of nitrogen deficiency.

High quality inoculant.

High quality inoculant provides effective, efficient living Rhizobium bacteria. Rhizobium strains need to be evaluated and selected for the crops and areas where they will be used. Mixing a few of the better strains of Rhizobium in an inoculant provides greater assurance of successful nodulation when used with different soybean varieties and soil conditions.

High quality inoculant also provides large numbers of effective, efficient living Rhizobium bacteria, but Rhizobium numbers in the inoculant can be reduced quickly by unfavourable storage conditions. Drying is very detrimental.

High temperatures (above 35°C) also decrease populations rapidly. Rhizobium numbers on inoculated seed exposed to a drying wind and sun can drop from a million (10^6) to less than a thousand (10^3) per seed. Slurry or dust methods are a convenient method of inoculation, but drying is extremely hazardous to the Rhizobium bacteria, and the seed provides them very little protection. The use of seed protectant fungicides increases the hazards for the Rhizobium. Since the number of Rhizobium bacteria that can cling to and survive on a seed is limited, the inoculated seed should be protected and planted as quickly as possible after inoculation. High quality inoculant can be assured only when adequate quality control is used and low quality inoculants discarded (Vincent, 1970).

Use of inoculants.

At least one million Rhizobium bacteria per seed appear to be desirable for field application, although lower numbers sometimes give good results if conditions are favourable. Among other reasons, large numbers of Rhizobium bacteria tend to increase soybean yields (a) by promoting early nodulation and growth, (b) by ensuring greater survival of Rhizobium bacteria during adverse storage or growing conditions, and (c) by competing more successfully against the soil Rhizobium bacteria, which may be less desirable than those in the inoculant.

The location of nodules on the root system is an indicator of the time of infection and nodule development, and as such should be observed (Weaver and Frederick, 1972). Nodules on the upper tap root form early, usually within the first 14 days of seedling growth. The presence of large numbers of

Rhizobium bacteria usually results in upper tap root nodulation and early nitrogen fixation. When most of the nodules are on the secondary roots or on the lower tap root, an indication of delayed nodule development, nitrogen deficiency may be prolonged, causing reduced yields. Delayed nodule development can be caused by low numbers of Rhizobium bacteria. When the numbers are low, the bacteria must colonize the root and proliferate, which often results in nodulation only on the secondary roots, especially when soil or climatic conditions are unfavourable. Thus, the pattern of nodulation on the root system is a rough indication of the abundance of Rhizobium bacteria present while the seedling was developing.

Improved methods of inoculation are needed, but until they are developed, the best methods currently available should be used. Education of the people who produce and distribute the inoculants and those who use them is essential. Because inoculants are cultures of living cells, they will be preserved best if handled like perishable produce such as meat or fresh vegetables.

Adding the inoculant in a thick layer around the seed to form a pellet has improved inoculation success with small-seeded legumes, but few data are available for this technique with large-seeded legumes. More studies of this inoculation technique for soybeans are needed.

Direct placement of the inoculant into the soil at the time of planting the soybeans has often improved inoculation (Scudder, 1975). Both liquid and solid (usually peat) carriers have been used with success. Placement in moist soil at or slightly below the seed has proved satisfactory.

Either much larger amounts of inoculant or inoculants carrying much higher numbers of Rhizobium bacteria are desirable for this improved method of direct soil inoculation.

The proper use of soybean inoculants should be an integral part of the educational "package" of practices for good soybean production. Inoculants provide the Rhizobium bacteria and good seed provides the soybean plants needed for this legume-Rhizobium symbiosis. These must be combined with proper planting, tillage, fertility, harvest, and storage practices, as well as with proper inoculation to provide adequate nitrogen without the use of fertilizer.

Use of promiscuous varieties.

Research at IITA, Tanzania, Zaire, Uganda and Zambia has demonstrated that a few soybean varieties can be infected with relatively wide range of rhizobia so that they nodulate well with the rhizobia that exists naturally in the soils, in the same way as cowpea nodulate. Such varieties can be grown successfully without use of inoculants. The breeding program at IITA is incorporating genes for promiscuous nodulation into high yielding varieties for the tropics.

6.3 Phosphorus.

Phosphorus is essential for energy transfer, thus is used in the formation and translocation of all intermediate and end products. Phosphorus uptake is relatively constant throughout the growing season, but peak absorption normally takes place during the early stages of seed development.

During late seed development, P is translocated from vegetative plant parts to seeds. Soybeans require relatively larger amounts of phosphorus throughout the season and should be mixed through the plough layer rather than concentrated near the surface. The top few centimetres of soil may become so dry that roots cannot feed effectively.

A multilocational exploratory trial conducted in 1979 to identify yield limiting factors showed P to be limiting at several locations. To determine the extent to which P and other nutrients limit yield a regional fertility trial was sent to 13 locations by IITA. From the results of five locations, there was a response in growth and/or yield to one or more of the nutrients tested. Growth and grain yield increased with addition of P at Kambo, Upper Volta, and Sotuba, Mali. At Koporokenie - Pe, Mali, P increased yield but had little effect on growth. In addition the 1979 results had shown that the response to P (150kg P_2O_5/ha) depended on plant type. Erect varieties showed an increase in yield and a spreading variety showed no response (IITA, 1980).

The interaction between P, secondary and micronutrients was studied at Mkar in Benue State, Nigeria, where it was observed that P fertilization increased yield of soybeans from about 0.5t/ha to 2t/ha without secondary and micronutrients and from 0.4t/ha to 2.4t/ha with secondary and micronutrients as shown in Figure 6.2 (IITA, 1981). Yield was decreased slightly but significantly by the application of secondary and micronutrients without P, possibly due to nutrient imbalance.

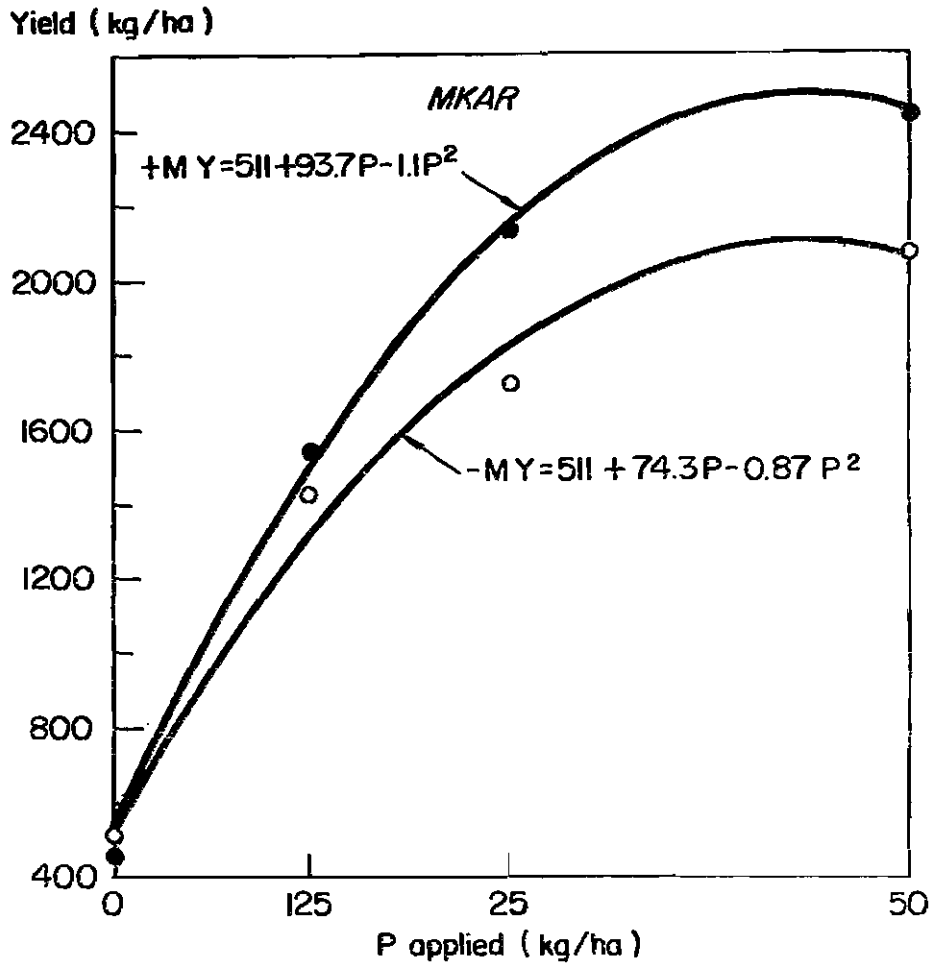


Fig. 6.2 Response of soybean variety TGm 579 to P and to secondary and micronutrients at Mkar. 1981. (M = secondary and micronutrients. S.E. = 59.5, 7.30 and 0.14 for intercept and first and second coefficients respectively).

Applying lime to some acid soils increases either the availability or the uptake of P. In some situations, lime application has reduced or eliminated the immediate need for P fertilization.

Excess P can be detrimental. Very high levels of P can induce Zn deficiency and they can also accentuate K deficiency. Phosphorus fertilizer is not readily leached through near-neutral soils, or soils that have large quantities of active Al and Fe. Lime applied to acid soils often reduces the formation of insoluble Al and Fe phosphates. Sufficient lime to neutralize the most active forms of Al often results in increased P absorption, by enhancing root proliferation. However, in some soils, high rates of P fertilizer are still needed to eliminate P deficiency, because these soils retain the capacity to fix large quantities of P. Adding P in excess of crop needs establishes a favourable equilibrium. Thereafter, moderate rates of P fertilizer are effective in increasing crop production.

In production areas where P is very deficient and active Al or Fe concentrations are high, it may not be practical to apply enough P initially to maintain adequate P availability. In such situation, banding smaller amounts of P fertilizer near the soybean rows probably will provide adequate P nutrition, but it may also restrict root development. Repeated band application of P will eventually result in higher levels of available P. A 2000kg/ha soybean crop may require between 30 and 50kg of P.

6.4 Potassium.

Soybean plants use relatively large amounts of K. The rate of potassium

uptake climbs to a peak during the period of rapid vegetative growth, then slows down about the time the beans begin to form. The uptake is completed two to three weeks before the seed mature. At maturity, soybean seeds contain 60 percent of the potassium in the plant.

When fertilizer K is applied to highly weathered sandy soils, much of it remains in the soil solution. This property makes it susceptible to leaching. In K deficient light sandy soils, high rainfall can leach much of the fertilizer K through the rooting zone. Less leaching occurs after the root system is well established. Thus in environments that are favourable to K leaching, the total K fertilizer should be divided between two applications. One application should be at or near planting and the other 30 or more days later, when roots are well established. Banding K fertilizer may enhance its absorption, but it may also increase losses from leaching. Whatever method is used, K fertilizer should be incorporated into the soil to prevent loss from surface runoff during heavy rainfall.

6.5 Secondary nutrients.

Secondary elements Ca and Mg compete with each other for uptake by plants. Because soybean plants use more Ca than Mg, the Ca : Mg ratio in the soil should be greater than 1:1.

When Ca is needed, it is often supplied as calcitic limestone. When Mg is also needed, dolomitic limestone can supply both elements. Dolomitic limestone contains up to about 40 percent $MgCO_3$ in addition to the major component $CaCO_3$.

The $MgCO_3$ component is less soluble. Also, when the lime particles are dissolved, Mg leaches more readily than does Ca. Thus, the ratio of Ca:Mg available to plants continues to be favourable for plant growth.

Agricultural lime not only supplies nutrients, but also increases soil pH. Frequently, the beneficial effects of increased pH are greater than the beneficial effects of the added nutrients, but the relative importance of the two effects are not easily measured.

Increasing the pH of highly acid soils increases the effectiveness of the symbiotic N fixation process, changing the soil pH also influences the availability of many soil-derived nutrients. For micro-nutrients other than Mo, increasing soil pH reduces their availability to plants.

Occasionally, Ca and Mg are needed on soils where an increase in soil pH would be detrimental. In such situations, calcium can be applied as gypsum ($CaSO_4$) and magnesium can be applied as Mg SO_4. These compounds have little effect on soil pH.

When agricultural lime is needed, it should be applied, and incorporated into the soil, several months before soybeans are planted. Highly weathered tropical soils should not be overlimed. Overliming some soils may not only reduce nutrient uptake, but it may also have an adverse effect on soil structure and on the total complex of soil organisms.

To study the survival and competitive ability of *R. japonicum* in acid soils, several isolates were screened for symbiotic competence in the greenhouse

using a highly acid soil from Onne (*Oxic paleudulf*, pH 3.7). The two best strains were selected and genetically marked with either streptomycin or spectinomycin resistance at 200 µg/ml antibiotic. No loss of symbiotic effectiveness by the nutrient strains relative to their "wild-type" parents was detected in a Leonard jar experiment.

The two antibiotic resistant strains were employed in a field trial at Onne in the highly acid soil and for comparison purposes in a slightly acid soil at IITA (*Oxic paleustalf*, pH 5.4); both soils contained fewer than five indigenous rhizobia/g prior to planting. Two cultivars TGm 80 and TGm 294-4, and four treatments were used: (i) uninoculated (ii) inoculated with IRj 1 1 spc, (iii) inoculated with IRj 114 str, and (iv) fertilized with 150kg N/ha in two doses. Lime at 1 t/ha was applied to half of the plots in the highly acid soil.

The results presented in Table 6.5 show that both cultivars in the uninoculated minus lime treatment produced little nodule and shoot dry matter; grain yields were also poor (0.3-0.4 t/ha). Lime application induced significant increases in nodule dry weights and grain yields, although only a small response was observed in terms of shoot dry matter production. These results demonstrate the ameliorating effect of lime on the soil acidity complex.

At six weeks, a duplicate experiment without liming treatments on the slightly acid soil at IITA revealed similar treatment differences to those described for the Onne trial, although shoot and nodule dry weights were of a higher order of magnitude due to the more favourable soil conditions (Table 6.6). However, at the final harvest there were no significant differences between treatments in terms of grain yield.

Table 6.5. The shoot dry matter production, nodule dry weights and grain yield of two soybean cultivars grown in an acid soil at Onne and receiving different inoculations and two levels of lime (IITA, 1978).

Treatments[a]	Mean[b] shoot dry weight (g/plant) at six weeks on soybean cultivar		Mean[b] nodule dry weight (mg/plant at six weeks on soybean cultivar		Mean[b] grain yield (kg/ha) on soybean cultivar	
	TGm 294-4	TGm 80	TGm 294-4	TGm 80	TGm 294-4	TGm 80
Lo 1^{o}	2.55	2.23	26.8	5.5	396	331
L_1 1^{o}	2.97	2.87	65.3	57.0	913	848
Lo N	3.82	3.69	1.4	1.1	1002	795
L_1 N	4.61	4.30	50.3	14.0	1241	1387
Lo str	5.44	6.32	228.0	226.0	1616	2075
Lo_1 str	6.51	6.13	240.5	262.8	1753	1963
Lo spc	5.73	5.75	237.8	187.8	1582	1932
L_1 spc	6.16	5.18	258.0	223.8	1800	1953

(a) Lo - No lime; L_1 - Lime applied at 1t/ha; N - Nitrogen fertilizer applied in two doses: 50 kg/ha at planting and 100 kg/ha after 6 weeks; uninoculated; str - inoculation with streptomycin-resistant strain, IRj 114 str. spc - inoculation with spectinomycin-resistant strain IRj 101 spc.

(b) Means are derived from four replicates each consisting of 10 plant values.

Table 6.6: The shoot dry matter production, nodule dry weights and grain yield of two soybean cultivars grown in a slightly acid soil at IITA and receiving different inoculation treatments (IITA, 1978).

Treatment[a]	Mean [b] shoot dry weight per plant (g) at six weeks on soybean cultivar		Mean [b] nodule dry weight per plant(mg) at six weeks on soybean cultivar		Mean [b] grain yield (kg/ha) on soybean cultivar	
	TGm 294-4	TGm 80	TGm 294-4	TGm 80	TGm 294-4	TGm 80
Lo No	5.63	5.37	90.4	38.4	2215	2102
Lo N	7.44	8.68	21.9	6.7	2300	2259
IRj 114str	8.07	7.45	328.3	296.2	2298	2335
IRj 101spc	8.12	7.39	280.7	249.9	2372	2332

(a) Legend as for Table 6.5

(b) Means are derived from five replicates each consisting of 10 plant values.

Soybean plants use nearly as much sulphur as phosphorus or magnesium. Sulphur is a component of some amino acids, thus is more likely to be deficient in high protein leguminous crops than in most non-legumes. Where sulphur is deficient and P fertilizer is used, the deficiency may be corrected by using ordinary superphosphate fertilizer rather than triple superphosphate. Ordinary superphosphate contains moderate amounts of SO_4. Sulphur can be supplied in the form of either K_2SO_4 or $(NH_4)_2SO_4$ and by rain water, especially near industrial areas.

6.6 MICRONUTRIENTS.

Micronutrients function in plant enzyme systems. Except for molybdenum, micronutrients are more readily available when soil pH is low. Because micronutrients are required in small amounts, deficiencies can be corrected by spraying the foliage with appropriate soluble salts. Soil applications of soluble salts are also used.

6.6.1 Boron.

This element is least available in strongly acid and alkaline soils. Boron in excess is extremely toxic to young seedlings and consequently should not be mixed into a band fertilizer for soybean even on a trial basis. If a test application is made, it should be broadcast and worked into the seedbed at a rate of about 2 kg/ha boron.

6.6.2 Copper.

Copper is required in very small amounts. Soils high in organic matter and weathered, sandy soils are more likely to be copper deficient.

6.6.3 Iron.

Iron deficiencies are limited to high pH soils, usually well above pH 7.0. This is because high pH produces the ferric form of iron which is unavailable. Other soil factors that cause iron deficiency are high calcium or magnesium carbonate and excess phosphorus, copper, manganese, and zinc.

Wet soil, usually low or high temperature, and intense sunlight make iron deficiency worse. Where a deficiency is only moderate, soybeans often outgrow the early deficiency symptoms, but yield is likely to be reduced. In marginal situations, some varieties are extremely stunted and yellow, whereas others are normal. Since iron shortage is due to soil fixation, application of soluble salts to the soil does not correct the trouble. Several sources of iron chelates may be used according to directions of the manufacturer. Some chelates are formulated especially for acid soils, others for those high in pH.

6.6.4 Manganese.

This element can be deficient, or it may occur in toxic amounts in areas which have a high watertable. A shortage of manganese is the most common micronutrient deficiency of soybeans. It is linked to pH, soil type, and organic matter.

Manganese deficiency causes plants to be stunted. The leaves are yellow to whitish, but have green veins. Application of phosphate fertilizers often correct mild manganese shortages. This is because the first reaction products of most phosphates (except diammonium phosphate) are strongly acid,

thus lowering the pH and bringing manganese into solution around the fertilizer granules. Meeting the needs of soybeans for manganese by adding phosphorus fertilizer is, of course, not the most profitable method unless phosphorus is also needed. Manganese deficiency can be treated in three ways:

(i) Spray manganese sulphate

(ii) Mix manganese in acid-forming fertilizer and band it near the row. The low pH in the band will keep the manganese in available form.

(iii) Apply chelated manganese if suitable formulation is available.

6.6.5 Molybdenum.

Molybdenum differs from other micronutrients in that availability increases with rising pH. Soybeans need molybdenum for nitrogen fixation. The deficiency symptom is pale green or yellow plants, typical of nitrogen shortage. The symptom is often caused by a lack of nitrogen, rather than a lack of molybdenum in the leaf tissue. The symptom usually does not occur on any soil that is high enough in nitrogen to make up for the lack of nodule fixation. Molybdenum is often applied as seed treatment, but when seeds are also inoculated with *Rhizobium japonicum*, molybdenum salts kill many seed-borne Rhizobia.

6.6.6 Zinc.

Zinc deficient soybean plants are stunted. The leaves are yellow or light green. The lower leaves may turn brown and drop. Flowers are scarce. The few pods that do set are abnormal and slow-maturing. In mild deficiencies, early growth is stunted and plants are very light green or chlorotic.

Zinc deficiency is likely on soils with a high pH, high phosphorus, and low organic matter, especially subsoils exposed by land-forming operations. Soybeans on sandy soils are more susceptible than those on finer-textured soils. The deficiency can be caused by heavy phosphorus fertilization, especially near the row.

Zinc sulphate is the most widely applied inorganic zinc source. Zinc may also be formulated as a chloride, oxysulphate, ammonium sulphate, or ammonium phosphate. A single broadcast application normally is adequate for two to four years. Several organic chelates are also available. Zinc toxicity has been known for many years near industrial plants that exhaust large amounts of the element into the air.

6.6.7 Chlorine.

Chlorine was identified as an essential element in solution culture work. Plants require more chlorine than any other micronutrient except possibly Fe. Chlorine has not been reported to be deficient in soybeans. Chlorine is more likely to be present in excessive amounts, particularly where crops are irrigated with water from saline lakes, streams or wells. It accumulates in clouds formed over seas and is deposited in rain-water. It is present in some fertilizers and agricultural chemicals. The most likely place for a deficiency is inland areas where rain water accumulates from sources other than the sea.

6.6.8 Cobalt.

Cobalt is needed for efficient symbiotic nitrogen fixation. Yield responses in soybeans have been small or absent in field studies, even in

areas where cobalt deficiency in animals is common. In experiments to determine if soybeans will respond to cobalt, very small quantities should be used.

6.7 Fertilizer calculations.

Fertilizer recommendations are given in kilograms of nutrient elements per hectare in the order NPK. If only nitrogen is needed, the rate is given in kilograms of nitrogen per hectare. When given the recommended rate of fertilizer and the fertilizer materials one can obtain locally, one should be able to weigh exactly the amount of the appropriate fertilizer material to apply to individual plots whose area is known.

Fertilizers are available in the form of single element fertilizer, incomplete fertilizers and complete fertilizers. Single element fertilizers contain only one fertilizer element. Such examples are ammonium sulphate. urea, super-phosphate and muriate of potash. On the other hand, incomplete fertilizers contain two fertilizer elements e.g. Ammonium phosphate. Compound fertilizers contain two or more elements. Fertilizers containing all three elements are designated as complete fertilizers.

The composition of a fertilizer element in a fertilizer formulation is expressed in percent. If ammonium sulphate has a formulation of 21 percent N, it means that in every 100kg of ammonium sulphate there is 21kg of available nitrogen. The analysis of most fertilizer materials available commercially is expressed by a numbering system showing the percentage of

composition of each element in the order N-P-K. These numbers are printed on the label of each fertilizer container.

Thus, a 5 - 10 - 15 grade contains 5% N, 10% P_2O_5 and 15% K_2O. In some countries grades are given in elemental form N.P.K. The remaining 70 percent of the product consists of other elements, such as calcium, chlorine and oxygen. If a nutrient is missing, it is represented by a zero, thus 45-0-0 for urea, 0-44-0 for triple superphosphate, 0-0-60 for potassium chloride and 21-23-0 for diammonium phosphate.

Several technical journals in recent years have adopted the "elemental" expressions, P and K, for phosphorus and potassium in lieu of the "oxide" expressions, P_2O_5 and K_2O..

To convert oxides to elemental forms and vice versa:

$$\% P_2O_5 = \% P \times 2.29$$

$$\% P = \% P_2O_5 \times 0.44 \text{ and}$$

$$\%K_2O = K \times 1.2$$

$$\%K = K_2O \times 0.83$$

The chemical composition of the fertilizers commonly found on the market in Africa which can be used to fertilize soybeans, depending on one's location, are shown in Table 6.7.

Table 6.7: Fertilizers commonly available on the market in Africa which could be used to fertilize soybeans.

Fertilizer	Available % N	P_2O_5	K_2O	Chemical formula
Urea	46	0	0	$CO(NH_2)_2$
Ammonium sulphate (2.4%S)	21	0	0	$(NH_4)_2 SO_4$
Ammonium Chloride (68% Cl)	26	0	0	NH_4Cl
Ammonium nitrate	33	0	0	NH_4NO_3
Ordinary superphosphate (12%S)	0	20	0	$Ca(H_2PO_4)_2.CaSO_4$
Triple superphosphate	0	46	0	$Ca(H_2PO_4)_2$
Ammonium Phosphate	11	20	0	$NH_4H_2PO_4$
Diammonium phosphate	21	23	0	$(NH_4)_2HPO_4$
Muriate of Potash (46% Cl)	0	0	62	KCl
Compound Fertilizers				Mixture of above

6.7.1 Computations.

When given the recommended rate of fertilizer and the fertilizer material one can buy locally, one must be able to weigh the exact amount of the appropriate fertilizer materials to apply to a given area.

Procedure for computation:

Operation 1. Calculating for single element fertilizer

Steps:	Key points
1. Decide what fertilizer material to use	Select a fertilizer material that is: (a) locally available (b) least expensive per unit of needed plant nutrients.

Steps	Key points
	(c) Suited to the soil conditions (slightly acid soil requires fertilizer with less residual acid effect)
	(d) Stored and applied with available equip ment.
2. List necessary data	The data needed are:
	(a) The recommended rate R of application of the single element (kg/ha).
	(b) The analysis (C) of the selected single element fertilizer material (%), and
	(c) Area A to be fertilized (m^2)
3. To compute the amount of fertilizer materials required per hectare	: Divide rate R by the analysis C Rate (kg/ha): $\frac{\text{Analysis (\%)}}{100}$ or $R = \frac{R}{\frac{C}{100}} = \frac{100R}{C}$
4. To compute the amount of fertilizer material required per square meter,	Divide the required amount per hectare by 10,000. $\frac{100}{C} \div 10{,}000$ or $\frac{100R}{10{,}000C} = \frac{R}{100C}$ (kg/m^2)
5. To compute the amount of fertilizer material required for area concerned,	Multiply the required amount per square meter by the number of square meters of the area. $\frac{R}{100C} \times \text{Area } (m^2)$ or $\frac{\text{Rate (kg/ha)} \times \text{Area}(m^2)}{100 \times \text{analysis (\%)}}$ = kg fertilizer required for the area

Operation 2. Calculations of fertilizer materials required by recommendations involving more than a single nutrient element.

Steps:	Key points:
1. Decide what combination of fertilizer material to use	The combined fertilizer materials should: (a) contain all the elements required (b) be available locally (c) be least expensive; and (d) be suited to the soil conditions

For example a recommended rate of 80-30-30 can be made up from the complete fertilizer 14-14-14 and urea, or from urea, triple superphosphate and muriate of potash.

2. To compute the amount of each fertilizer material to satisfy the recommended rate	(a) If you select fertilizer materials containing only single elements, proceed to Operation 2A. (b) If you select fertilizer material containing an incomplete or a complete fertilizer, proceed to Operation 2B.

Operation 2A: Calculation of fertilizer materials required by recommendations involving more than a single element. Case 1: Combination of single element fertilizer materials.

Steps:	Key points.
1. List the given data and the analysis of selected single element fertilizer materials	Given Data: (a) the area (A) to be applied (m^2) (b) the recommended rates of fertilizer application (RN-RP-RK) with RN (kg/ha N) RP (kg/ha P_2O_5) RK (kg/ha K_2O)

In the above example urea, triple superphosphate and muriate of potash are selected, therefore:

Urea	45%N
Triple superphosphate	44% P_2O_5
Muriate of potash	60% K_2O

2. To compute the individual amount of each single element of fertilizer material required for the area concerned	Refer to Operation 1: Compute first the amount of urea required then those of triple superphosphate and muriate of potash to satisfy the recommendation of 80-30-30 in the example above.

Operation 2B. Calculation of fertilizer materials required by recommendations involving more than a single element. Case 2. Combination of single element and incomplete or complete fertilizer materials.

Steps:	Key points.
1. List the given data and the analysis of selected fertilizer materials	(a) Given data: Area and recommended rate (b) For example, if 14-14-14 and urea are used to satisfy the recommendation 80-30-30, list down: 14-14-14: 14%N, 14%P_2O_5 and 14% K_2O; urea 46%N, (c) or if ammonium sulphate, monoammonium phosphate and muriate of potash are selected, list: ammonium sulphate: 21%N, monoammonium phosphate : 11%N, 20% P_2O_5 muriate of potash: 60% K_2O
2. To compute the amount of fertilizer material that satisfied the element required in the smallest quantity	In the recommended rate 80-30-30, phosphorus and potasium are least required. They must be computed first. If the combination 14-14-14 and the urea is used, 30kg of P_2O_5 and 30kg of K_2O are supplied by the 14-14-14 $\frac{30 \times 100}{14}$ = 214.2 kg/ha of 14-14-14
3. To compute the remaining amount of the element required	In the example above, 214.2kg of 14-14-14 gives 30-30-30. Subtract this from the rate 80-30-30. 80-30-30 - 30-30-30 50-0 - 0 or 50kg of N is yet to be supplied by urea.

4 To compute the amount of fertilizer material that satisfies the remaining amount of the element required.	Divide the remaining amount by the analysis of the fertilizer material. If 50kg of N is supplied by urea the weight of urea is obtained $\frac{50}{45} \times 100 = 111.1$ kg/ha of urea.

Further examples:

1. Calculate how much ammonium sulphate is needed to supply 100 kg/ha of nitrogen to an area of 2,500 sqm.

Solution

Step 1.	Fertilizer material to use: ammonium sulphate
Step 2.	Necessary data Rate R = 100 kg/ha N. Analysis of ammonium sulphate C = 20% Area A = 2,500 m^2
Step 3.	Required amount per hectare = $\frac{100R}{C} = \frac{100 \times 100}{20} = 500$ kg/ha
Step 4	Amount required per square meter = $\frac{R}{100C} = \frac{500}{10,000} = kg/m^2$
Step 5.	Amount required per area of 2,500m^2 0.05 x 2,500 = 125 kg of $(NH_4)_2 SO_4$

Example 2.

Suppose a certain soil requires a fertilizer rate of 120-40-10. List the possible combination of the following materials which might be used to make up the recommended rate: urea, ammonium sulfate, monoammonium phosphate, triple superphosphate and 16-20-0.

Example 2A : If urea and triple superphosphate were selected for instance, show how much of each material is needed to fertilize a plot of 625 sqm.

Solution:

Step 1. Listing

- Area : $625m^2$
- Rate of application : 120 kg/ha N and 40 kg/ha P_2O_5
- Urea : 45%N
- Triple superphosphate: 44% P_2O_5

Step 2. Amount of urea required

$\frac{120 \times 625}{100 \times 45}$ = 16.6 kg urea

Step 3. Amount of triple superphosphate required

$\frac{40 \times 625}{100 \times 44}$ = 5.7 kg triple superphosphate

Example 2B.

If urea and monoammonium phosphate were selected, show how much of each material is needed to fertilize the same plot of $625m^2$.

Solution

Step 1. Listing

Area : $625m^2$
Rate of application : 120 kg/ha N and 40 kg/ha P_2O_5
Urea : 45% N
Monoammonium phosphate : 11% N and 45%P_2O_5

Step 2. The element which has the smaller rate is P_2O_5. It is supplied by monoammonium phosphate. The amount of monoammonium phosphate needed is: $\frac{40}{45} \times 100 = 88.9$ kg/ha

or $\frac{40 \times 625}{100 \times 45}$ = 5.55 kg for the urea

Step 3. 89.9 kg of monoammonium phosphate contains

$\frac{11 \times 88.9}{100}$ = 9.7 kg N.

Remaining amount of N to complete the rate
120 - 9.7 = 110.3 kg of N supplied by urea.

Step 4. Required amount of urea

$$\frac{110.3 \times 100}{45} = 245.1 \text{ kg/ha urea}$$

or $\frac{110.3 \times 625}{100 \times 45}$ = 15.3 kg urea for the area

6.7.2 Fertilizer calculation involving volume of soil rather than area of land :

This is important especially when working in a greenhouse where plants are grown in pots. Here the important point is the weight of the soil which can easily be obtained by weighing it on a suitable balance. The weight of the soil in the pot is then taken as a fraction of the weight of soil that is present in one hectare furrow slice of the land.

One hectare furrow slice of normal agricultural soil weighs about 2,240,000kg of soil. So if one has soil weighing 10kg in a pot (the weight of the pot is excluded); It can be computed as follows on a per hectare basis:

$$\frac{10}{2,240,000} = 0.000004464 \text{ ha.}$$

From here one can follow the same procedure as in example one, bearing in mind that the final weight to be weighed will be in grams or milligrams so that one can have figures which are manageable.

6.8 Mixing of fertilizers.

When a fertilizer treatment requires material containing more than one element, it is likely that an incomplete or a complete fertilizer will be used. These materials may be weighed and applied separately, or they may be blended and the mixture applied to the soil. The latter procedure is more

convenient and facilitates field application, especially in large mechanized farms. However, not all fertilizer materials can be mixed. For example, strong basic materials, such as lime, should not be mixed with urea since nitrogen may be lost as ammonia. It should be understood that fertilizers of greatly different particle size should not be mixed as these tend to separate during handling.

Procedure:

If mixture weighs more than 75kg, it should be prepared in two or more batches, as it is difficult to achieve uniform blending of a large quantity. Spread out the materials in thin layers, one above the other, over a smooth, clean surface. Two men with shovels will take positions facing one another on either side of the fertilizer. Each simultaneously raises a shovel full of materials and passes the contents to meet the contents of the other's shovel. This mixing action is continued, and the two men occassionally change their positions, until it is impossible to distinguish a streak of individual material in the mixture.

For less than 10kg, one man can easily accomplish the above mixing procedure with his hands, or by shaking the materials in a bag. Micronutrients which are required in very small amounts need special treatment to ensure uniform spread. In such circumstances they should be mixed with a major fertilizer. Where this is not possible, the small quantity of fertilizer should be mixed with sand so that enough volume is obtained which can then be spread in the field uniformly.

With pot experiments in the greenhouse, uniform spreading of the

fertilizer can be achieved by dissolving the fertilizer in water and then spraying the dissolved fertilizer into a rotary mixer containing the soil, or applying through the irrigation water.

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CHAPTER SEVEN

WEEDS AND THEIR CONTROL

7.1 Introduction.

Weeds compete with soybean plants for water, nutrients, and sunlight. Weed problems are generally greater in the tropics than in the temperate zone owing to higher densities and more vigorous growth of a wide range of weed species in the tropics. The average yield losses of cowpeas and soybeans due to weed competition in Nigeria and India were about 50% (Bhan, 1975; Moody and Whitney, 1974) whereas in the United States the average yield losses of soybeans were about 17% (Vega *et al.*, 1970).

Weed growth can be extremely rapid in the tropics, and control by any means can be difficult. In Jamaica weeds have produced 700 kg/ha above ground dry matter in four weeks, even though growing with a vigorous crop of soybeans (Hammerton, 1979). High soil temperatures may reduce establishment and early growth of soybeans (Aquino and Beckendam, 1969), placing the crop at a competitive disadvantage. High temperatures, combined with heavy and/or frequent rains, reduce herbicide efficacy. Cultural control - by motorised or hand equipment - may be impractical or largely ineffective if persistently wet soil prohibits access and facilitates re-establishment of weeds. Rapid establishment from seed can result in heavy weed growth following effective control, particularly before crop canopies have closed or when they open as the crop matures. Weeds present at harvest can seriously reduce yields and affect quality of the crop (Nave and Wax, 1971). Prickly weeds, such as

Cenchrus spp.,*Rottoboelia exaltata*, and *Mimosa pudica* are particularly serious with hand harvesting (Hammerton, 1979).

Not only are soybeans inefficient photosynthetically compared with several important tropical weeds (Black *et al.*, 1969), but as an "alien" species, they are at a competitive disadvantage relative to the indigenous weed flora. If nodulation is poor or ineffective, the crop's competitive ability is further reduced. Planting date can affect crop stature, due to the photoperiodic response of most varieties. Weed control, planting date, and spacing will therefore interact (Chan and Tsaur, 1973).

At IITA the major weeds found which can seriously reduce the yield of soybeans are three species of grasses (*Eleusine indica*, *Digitaria horizontalis* and *Brachiaria deflexa*) and seven species of broadleaved weeds (*Amaranthus spinosus*, *Euphorbia heterophylla*, *Commelina benghalensis*, *Physalis angulata*, *Phyllanthus amarus*, *Talinum triangulare* and *Synedrella nodiflora* (Nangju, 1978). The proportions of grassy and broad leaved weeds can vary from field to field depending on the cropping history.

Hemmerton (1979) has listed the most serious weeds so far reported in soybeans in tropical and subtropical areas. Some are regional in distribution but others are pantropical. Those with an asterisk are among the world's most serious weeds (Holm and Herberger, 1970).

1. Perennial grasses and sedges: **Cyperus rotundus*, **Cynodon dactylon*, *Panicum muticum*, *Imperata cylindrica*, **Paspalum fasculatum*, **Sorghum halepense*.

2. Grasses reproducing by seed: *Andropogon spp.*, *Cenchrus spp.*, *Digitaria sanguinalis*, **Echinochloa spp.*, **Eleusine indica*, *Panicum spp.*, **Rottboelia exaltata*, *Setaria spp.*

3. Broad-leaved weeds: *Amaranthus spp*, *Boerhavia spp.*, *Bidens pilosa*, *Cassia spp.*, *Cleome spp.*, *Commelina spp.*, *Euphorbia spp.*, **Ipomoespp.*, *Macroptilium lathyroides*, **Portulaca oleracea*, *Sida spp.*

Those in 1 are difficult to control by all control methods. Many in 2 are only moderately susceptible to many pre-plant incorporated or pre-emergence herbicides. Many of the species in 3 are susceptible to herbicides, but *Ipomoea spp.*, *Commelina spp.*, and *P. oleracea* are difficult to control.

7.2 Control problems.

Weed control must commence early, must be maintained for about six weeks, and may need "reinforcing" to avoid weediness at harvest. Possible control methods include not only tractor-mounted hoes and cultivators but walking motorised inter-row cultivators, animal-drawn cultivators, herbicides applied by knapsack or tractor-drawn sprayers, and hand-hoeing and hand-pulling of weeds. Hand-hoeing is here used to include the use of all types of hand tools for weed control, including machetes. Hand labour may be the major, or the sole, control method in peasant farmer production, although herbicides may assist the peasant farmer to achieve greater timeliness of control.

7.3 Mechanical methods of weed control.

Mechanical methods are widely used in Africa and other developing areas to keep soybean fields free of weeds. These methods include manual removal

which may also include the use of hand tools like spades and hand hoes. Manual removal of weeds using a hand hoe accomplishes the job effectively. Two weedings at approximately 15 and 45 days after sowing usually keeps the field clean throughout the cropping period.

Animal or tractor drawn inter-cultivators are also used. Size of hoe in the intercultivating equipment varies with soil type and moisture conditions prevailing in the field.

The only problem often faced in hoeing is the presence of weeds between the plants within a row, which cannot be removed by hoeing. A similar problem is found when the animal or tractor powered intercultivators are used. Mechanical weeding techniques, especially hoeing and use of inter-cultivators is difficult to practice after 30 to 40 days of crop growth because of dense canopy that develops after that period. This impedes movement and crop plants are often damaged. Mechanical methods of weed control though effective are costly and time consuming. Availability of labour at the right time for weeding is difficult because of the many other demands on the farm for the farmer's labour at the early stages of crop establishment. In some countries in the humid tropics, almost continuous rains during the growing season do not permit effective use of mechanical control methods. Where the farm area is large, manual removal of weeds is too time-consuming to cover the area at the right time.

The use of draught animals for weed control has many advantages over the tractor, including local production, use of local and renewable fuel (largely crop residues), a lack of spare parts problems, and, in the case of work oxen, negative depreciation as they can always be sold for meat

at more than their purchase price (Ogborn, 1978). The main disadvantage seems to be low draught and susceptibility to trypanosomiasis.

7.4 Cultural methods.

Among the cultural methods, plant density and plant type have been reported to play significant roles in weed control. As row spacing decreases, fewer interrow cultivations and lower rates of herbicide are needed to achieve comparable weed suppression (Burnside, 1972). High plant populations enable soybeans to smother weeds during the early critical stage. Later, soybean plants spread enough canopy to compete successfully with weeds, thus controlling them (Table 7.1).

Table 7.1: Effect of spacing on weed control in soybean (After Nangju, 1978)

Spacing (cm)	Weeding treatment	Seed yield(kg/ha)	% losses due to weeds
10 x 75	Without	682	54
	With	1481	
20 x 37.5	Without	1575	19
	With	1934	
30 x 25	Without	1445	18
	With	1765	
5 x 75	With	1172	44
	Without	2070	
10 x 37.5	With	1611	27
	Without	2209	
15 x 25	With	1732	11
	Without	1955	
	LSD (0.05)	230	

However, at either plant density, the 75cm row spacing had higher percentage of yield losses due to weeds than the 37.5 or 25cm row spacings. This indicates that narrow row spacing was more effective in suppressing weed growth than wide row spacings, even when plant density was altered. Time of weeding is important even in narrow spaced soybeans, Early and timely weeding will enable the crop to have an early establishment.

Soybeans planted at narrow row spacings, with timely weeding, yielded more and were much more effective in suppressing weed growth than soybeans planted at wide row spacings and weeded late. This was probably because of increased competition and faster shading of the soil surfaces as illustrated by data in Table 7.2 (Moody, 1976).

Table 7.2: Effect of time of weeding and row spacing on yield of three soybean varieties in Nigeria.

Weeding treatment (weeks after emergence)	Soybean yield (kg/ha)					
	CES 408		Hardee		Kent	
	50 cm	75 cm	50 cm	70 cm	50 cm	70 cm
As needed	1,014	648	2,873	1,788	1,344	719
1 + 4	1,119	490	2,565	1,450	1,403	816
1 + 3	771	574	2,836	636	1,381	989
4	1,160	338	2,132	1,145	1,244	530
3	848	679	2,487	332	945	499
No weeding	152	241	387	95	556	104

However, soybeans cannot be grown at extremely narrow spacing as this can result in yield loss due to lodging and/or interplant competition. Furthermore, the use of narrow spacings can make interrow cultivation impractical.

Studies conducted at IITA (Nangju, 1978) to evaluate the effects of plant density, spatial arrangement and plant type on weed control in soybeans showed that the short, early cultivar Williams had the lowest leaf area index and the highest weed weight compared with Bossier and Jupiter (Table 7.3).

Table 7.3: Effect of weeding and spacing on growth, yield and quality of soybeans, 1977. (After Nangju, 1978).

Cultivar	Spacing	Seed yield (kg/ha)		Seed weight (kg/ha)		LAI		Smooth clean seed (%)		Germination (%)	
		W0*	W1**	W0	W1	W0	W1	W0	W1	W0	W1
Williams	5x75	507	1625	3130	8	1.74	3.07	36.0	66.8	45.3	73.5
	5x37.5	1230	1617	1000	227	2.85	2.84	55.5	65.3	63.8	66.3
Bossier	5x75	851	1808	1400	13	2.90	3.50	51.0	66.0	56.3	65.5
	5x37.5	1369	1644	280	13	4.39	3.67	51.0	73.3	67.5	75.5
Jupiter	5x75	327	558	810	13	3.11	3.96	33.8	57.5	35.8	60.0
	5x37.5	300	476	120	0	4.08	4.15	52.0	60.3	53.0	68.3
LSD (0.05)		166		440		0.71		8.1		9.3	

W0* = No Weeding

W1** = With two weedings

The tall, late-maturing Jupiter had the highest leaf area index and lowest weed weight. Row spacing had no effect on seed yield when the weeds were properly controlled, but increased the yields of soybeans up to 142% in weeded plots. Weeds not only reduced seed yield but also seed quality and germination of soybeans (Table 7.3). The effect of weeds on seed quality and germination was noticeable only in Williams and Bossier which matured during the rainy season, but not in Jupiter which matured during the dry, sunny weather. Apparently the weeds around soybean plants altered the microclimate around the pods since the relative humidity and seed moisture content were higher in weedy plots than in weed free plots at a given time during the day. This was reflected in the higher percentage of purple-stained seed and lower percentage germination of seed obtained from weedy plots.

In addition, weeds present during pod ripening of soybeans significantly reduced the percentage of smooth, clean seed and germination of soybeans when maturation occured during wet weather (Table 7.4)

Table 7.4: Effect of weeding on seed yield and quality of soybeans, 1977 (After Nangju, 1978)

Cultivar	Weed weight(kg/ha)		Seed yield (kg/ha)		Germination %		Smooth Clean Seed (%)	
	W0*	W1**	W0	W1	W0	W1	W0	W1
Williams	3801	1066	1221	1709	75	69	69	95
Bossier	1546	235	1472	2049	92	91	90	97
Jupiter	2354	463	1416	1949	95	94	94	94
LSD (0.05)	1649		237		3		2	

W0* = No weeding

W1** = With one weeding at 30 DAP

The plant characters associated with the competitive ability against weeds were plant height, leaf shape and size, and leaf area index.

7.5 Chemical control.

Chemical control may start with a preplant application of a pre-emergence herbicide. Preplant herbicides are normally sprayed before or immediately after planting. Some which are volatile and may be lost if left on the surface must be worked into the soil before planting. Some are photosensitive and must be protected from the effect of the sun. Such herbicides, therefore, need to be incorporated with the soil to prevent rapid degradation and loss. Incorporated herbicides are usually less dependent on rainfall after application than those applied on the surface. The success of both types of chemicals is influenced by such factors as soil type, soil moisture and rainfall. The effectiveness of some herbicides is influenced by the organic matter content of the soil. As a result of this, an application rate that causes crop injury in one field may fail to control weeds elsewhere.

Limited work on chemical weed control in soybean show that pre-emergence application of metolachlor at 1.5 - 2.5 kg/ha; alachlor, at 2.0 kg/ha can be used for control of most annual grass weeds and some annual broadleaf weeds. Acifluorfen, Blazer and Bentazon have also shown promise as post-emergence herbicides for use in soybeans to control broadleaf weeds. Field evaluation of several herbicides to identify appropriate rates for tropical conditions is currently underway at IITA.

An integrated approach involving preventive, mechanical, physical, chemical and cultural methods of weed control is required for effective weed control in the tropics. The keys to successful weed control, however, are good stand (optimum density ranges between 300,000 to 500,000 plants/ha), early weed removal, narrow rows (between 30 to 60cm) and fairly tall varieties which can shed weeds effectively. At the same density narrow rows generally produced higher yields, better distribution of soybeans over the soil surface, increased competitiveness of soybeans against weeds and reduced soybean lodging compared with wider rows (Nangju *et al.*, 1978).

Relatively clean land should be used for soybeans. Maize can be used as a preparatory cleaning crop, and in rotation with soybeans. Dry season fallow may help, or during rainy seasons, paraquat might be used to prevent seeding and propagule production.

Minimum tillage reduces soil erosion and deserves wide investigation for soybean and other crops. Crop rotations must aim at progressively reducing weed infestations but must take cognizance of rainfall patterns, photoperiods and the need to provide employment of hand labour where it is cheap. Sequential herbicide treatments need to be devised where hand labour is not available.

7.6 Herbicide application

The present methods of applying herbicides available to the small scale farmers are: (i) Knapsack sprayer, two types (a) pressurized tank (Pnuematic) the type required to be pumped up and then used and (b)

pressurized dome (hydraulic) which is pumped with one hand as you spray. (ii) Controlled Droplet Applicator (CDA). The advantage of the knapsack sprayer is that it is widely used and its application and maintenance are understood better than the controlled droplet applicator.

The pressurized tank type of knapsack sprayer is less likely to contaminate the operator than the pressurized dome type. This is because the pressurized tank is sealed when in use and chemicals will not spill out on the operator, whereas with the pressurized dome type chemicals will spill out of the filling cap as it is not sealed. Due to this, the operator's back may be continuously wet with chemicals. This problem may have already been solved, if not then it needs attention. A pressure regulator is important to keep even application rates. Both the pressurized dome and pressurized tank type sprayers can be found with regulators. The regulator on the pressurized dome is probably less complex in relation to maintenance. Some pressurized tank sprayers are designed so they can be pumped up onee and completely empty the tank with only 4 atmospheres of pressure (60 psi).

The controlled droplet applicator (CDA) has the advantage of a low liquid application rate per hectare. It works well on pre-emergence herbicides and systemic herbicides. Its effectiveness with some contact herbicides seems to be questionable under conditions which will exist on the small scale farm. These sprayers are electrically operated which gives a new dimension to maintenance which is not understood in the rural areas.

Motor corrosion and bad electrical contacts are very common due mostly to poor cleaning of equipment. The nozzle is probably the most important part of the sprayer. Other parts exist only to help the nozzles operate properly. Nozzles determine uniformity of spray application, rate of application, and spray drift.

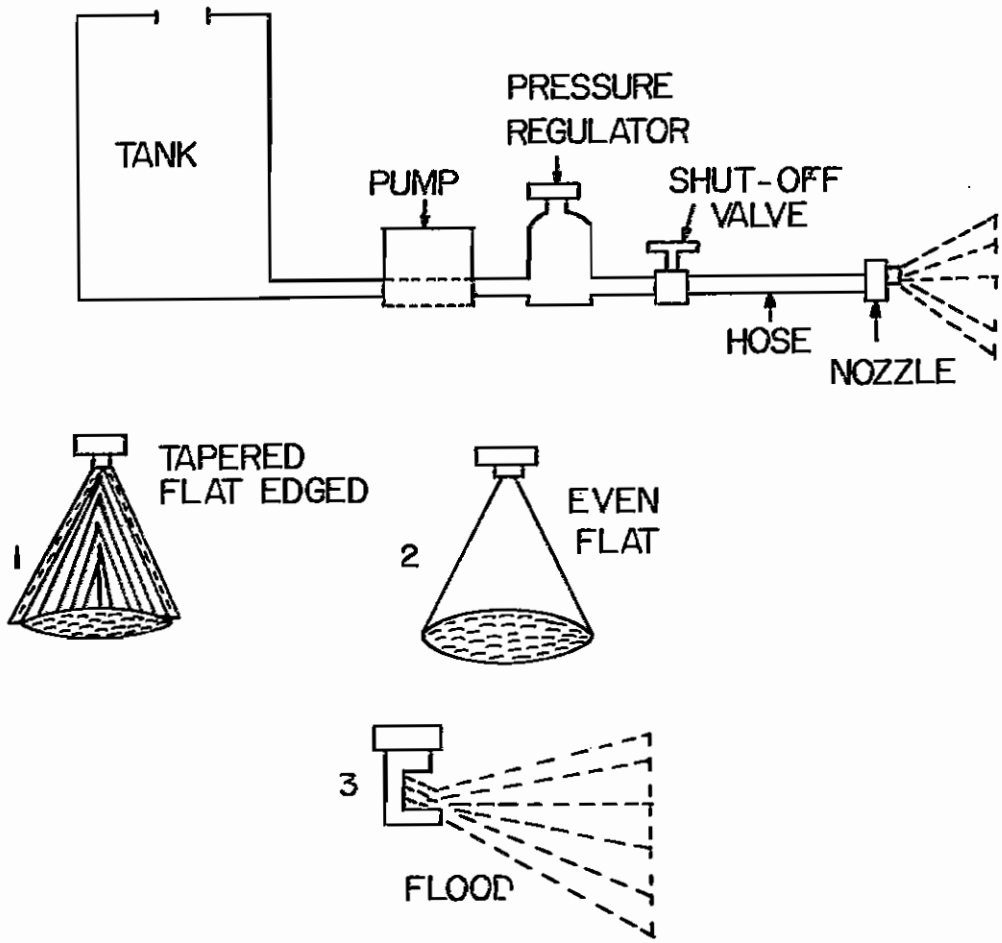


Figure 7.1. Sprayer component and types of nozzles used for weed control:

1 & 3 : Used for broadcast spraying (preemergence or post-emergence)

2 : Used for directed spraying.

Most commonly used nozzles are the flat-fan, tapered nozzles, and wide-angle hollow-cone nozzles (for broadcast spraying), the flat-fan, even-edge, and the hollow cone nozzles (for band application) and the flooding nozzles (Figure 7.1).

All of these sprayers have one problem in common: the feet of the operator are constantly in the chemical. All but one of the sprayers spray in front of the operator and he immediately walks through the sprayed vegetation with his bare feet. One CDA sprayer is held behind the operator but if he has a reasonable walking stride the back of his foot will be sprayed.

It is necessary to develop a boom sprayer for the small scale farmer, as it increases his rate of work as well as reduces the number of his spray misses due to insufficient overlaping. This could be a 4 meter boom carried behind the operator attached to the sprayer, eliminating walking through the sprayed surface. A long boom carried by two men could also be used. This does not eliminate contamination of the feet. The advantage of this type of boom is that a more constant height above the surface being sprayed can be achieved whereas a boom sprayer at the back of the operator will vary in height depending on the position the operator takes. If he leans forward the boom becomes higher, if he leans backward it will become lower. The operator's position will vary with the fullness of the sprayer on his back.

7.7 Small spraying equipment.

Irrespective of design, most spray units have the following parts in common: nozzles, a container (tank) to hold the spray, and a pump to force

the spray through the nozzle. Other accessories usually found in sprayers are filters or strainers, pressure guage, pressure regulator, shut-off valve, and connecting hoses. The purpose of spraying is to control pests and diseases. In order to control pests and diseases with a sprayer a certain amount of accuracy is necessary.

(i) Correct rate. The correct rate of application is necessary. The correct rate will save money, save time, control pests, increase revenue from the crop and minimize pollution.

(ii) Even application. The spray needs to be applied evenly to the target. For example, uneven applications of herbicide will cause weeds to be controlled only where enough herbicide was applied. To do accurate work the spraying equipment needs to be maintained in good condition in order that (a) the operator does not get contaminated (b) work gets done when itis needed (c) the life of equipment is increased.

(iii) Factors responsible for incorrect rate and uneven application. The major problem in the field is applying a chemical at a wrong rate. The reasons for this are:

(a) wrong chemical : water ratio

(b) wrong walking speed,

(c) wrong equipment - wrong nozzle, insect sprayer for herbicides

(d) defective equipment - (i) dirty screen, (ii) plugged nozzle, (iii) over-sized nozzle

(e) wrong pressure setting,

(f) wrong chemicals for sprayer,

(g) too high wind speed,

(h) wrong height above surface receiving spray.

7.8 Sprayer calibration.

(i) Calibration. is the most important thing. Even wrong equipment will often work reasonably well if calibrated correctly.

(ii) How much chemical to put in tank. The following information is necessary before starting to calibrate a sprayer.

(a) Walking speed - 0.75m/sec. (45m/min., 2.7 kph) is a reasonable speed for normal field conditions. One can use any speed but the operator must be able to keep going at that speed in the field all the time he is spraying. If you choose to use 0.75m/sec. then you have to practice.

Set out 2 poles 45m apart on conditions similar to the field to be sprayed. It takes one minute to walk between these two poles when walking at 0.75m/sec. If operating at another speed walk for one minute and measure the distance. This measurement is meters per min. ($\frac{\text{m}}{\text{min.}}$)

(b) Width of nozzle coverage. Hold nozzle at the height recommended by its manufacturer - 0.30m to 0.75m above top surface to be treated. A string this length with a small stone tied at its end helps tremendously to maintain the correct height above the surface being sprayed (see Fig 7.2). To check width, hold nozzle at the operation height over concrete or bare ground, operate sprayer, measure width on the surface in meters. This should be done carefully with the correct amount of chemical in water being

used as this affects the pattern width. 2ml of liquid detergent usually will work instead of chemical. An overlap of spray is necessary. It is usually 20-50% of the total width. This must be subtracted from the above measured width to get the effective width for calculation purpose as well as the width used in the field.

(c) Measure sprayer output liter/min. (i) operate sprayer at the correct pressure with chemical or liquid detergent as mentioned, (ii) collect all liquid for one minute coming from the nozzle, (iii) measure this liquid in liters = $\frac{\text{liters}}{\text{min.}}$. With the above information the sprayer can now be calibrated mathematically.

(d) Calculation. The liters of liquid (water + chemical) to be applied per hectare can be calculated using the following formula:

Equation No.1:

$$\frac{\text{Liters}}{\text{ha}} = \text{Nozzle output } \left(\frac{\text{liters}}{\text{min.}}\right) \div \text{spray pattern width(meters)} \div \text{forward walking speed } \left(\frac{\text{m}}{\text{min}}\right) \times \frac{10000\,\text{m}^2}{\text{m}}$$

Calculation of the amount of chemical to put in the sprayer tank:

Equation No.2.

$$\text{Amount of chemical to put in tank(liters/kg)} = \text{spray tank capacity(liters)} - \frac{\text{liters}}{\text{ha}} \times \text{amount of chemical to be applied per ha*}$$

(from equation No.1)

* This may be in liters if a liquid or in kg if a powder.

(e) Examples:

Chemical to be applied = Gramoxone

Rate of application = 2.5 liter per hectare

Walking speed = 45m/min.

Total nozzle width of coverage = 1.5m

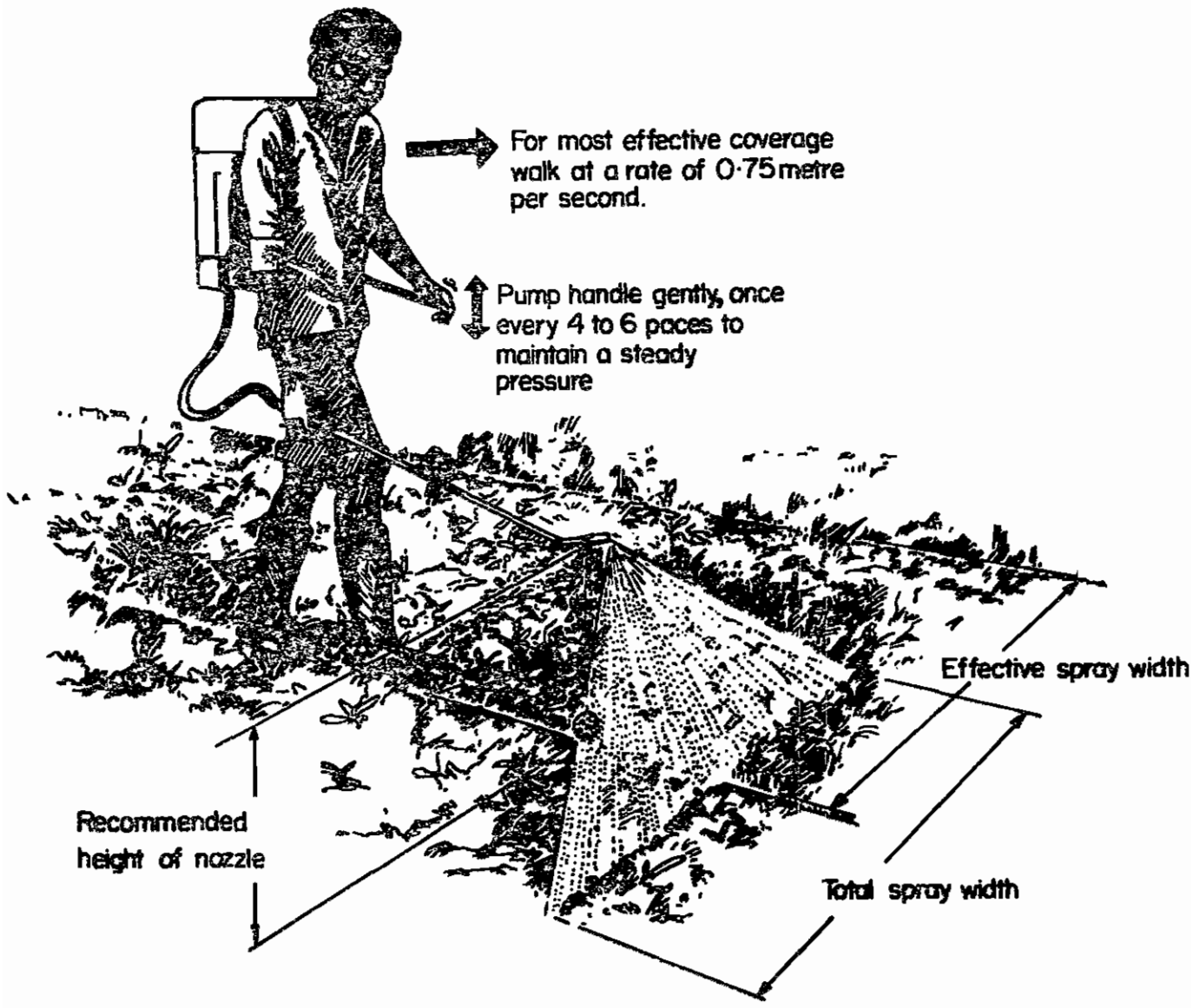


Figure 7.2 Knapsack sprayer (Adapted from Ray wijewardene)

Overlap 20%

Nozzle output at 1 bar or 14 psi is 0.4 liters/min.

Sprayer = CP3, 20 liter tank.

Using Equation No.1, the first thing to do is to check the units. The nozzle width of coverage is not the effective width.

$$\text{Effective width} = \text{Total width of coverage} - \text{Total width of coverage} \times \frac{20}{100}$$

$$= 1.5\text{m} - \left(1.5 \times \frac{20}{100}\right)$$

Effective width = 1.2m

$$\frac{\text{Liter}}{\text{ha}} = \text{Nozzle output} \left(\frac{\text{liter}}{\text{min}}\right) \div \text{Effective spray pattern width(meters)} \div \text{forward walking speed} \left(\frac{\text{m}}{\text{min.}}\right) \times \frac{10000\text{m}^2}{\text{ha}}$$

All units check, put the figures into the equation:

$$\frac{\text{Liter}}{\text{ha}} = 0.4 \frac{\text{liter}}{\text{min.}} \div 45\text{m/min} \times \frac{10{,}000\text{m}^2}{\text{ha}}$$

$$\frac{\text{Liter}}{\text{ha}} = 74 \frac{\text{liter}}{\text{ha}}$$

$$\text{Amount of chemical} = \text{spray tank capacity(liters)} \div \frac{\text{liters}}{\text{ha}} \times \text{amount of chemical to be applied per hectare}$$

$$= 20 \text{ liters} \div \frac{74 \text{ liters}}{\text{ha}} \times 2.5 \text{ liters}$$

Amount of Gramoxone to put in tank = 0.68 liters

(f) Practical calibration

(i) Put a small amount of water into the spray tank and spray it out. There will be some water left in the bottom of most sprayers.

(ii) Now add 5 liters of water to the tank (You may wish to fill the tank, this is actually a better way).

(iii) Start spraying at a marked spot, walk at the pace to be used when actually spraying, keep walking until the total 5 liters or full tank is used up.

(iv) Measure distance walked (step 3 and 4 can be done by placing 2 stakes 50m apart and walking back and forth until the water is all used up. The last distance can be estimated as to what part of 50m it is.

(v) Multiply this distance by the effective spray width. This will give you the m^2 covered. If you have used only 5 liters, multiply the m^2 covered by tank capacity (liters) and divide by 5. This will give you the area covered by one tank $\frac{m^2}{5 \text{ liters}}$ X tank capacity in liters = Area full tank will cover.

(vi) Divide this figure into $\frac{10000m^2}{ha}$, the answer is how many tankfuls will be necessary to spray one hectare.

(vii) Divide the total amount of chemical to be applied per hectare by the number of tanks per hectare. This will give the amount of chemical to put in each tank $\frac{\text{chemical}}{\text{tank}}$ = chemical per hectare (liters or kg) $\div$ tankful per hectare (of chemical)

(g) Example for practical calibration

Chemical to applied = Gramoxone at 2.5 liters per hectare

Sprayer holds 20 liters

(i) Area sprayed with 20 liters of water, sprayed back and

forth between 2 stakes 50m apart $26\frac{2}{3}$ times. Distance travelled is $50 \times 26\frac{2}{3} = 1333m$. The effective width of spray pattern is 0.9m Area sprayed is $1333m \times 0.9 = 1200m^2$.

(ii) Number of times to fill sprayer tank per hectare

$$\frac{\text{Sprayer tank fills}}{\text{hectare}} = \frac{10000m^2}{ha} \div 1200m^2$$

$$\frac{\text{Sprayer tank}}{\text{hectare}} = 8.33 \text{ spray tanks}$$

(iii) How much chemical to put in each tank when it is filled:

$$\frac{\text{Chemical}}{\text{tank}} = \text{Chemical per hectare (liters or kg)} \div \text{tank fills per hectare}$$

$$= 2.5 \text{ liters} \div 8.33 \text{ spray tanks}$$

$$\frac{\text{Chemical}}{\text{tank}} = 0.3 \text{ liters per spray tank}$$

Caution: Be sure the chemical recommendation used for calculation in all the above calibrations is actual product and not active ingredient.

7.9 Controlled Droplet Applicator (CDA)

The CDA sprayers for the small farmer all work on a principle of a spinning disc, powered by batteries. This disc has a nozzle above it which meters a flow of spray solution into the disc. The centrifugal force placed on the liquid by the fact that the disc is spinning causes the solution to flow to the edge of the disc where it is broken up into droplets as it leaves the edge of the disc. The droplets are very uniform in size. The size depends to a large extent on the speed of the disc - a faster speed gives smaller droplets and vice versa. Too high a flow rate through the nozzle (over 100 ml. per min) will cause overloading of the disc which will cause

large droplets.

The uniform droplet size allows a more uniform coverage with less liquid. The CDA herbicide sprayers all break up the spray solution into droplets mostly in the range of 200µm. With a conventional sprayer the droplet size will vary from 60µmm - 600µm with most of the spray volume in the 400µm - 500µm range.

The elimination of the droplet below 200µm with the CDA sprayer reduces the amount of drift due to wind. A droplet of 80µm is going to be blown more easily by wind than a droplet of 200µm. This means that the CDA sprayer can be used at wind speeds slightly higher than a high volume sprayer like the knapsack sprayer. The CDA sprayer should not be used when the wind is over 7kph.

When a spray droplet leaves a spray nozzle it starts to evaporate. (Water carried chemicals evaporate faster than oil-carried). If the droplet is small to start with (60-70µm) it may be reduced in size sufficiently so it will become suspended in the air and will now travel somewhere else. The lower the humidity the greater the problem of airborne chemicals due to evaporation. The CDA sprayer reduces this problem.

The reason the CDA sprayer is important to the small farmer is that it is able to apply lower volumes of liquid and still get effective pest control. This is made possible by having the droplet size kept constant thus the chemical is distributed evenly over total surface. With a conventional high volume sprayer most of the volume of liquid is in droplets of around 500µm.

When 40 liters per hectare is applied there will be one droplet for every two cm^2 of the hectare while with a 200µm droplet with the same application rate there will be 9.5 droplets per cm^2 of the hectare. Both will be applying the same amount of active ingredients but the 200µm droplet will have a better distribution of chemical over the surface. Table 7.5 shows the number of droplets per cm^2 for different droplet sizes with both a 40 liter per hectare and 20 liter per hectare application rate.

Table 7.5: Number of droplets per cm^2 for different droplet sizes

Droplet sizes (µm)	40 liter/ha Droplet/cm^2	20 liter/ha Droplet/cm^2
500	0.6	0.3
400	1.2	0.6
250	4.9	2.5
200	9.5	4.8

For higher volume application the plastic poly jet nozzle can also be used. The CDA sprayer gives a very good control of droplet size but batteries are required, electrical problems do occur, and it is not recommended that paraquat be applied in concentrations of less than 50 parts of water to one part of chemical. This low volume does not seem to give a good result with contact herbicides but works very well with systemic herbicides.

The knapsack sprayers with the low volume flood jet has not been as widely tested as the CDA sprayer. They do work, but their effectiveness has not been fully tested. They do not give the droplet size control that the spinning disc control droplet applicator gives. There are more fine droplets which do drift easily. A pressure regulator is necessary for the nozzle.

7.10 Sprayer problems.

All sprayers give their users problems as well as create problems for people living in areas of spraying. Some of these are:

(i) Plugged nozzles due to dirty water or undissolved chemicals

(ii) Incorrect application rate due to:

(a) wrong calibration,

(b) wrong amount of chemical put into the spray tank,

(c) plugged screen or nozzles,

(d) incorrect pressure

(e) incorrect walking speeds.

(iii) Contamination of operator from leaks or not washing hands after mixing chemicals.

(iv) Contamination of water supply with chemicals

(v) Contamination of operator due to walking through freshly sprayed weeds or from drift from the spray nozzle. The knapsack sprayer with the low volume flood jet is more subject to drift thus getting the operator wet with spray.

7.11 Procedure for spraying.

(i) Straight lines. It is important to be able to walk in straight lines (Fig. 7.3). If the operator does not walk in straight lines there will be places where there is too much overlap of spray as well as places where there is no spray at all as illustrated in Figure 7.4

In Figure 7.4 the areas marked with too much chemical application due to too much overlap will have no weeds, while the area marked as having no

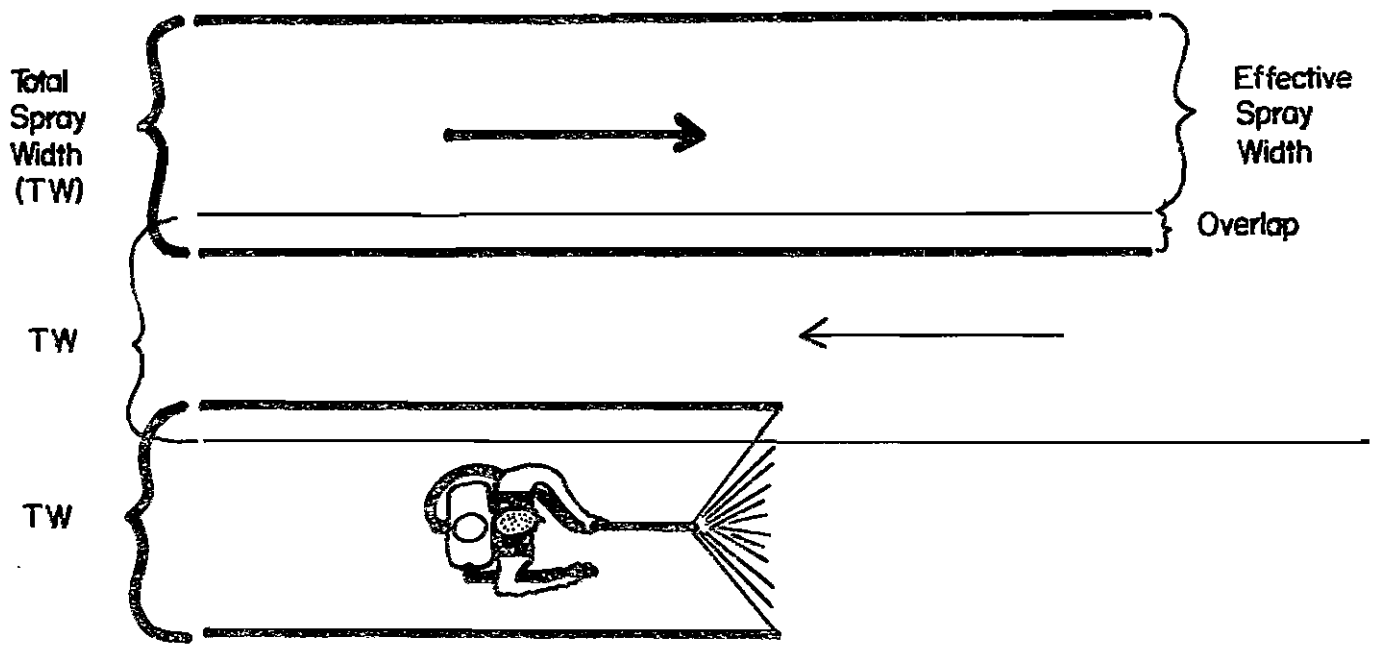


Figure 7.3: Picture of even overlap

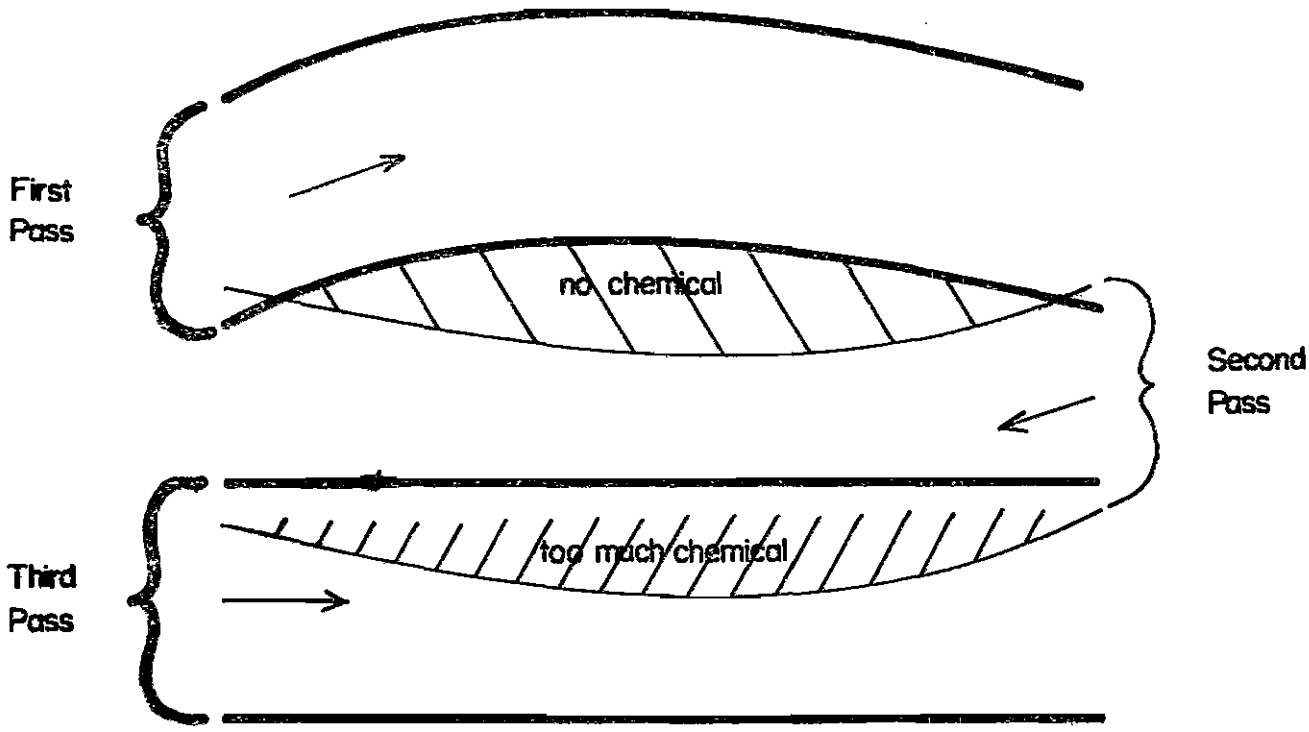


Figure 7.4 Picture of uneven overlap

chemical, weeds will grow. From the diagram the importance of walking in a straight line and at a constant distance from the previous line can be seen. There are several methods which can be used to assist in walking in straight lines. These are: (i) Using a string, (ii) Using range poles.

(a) The string method: This method is not good for a field over 20m as the longer length of string gets unmanageable by one person.

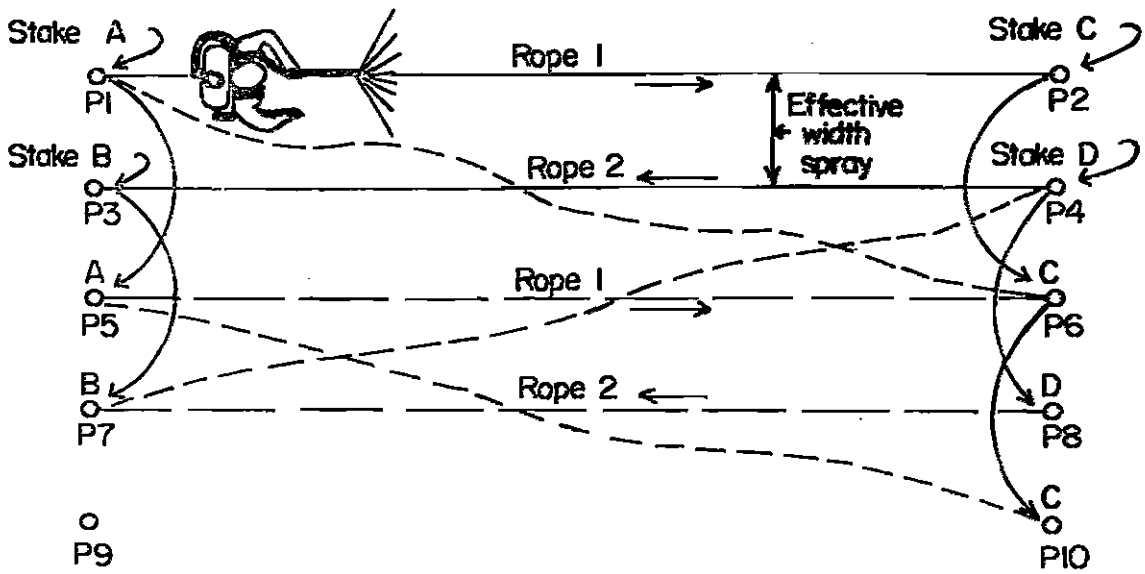


Figure 7.5: Diagram of moving 2 ropes across the field for purpose of spraying or planting

Figure 7.5 shows the method of string movement. The two solid lines from position P_1 to position P_2 and from position P_4 are the original position of the ropes before starting spraying. This is the only time the ropes are parallel.

(i) When spray man reaches position P_2 he moves stake C to position P_6 leaving the string loose and at an angle across the field and returns to stake D at P_3 to spray path $P_3 - P_4$.

(ii) When spray man reaches position P_4 he moves stake A to P_5 and pulls the string straight so there is a straight line between P_5 and P_6 then he moves stake B to P_8 leaving the string loose then he returns to P_5 and sprays $P_5 - P_6$.

(iii) When spray man reaches P_6 he moves stake D at position P_3 to P_7 and P_8 and then moves stake at P_6 to P_{10} leaving it loose.

After the sprayer has reached stake C there will always be one rope crossed over the other. When the ropes are lined up for spraying they must be pulled into a straight line between the two stakes. When the string is left at an angle across the field it does not matter whether it is straight or not. All stakes need to be pressed into the ground firmly enough so they won't be pulled out when moving the string and pulling it into a straight line from the opposite end of the field. This procedure is time consuming but is the most accurate procedure to follow.

(b) <u>The Ranging rod-method</u>:

This method allows longer fields to be done. Stakes should be placed down the field at regular intervals of approximately 30m or less (see Fig.7.6) Each stake should have a mark on it indicating the space between stakes from one row to the next. This marked length should be equal to the effective spray width (see Fig. 7.3 for effective spray width).

All stakes should be lined up in a line. As the person spraying advances down the field he must keep his eyes on the poles making sure he doesn't go out of line. When he reaches a pole he must stop and move the pole over to the next row using the mark on the stake to measure the position of the new row. When he reaches the second but last pole he must select something off in the distance which is in line with the line of sight he has been using, so that he can continue to walk in a straight line and sight on that distant object as if it were a stake. If this is not done the operator can continue to walk towards the correct stake and yet be off the correct path (Fig. 7.7).

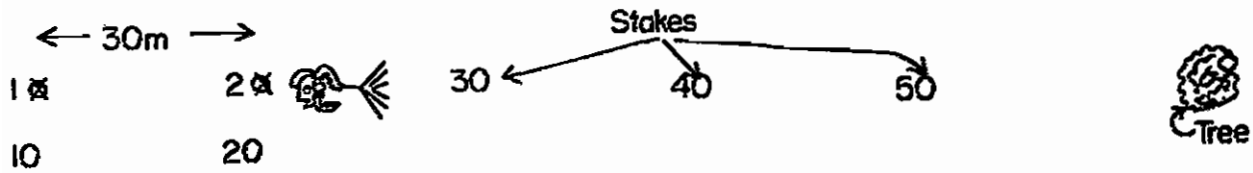


Figure 7.6: Ranging rod methode

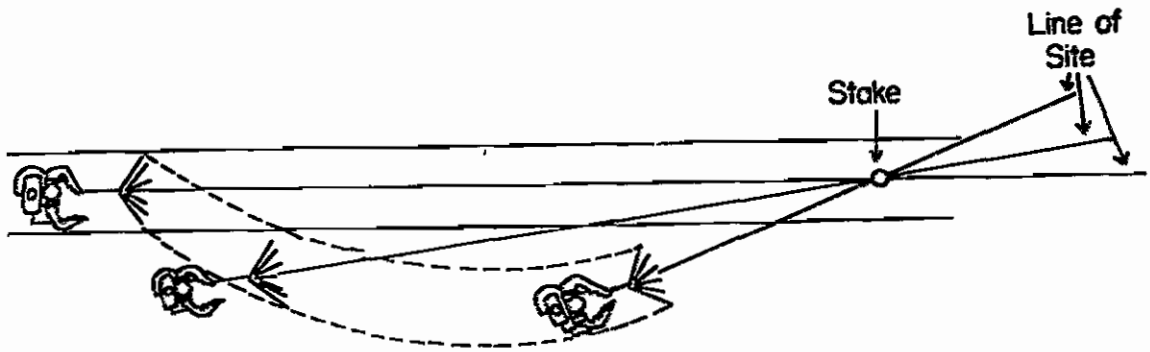


Fig. 7.7: Incorrect sighting.

In Figure 7.6 the stakes are moved as sprayer moves across the field @ indicates stakes have been moved from their position. Before sprayer moves stake No.3 he must pick a distant object to sight on, in this case a tree.

If no object is picked in the distance and there is only one stake left the sprayer as shown in Figure 7.7 can move to his right and always be heading for the stake. The solid lines show the path he should have taken. The dotted line shows the path he took. He has missed his target and the weeds will grow there.

Fewer misses will occur in a field when the sprayer (width) is made wider. A field sprayed with a 3-meter hand-carried boom would have 1/3 as many misses as a one meter boom. It would probably cut the time to spray a hectare to almost 1/3 that of a one meter boom sprayer.

7.11 Mixing chemicals.

It is best to make a habit of putting most of the required water in the spray tank before adding the chemical and then finish filling the last little bit with water. This avoids getting the concentrated chemical in the pump. If the first spray to come out of the nozzle after filling is highly concentrated chemical, the first area sprayed will be over dosed as well as leaving the rest of the tank with an improper amount of chemical in it. Any spilled chemical should be washed off hands outside of sprayer and outside chemical bottle (do not wash up near a water supply).

7.12 Granular applicator.

Granular applicators or spreaders are used for applying granular herbicide formulations. All granular applicators consist essentially of a hopper (tank), a granular dispensing mechanism (distributor), and a spout (nozzle). In hand-operated models, the distributor is hand cranked while a set of gears operate the tractor mounted models. The hand operated applicators are generally light weight with a hand crank to activate the spreader. The hopper is made of corrosion-proof materials.

7.13 Maintenance of sprayers.

The most important part of sprayer maintenance is cleaning the sprayer after each use and before storage. Both the inside and exposed

parts of the sprayer should be thoroughly cleaned after each use of the sprayer. As a rule, first rinse the sprayer with a material which acts as a solvent for the herbicide. Kerosene and fuel oil carry away oil-soluble herbicide e.g. 2, 4-D esters. Remove the oil by rinsing with a detergent in water, and finally, rinse with water. Wettable powders and solutions are easily cleaned from sprayers by rinsing thoroughly with water. The following steps are suggested for thorough cleaning of sprayers.

(i) Fill the tank full with clean water and shake vigrously to loosen out herbicide particles adhering to the sides of tank. Then flush out the cleaning water through the nozzle by operating the sprayer.

(ii) Repeat the procedure in step 1.

(iii) Remove nozzle tips and screens. Clean them in kerosene or detergent solution using a soft brush. Do not use knife, wire or any hard material to clean nozzle tips.

(iv) Fill the tank about half full of water and add about 1/2 - 1 cup of any household detergent.

(v) Operate the pump to circulate the detergent solution through the sprayer, then flush it out through the spray nozzle.

When the season's operation is over, follow through with the cleaning operations listed above and finally rinse sprayer with a light oil to protect the metal parts from corrosion. Remove and store nozzle tips, strainers and screens in light oil. A sprayer will give many years of trauble-free service if properly handled and maintained.

Phenoxy herbicides eg. 2, 4-D are difficult to clean from sprayers. Ideally, use a separate sprayer for spraying them but when this is not possible, rinse the sprayer thoroughly following the procedure outlined above. Fill the sprayer with a mixture of water and a strong detergent (use household ammonia if available). Circulate this solution throughout the sprayer and let stand overnight. Then drain completely and rinse with water. To ensure that the phenoxy herbicide is completely removed from sprayer, fill the spray tank with water and spray a few seedlings of tomato or beans. If no injury (epinasty) develops within two days, the equipment is safe for further use.

7.14 Disposal of empty containers.

Empty herbicide containers should be safely disposed of immediately in a way that will not pose any hazard to man, animals or valuable plants. Container disposal is accomplished by fire or burial.

Do not leave empty paper containers lying about as they may be blown away and end up in the wrong locations. Burn empty paper packages and cartons unless an instruction not to do so is stated on the package. Bury the ashes. Fumes from burning pesticides could be poisonous. Inhalation should therefore be avoided. Punch holes in other containers, flatten and then bury them deep in locations where the possibility of contaminating a water supply is minimal. Glass containers should be broken and then buried.

7.15 Safety:

(i) Wear boots while spraying

(ii) Be sure there are no leaks in the sprayer (hose pipe, nozzle, tank valve, filling cover etc.).

(iii) Do not smoke or eat while spraying, wait until you have washed your hands.

(iv) Always wash hands with soap and water after mixing chemicals

(v) If a concentrated chemical gets on your clothes, they should be immediately taken off and washed. The man should also wash himself with soap and water where the chemical came into contact with him.

(vi) After spraying, the operator's clothes should be taken off. They should not be worn again until they are washed; be careful not to wash near a water supply.

(vii) Always keep the sprayer clean

(viii) Always have clean water in the field when spraying. This is to wash out the eyes if chemical gets splashed into them by accident.

(ix) Always store chemicals in clearly marked containers out of reach of children, including while working in the field.

(x) Do not spray when the wind speed is over 8kph. (Excessive drift will occur).

(xi) Wash the sprayer with soap and water after use.

(xii) Do not use pesticide containers to store any food or drink. Some pesticides are very difficult to clean out completely. It is not recommended to spray insecticides on crops with a sprayer which has been used for herbicides. Often the residual herbicide in the tank and pump will damage the crop.

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CHAPTER EIGHT

SOYBEAN BREEDING

8.1 Introduction.

Of the various ways that man can increase agricultural production - increasing cultivated land area, improving cultural practices - perhaps the most cost effective is by breeding plants with higher yield potential as a result of improved physiological efficiency, disease and pest resistance, or adaptation to new agricultural areas. One example of the last case is that of sorghum, a tropical grass which through plant breeding has been successfully adapted to a temperate environment in North America. A second example is that of soybeans. The center of origin of soybeans is temperate China and the area of greatest production is currently in the temperate Americas; but recently plant breeders in Africa, South America, and Asia haveshown that soybeans can be selected for tropical climates.

Though plant breeding is an applied science based on the study of genetics it is by no means a new endeavor but has been practiced since plant cultivation began. For example the first farmers no doubt selected plants that retained their seeds until they could be harvested. Ancient farmers like modern plant breeders certainly selected the best plants for the next season's planting, rejecting weak and diseased plants and choosing the more vigorous and higher yielding plants.

8.2 Genetics:

Modern plant breeding has become a science as a result of discoveries in genetics. A plant breeder, understanding the principles of inheritance, can

often make rapid progress in plant improvement.

8.3 Some genetic terms:

The phenotype of a plant is the observable properties of that plant. This includes traits easily seen or measured such as flower color or height, traits that can be seen only under a microscope such as the number of stomata on the leaves, and traits that can be distinguished only by chemical analysis such as the percentage of oil in the seeds.

The phenotype derives from two factors: the genotype, the inherited genetic make-up of a plant, and environment which modifies the expression of the genotype. Phenotypic variation may result from either or both of these factors. Genetically identical plants grown in different environments may differ in stature, flowering date, or in many other traits as a result of environmental variation. Genetically different plants grown in identical environments will look different as a result of genetic variation. A plant breeder must select on the basis of phenotypic variation, but he or she tries to control the environment to assure that superior plants will pass on the superior traits to the next generation and that plants discarded are truly inferior and not the result of an unfavourable environment.

8.3.1 Heredity is the process by which characteristics of parents are passed on to their offspring. The science of genetics is the study of the differences and similarities between parent and offspring and how the similarities are transmitted from generation to generation.

Genetic information is transfered by genes, small chemical factors which control growth and development, indeed all physiological processes of an organism. A single gene can control a single character or several characters.

or it may act in combination with other genes. Genes are located on chromosomes which are long, complex molecules contained in the nucleus of every cell in an organism. Every organism has a characteristic number of chromosomes. In soybeans there are 40 chromosomes in every plant cell. Each gene is found at a specific location (locus) on a specific chromosome. Several alternate genes may exist at the same locus; for example alternate genes at the same locus may confer either white or purple flower color. Alternate genes at the same locus are alleles.

Two similar sets of chromosomes exist in each cell. One set of 20 chromosomes (in soybean) is from the maternal parent and the other from the paternal parent. Each parent plant contributes one set of chromosomes to its offspring. These chromosomes are contained in the sex cells, pollen and egg, which are called gametes. If one parent was white flowered and the other purple, the hybrid (offspring of two dissimilar parents) will have one gene for white flowers and another gene for purple flowers.

8.3.2 Segregation, As the term is used by plant breeders, means the phenotypically recognizable separation of dissimilar genes in progeny generations. Segregation depends on the action or strength of the particular dissimilar genes, the environment, and the sexual behavior of the plant. Soybeans are normally self-fertilized, meaning that the same plant contributes both the pollen containing the male genome (set of 20 chromosomes) and the ovule or egg containing the female genome.

8.3.3 Single factor inheritance - an example:

Flower color in soybeans is controlled by two alternate alleles at the same locus. If two plants with different flower color are crossed the hybrid will have one gene from each parent, i.e. one gene for purple flowers and one gene for white flowers. In soybeans purple flower color is dominant so that if one gene for purple flower color is present the plant will have purple flowers whether the gene for white flower color is present or not. White flower color is recessive so that the plant has white flowers only if both genes for flower color are for white. Traits are usually symbolized by the recessive phenotype; so the gene for white flowers is notated by a lower case "w" and the dominant gene for purple flowers is notated by an upper case "W".

Not all genes behave in this way. Other traits may be controlled by genes that are neither dominant nor recessive, but intermediate. A complex trait such as grain yield may be controlled by many genes, some dominant or recessive and some intermediate, each of which may have only a small effect on the complex trait.

A plant is homozygous if both alleles at the same locus are the same (WW or ww), and it is heterozygous if the alleles are different (Ww). Segregation occurs only when the parents are heterozygous. For instance all progeny of plants with white flowers will necessarily have white flowers and no segregation can occur in the progeny for this trait.

If a plant homozygous for purple flowers (WW) is crossed with a plant with white flowers (ww) each plant will contribute one gene for flower color in its gametes which will join by fertilization to form a hybrid seed. The plant from this cross is refered to as an F_1 plant (first filial generation).

Subsequent generations are refered to as F_2, F_3, etc.

As noted earlier, the F_1 hybrid will have purple flowers because purple color is dominant (Figure 8.1). No segregation occurs in the F_1 generation if both parents were homozygous: all the F_1 plants have the same phenotype. Segregation does occur in the F_2 generation because the F_1 is heterozygous and produces dissimilar gametes (Figure 8.2). The genotype of the F_2 offspring can also be shown by a diagram in which the male and female gametes are shown on the outside of the diagram and possible genotypes are shown in the boxes, as in Figure 8.3. Since the parent plant is just as likely to produce a W gamete as a w gamete, the frequency of each progeny genotype will be the same:

1/4 WW (purple)

1/4 Ww (purple)

1/4 wW (purple)

1/4 ww (white)

Genotypes Ww and wW are the same and the ratio is usually given as:

1/4 WW (purple)

1/2 Ww (purple)

1/4 ww (white)

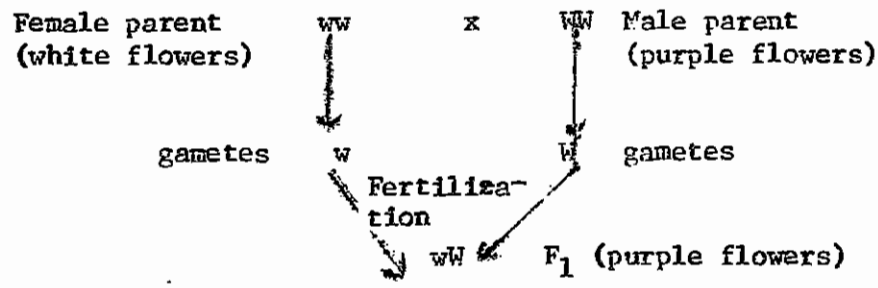


Figure 1: Genotype and phenotype of parents and F_1 hybrid in a cross between purple and white flower plants.

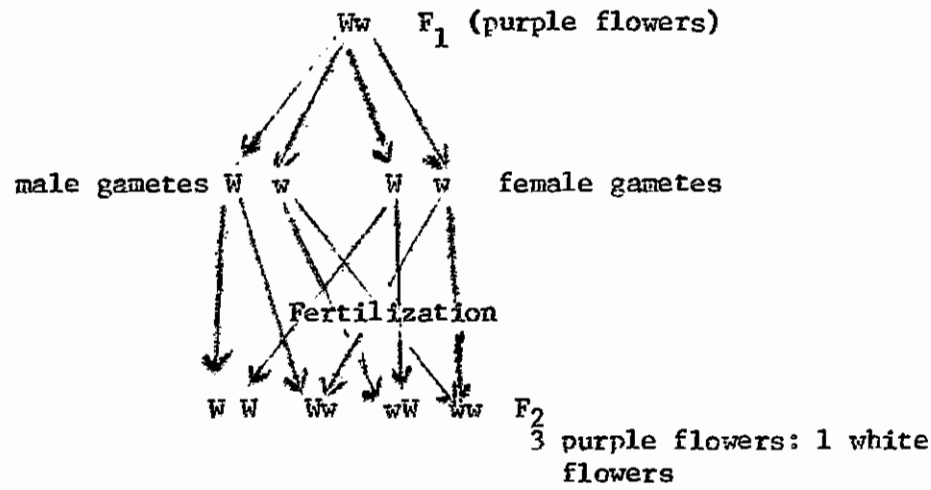


Figure 2: Gametes and F_2 progeny from the F_1 of a cross between purple and white flower plants.

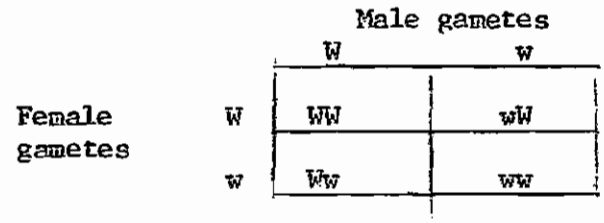


Figure 3: Gametes and F_2 progeny from the F_1 of a cross between purple and white flower plants.

The phenotypic ratio in the F_2 generation will be 3/4 purple flowered plants to 1/4 white flowered plants.

If all F_2 plants are left to produce F_3 progeny or if a large number of F_2 plants are selected at random, the genotypic and phenotypic ratios in the F_3 and in all subsequent generations so treated will be the same as in the F_2. But the breeder can change the gene frequencies by selection. If the breeder selects only white flowered plants from the F_2 population and discards all the purple flowered plants, the F_3 and all subsequent generations will have only white flowers. The frequency of the 'w' gene will be 100%. If the breeder prefers purple flowers and selects only purple flowered plants in the F_2, he or she has no way of knowing whether the plant selected is homozygous WW or heterozygous Ww.

A convenient way to handle this problem is to thresh and maintain seed from each selected F_2 plant separately and to plant progeny rows with seed from each selected plant. If all plants in a particular F_3 progeny row have purple flowers, the selected F_2 plant must have been homozygous for purple flower color. If the plants in the F_3 progeny row are segregating 3 purple: 1 white, the selected F_2 plant was heterozygous.

8.3.4 Multiple factor inheritance:

Figure 8.4 illustrates a cross between two homozygous plants that differ for two characters : flower color and pubescence color. Pubescence color can be either tawny (brown) or grey. This trait is controlled by a single gene "T". Tawny color is dominant and grey color "t" is recessive. The ratio 9:3:3:1 for two-factor inheritance is shown in Figure 8.4.

If a trait such as seed size is controlled by many genes (polygenic trait), the F_1 will usually be intermediate. Most plants in the F_2 population will be intermediate and a few plants will resemble the parents. Since most plants in the population will be heterozygous, it is usually more efficient to wait until more advanced generations when most plants are homozygous to select for a polygenic trait.

WWTT (purple flowers tawny pubescence) x wwtt (white flowers grey pubescence)

WwTt — F_1 (Purple flowers Tawny pubescence)

F_2	WT	Wt	wT	wt	F_2 Phenotypes	
WT	WWTT	WWT	WwTT	WwTt	Purple, Tawny	9
Wt	WWTt	WWtt	WwTt	Wwtt	Purple, grey	3
wT	WwTT	WwTt	wwTT	wwTt	White, Tawny	3
wt	WwTt	Wwtt	wwTt	wwtt	White, grey	1

Figure 8.4: Progeny of a cross between a plant homozygous for purple flowers and tawny pubescence and a plant with white flowers and grey pubescence.

8.4 Breeding methods:

8.4.1 Soybean is a self-pollinated (antogamous) species: The flowers are perfect, conteaning both male and female parts. Fertilization normally occurs before the flowers have opened and natural outcrossing is rare. Most successful soybean breeding techniques are based on artificially crossing one parent with another to produce hybrid seed then selecting self-pollinated progeny in subsequent generations until a superior pure line is produced.

8.4.2 Goals:

Each cross should be made with a definite goal in mind. High yield is generally the foremost goal in any breeding program and goals such as disease and pest resistance, improved plant architecture, stiff stem, and resistance to shattering are complementary to the goal of higher yield. Other goals may include improved seed quality, oil or protein content, or plant type suitable for machine harvesting.

The breeder must also know how he or she will select or screen for a trait before making the cross involving that trait. For instance, if the cross is for resistance to leaf hoppers, the breeder should have some idea how to assure growing the progeny in an environment with an adequate population of insects so that resistance and susceptability can be distinguished.

It often takes six to twelve years or more from the time a cross is made until a line from that cross can be adequately tested, found superior, multiplied, and distributed to growers. The breeder must think of the needs of growers in the next decade when planning a crossing program.

8.4.3 Crossing:

The soybean flower is small and special care and a delicate touch is required to cross soybeans; therefore, this procedure is best done in a controlled environment. Plants intended for crossing may be grown in the soil in a glass house or a screen house or in pots so they can be placed at eye level for crossing. The only tool essential is a pair of fine, pointed forceps such as a jewler uses. Some people also use magnifying lenses worn like eye glasses or attached to a band worn around the head.

To make a cross:

1. Gather freshly opened flowers from the plant intended as the male parent.
2. Chose a bud on the plant intended as the female parent with the petals just showing above the sepals. Remove all other flowers and buds at that node.
3. Remove the sepals. Gently remove the petals by lifting them with the forceps, thus exposing the anthers.
4. Tease the anthers out with the tip of the forceps being careful not to damage the stigma. Test the anthers to see if they are ripe. If they have already shed pollen, chose another bud.
5. Hold the flower to be used as a male and remove the sepals. Touch the anthers of this flower to the stigma of the emasculated flower.
6. Attach a tag to the stem at the node where the cross was made. The tag must include a description of the cross (female and male pedigrees or plot numbers). It may also include the date and the crosser's initials.

Other crosses using the same or a different parent may be made on the same plant as long as each cross is properly labeled. Crossed seeds of the same parent combination should be space planted in an F_1 population or nursery. It is wise to sow seeds of both parents nearby. If both parents are homozygous, the hybrid plants should be phenotypically different in some ways from both parents and identical to each other (disregarding environmental variation).

If a plant in the F_1 population is different from the others and resembles the female parent, it should be discarded as a self pollinator. If the parent plants differ for a trait such as flower or pubescence color, the recessive plant should be used as the female. Parental lines may also be sown near the F_2 population. If an F_2 population is highly uniform and resembles the female parent, it should be discarded as a self.
Seed from each F_1 plant should be planted separately to identify non segregating lines, i.e. self pollinations.

8.4.4 Pedigree selection:

Many successful soybean breeding programs are based on a pedigree method of breeding. A time pedigree method requires that meticulous records be kept on the origin of selected plants and that the breeder select superior plants in every generation until an adequate level of uniformity is reached.

Pedigree selection is usually practiced in a plant to row system: in early generations superior plants are selected and seeds from these plants are maintained separately and planted in a row the following year. If adequate seeds are available they may be divided and planted in several replicates or in different locations. This gives some insurance against unfavourable climate and reduces the possibility that a superior line is discarded because it was grown in poor conditions. Early generation lines should be sown at a low enough density that individual plants can be evaluated and harvested .
A method for pedigree selection follows:

1. Parents are selected and crossed to produce F_1 seed.
2. The F_1 population is grown and selfed plants are discarded. Seed from identical F_1 plants may be bulked to form an F_2 population.

3. The F_2 population should be grown in the normal environment, i.e. in the season and area where the crop will normally be grown. Plants with undesirable, highly heritable traits may be removed periodically. For example, if one of the parents was resistant to bacterial pustule, susceptible plants in the F_2 population may be uprooted, leaving only resistant plants. The number of plants selected from a particular population will depend on the goal of the cross, the overall desirability of the population, and the resources of the breeder. If too few plants are selected to advance to F_3, some of the variation for complex traits such as yield may be lost. If too many plants are chosen the breeder may not have the resources (land or time) to adequately evaluate them.

4. F_3 seed from selected F_2 plants is threshed and maintained separately. Seed may be divided for replication. The breeder may choose to grow the F_3 lines in the off-season under irrigation, but selection of single plants is best left for the normal growing season. If F_3 lines are grown in the off-season, obviously inferior lines can be discarded and the remaining lines may be harvested for single plant selection in F_4.

5. Seed from single F_3 plants will be planted in F_4 progeny rows, preferably in several replicates or at several locations. Inferior F_4 lines may be discarded. Plants in segregating lines may be selected individually. Some F_4 progeny rows may appear uniform. Those of good agronomic character can be harvested in bulk and a sample can be taken to test for seed longevity.

6. Seed from single F_4 plants can be treated as above. Bulk harveste seed from superior F_5 plots can be tested for seed longevity and planted in larger plots in the off season. If the F_6 seed has good storability and if the F_5 plot is uniform it can be bulked harvested to provide seed for a yield trial in the normal growing season.

7. There should be sufficient seed from F_6 plots for a replicated yield trial at several sites. Agronomically inferior plots can be discarded. Superior entries can be evaluated for seed longevity, promiscuous nodulation, yield, lodging, shattering, disease resistance, etc.

8. Trials are usually conducted for at least three years at a range of locations before a new variety is considered for release. This should include trials in large plots in conditions in which the crop is grown commercially, i.e., farmers' fields.

A possible timetable for cross to release is shown in Table 8.1

Table 8.1: A sample timetable for a pedigree selection scheme:

Year:	Season:	Activity:
1	Rainy	Cross
2	Dry	Grow F_1 populations
2	Rainy	Grow F_2 populations. Select single plants.
3	Dry	Grow F3 progeny rows. Discard inferior rows. Harvest superior rows.
3	Rainy	Grow F_4 populations. Select single plants
4	Rainy	Grow F_5 progeny rows. Harvest superior rows. Test for longevity.
5	Dry	Grow F_6 plots. Harvest superior plots for yield tests.
5	Rainy	Grow F7 lines in replicated multilocational trials. Evaluate yield, nodulation, lodging, etc.
6,7		Multiply in dry season. Test superior lines in rainy season in multilocational trials including trials in farmers' fields.
8		Multiply seed for distribution to seed growers and extension services.

8.4.5 Record keeping:

Every row or plot should have a number unique for the season and location in which it is grown. This row number should be recorded in a data book with the pedigree of the row or plot and the source of the seed used for planting. Data and observations may be recorded in the same book. In this way any plot in the field can be traced back through previous record books to the original cross.

Any sizeable breeding program will usually assign code numbers to crosses rather than maintain long and complex pedigrees in record books. For instance the IITA soybean program assigns unique numbers to each cross with the prefix TGx (Tropical *Glycine* cross). A separate file is kept of the actual pedigree for each cross code number.

An example of entries in a data book is given in Figure 8.5. In this example the column labeled source contains the year (81, 82), season (dry, rainy), plot number, and location (Ibadan, Mokwa) where the grain for each plot was harvested.

Preliminary Yield Trial
1983 Rainy Season, Ilorin

	Row	Pedigree	Source	Observations-
	1001	TGx 1157	83D431 IB	
	1002	TGx 1158	83D432 IB	
	1003	TGx 1231	82R182 MO	
	1004	TGx 1240	82R191 MO	
	1005	TGx 1243	83D503 IB	

Figure 8.5: Sample data book entries for a pedigree selection program.

8.4.6 A modified pedigree breeding system:

Brim (1966) proposed a modified pedigree method of selection called Single Seed Descent. It is possible by this method to evaluate a large number of nearly homozygous lines from a cross in a relatively short time without multiple generations of selection and record keeping.

In Single Seed Descent, a cross is made and the F_1 and F_2 populations are grown as in the pedigree method. Obviously inferior or disease susceptable F_2 plants are discarded and one seed is harvested from each remaining F_2 plant. These seeds can be planted immediately in pots or hills in very dense populations, 10-20 plants per pot or hill. One seed is harvested from each plant without selection in subsequent generations to F_5 or F_6. At this stage each seed is space planted and harvested separately. Progeny rows are grown from these plants and evaluated for agronomic merit, nodulation, seed longevity, etc. Bulk harvested seed from selected rows is used for yield testing. A possible timetable for this scheme is shown in Table 8.2.

In this system, only the pedigree needs to be recorded until progeny rows are tested. Then it is a good idea to maintain a record of the seed source as with the pedigree system.

Table 8.2: A sample timetable for single seed descent.

Year:	Season:	Activity:
1	Rainy	Cross
2	Dry	Grow F_1 population
2	Rainy	Grow F_2 population. Discard inferior plants.
3	Dry 1	Grow F_3 plants in pots or hills.
3	Dry 2	Grow F_4 plants in pots or hills.
3	Rainy	Grow F_5 plants in pots or hills
4	Dry	Grow F_6 plants in spaced populations
4	Rainy	Grow F_7 progeny rows. Evaluate and select
5	Dry	Multiply.
6	Rainy	Grow multilocational trials.

8.4.7 Backcross breeding:

Backcross breeding normally involves trasfering a single desirable trait from one parent to another plant type. For example, the recurrent parent may be one with superior agronomic character and high yield but susceptible to a disease. A backcross scheme might be used to transfer disease resistance from a highly resistant source to the superior type while maintaining the essential character of the superior plant type. Usually the trait to be transfered is controlled by one or a few genes but the main criterion is that the trait be clearly recognizable in every generation where plants are selected for backcrossing.

To illustrate the backcross breeding method two examples will be given: one for the case of a single dominant gene and the other for a single recessive gene.

Case 1: Resistance to bacterial blight is confered by a single dominant gene R_{pg1}. A backcrossing scheme is illustrated in Figure 8.6.

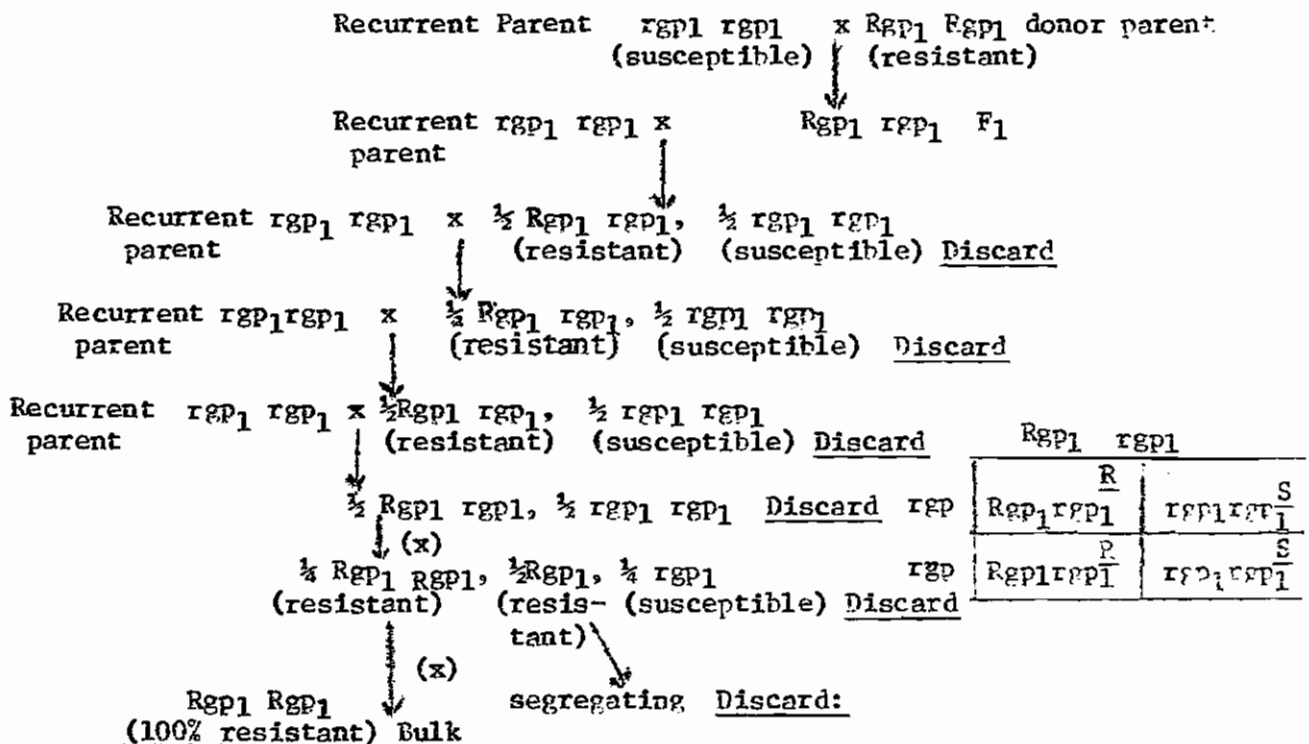


Figure 8.6: A backcross breeding method for transfering a single dominant gene to a recurrent parent.

The susceptible recurrent parent is crossed to the resistant donor parent. The F_1 progeny is resistant. The F_1 is back-crossed to the recurrent parent and the progeny are grown in epiphytotic (highly diseased) condition. Resistant plants are crossed to the recurrent parent. Care must be taken to choose only resistant plants for crossing. Therefore there must be a high enough level of disease that all susceptible plants are infected and that disease-free plants are truly resistant, not just escapees from the disease. Since the goal is to recover the plant type of the recurrent parent, faster progress can be made if resistant plants resembling the recurrent parent are crossed. This screening for resistant plants and crossing to the recurrent parent continues until the crossed population is uniform and resembles the recurrent parent. Four or five backcrosses are usually adequate. When this is done, resistant plants are selfed. Three parts of the progeny will be resistant and ¼ susceptible. Harvest resistant plants separately and plant progeny rows. Bulk the seed from rows when 100% of the plants are resistant and discard rows segregating for resistance.

Case 2: Resistance to bacterial pustule (*Xanthomonas phasioli*):

The case of backcross breeding is illustrated in Figure 8.7. Resistance is conferred by a single recessive gene rxp. In this case the heterozygote F_1 is susceptible. If the F_1 is crossed, half of the progeny will be homozygous for the dominant (susceptible) gene and half will be heterozygous. All plants will be susceptible to bacterial pustule. Selfing the plants from the first backcross will yield a population with 7/8 of the plants susceptible and only 1/8 resistant.

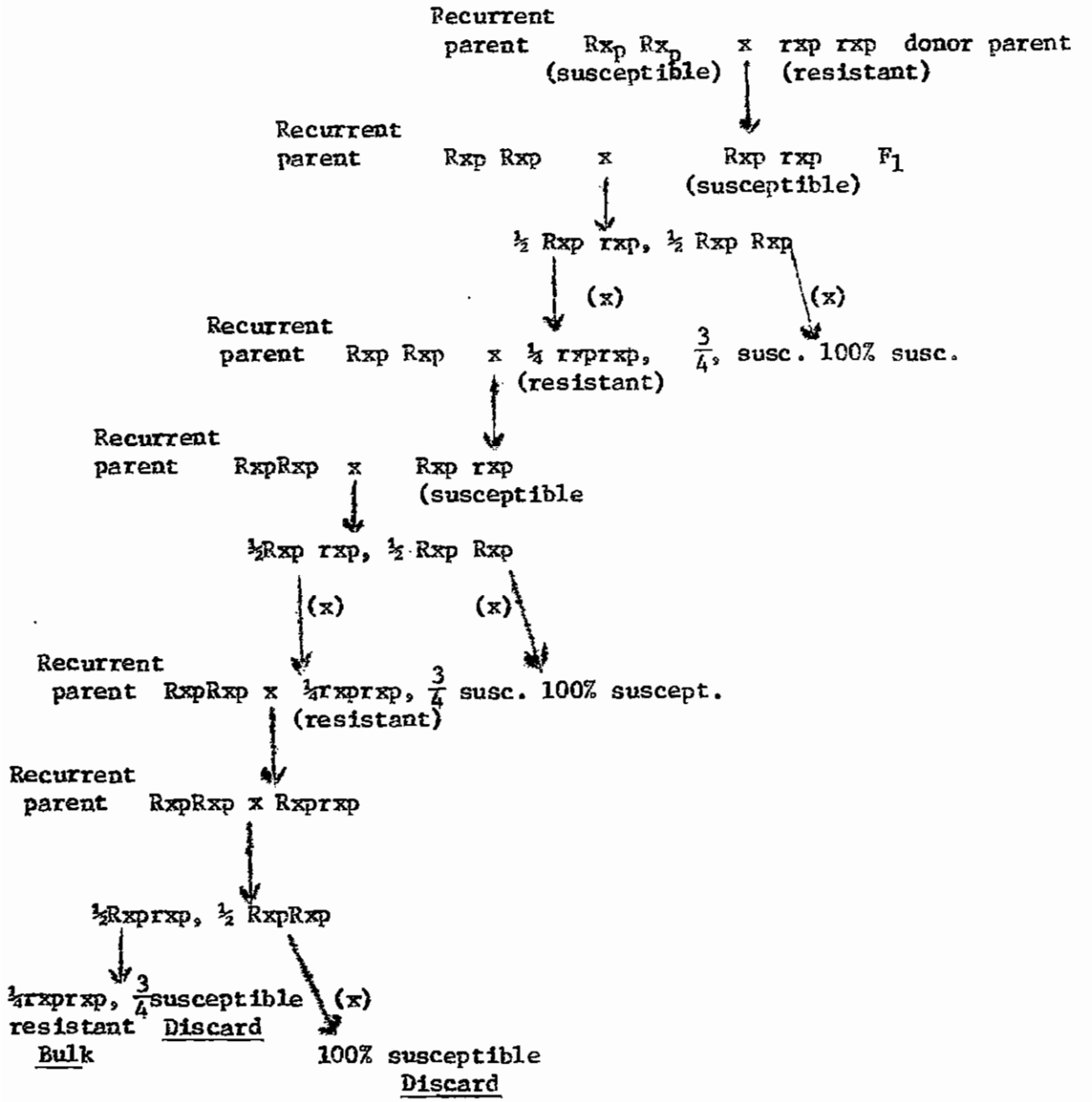
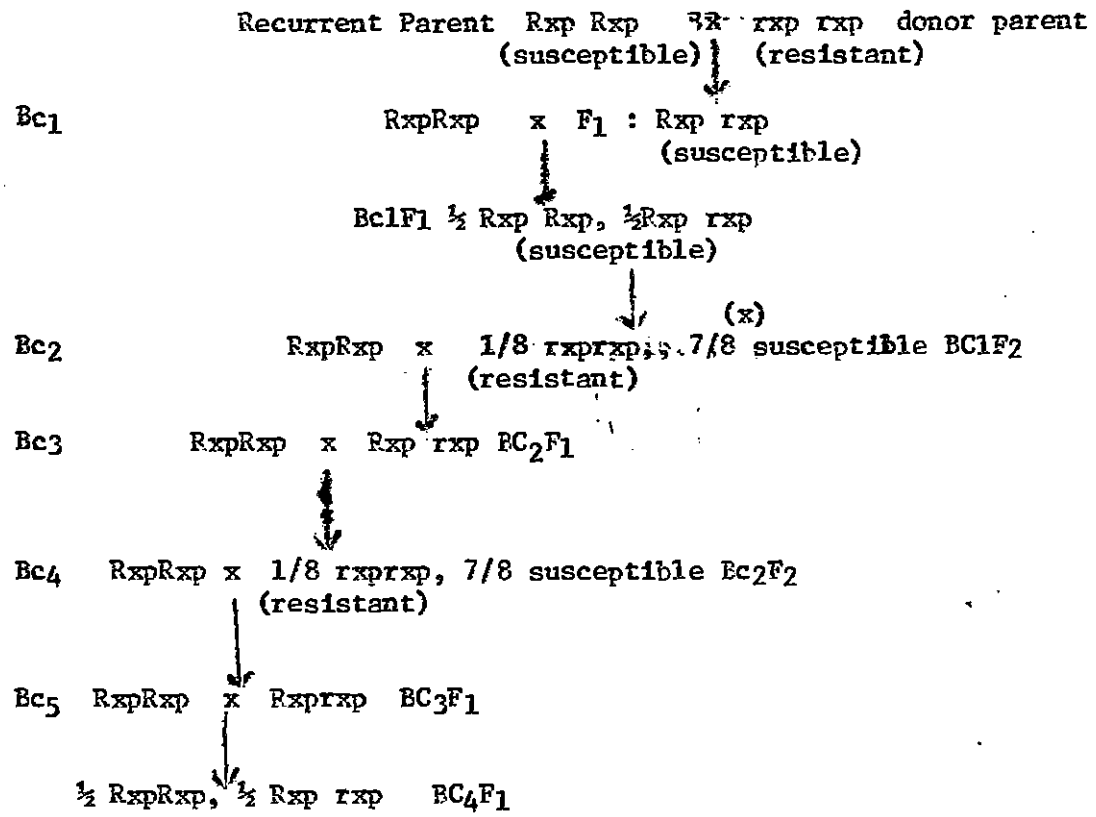


Figure 8.7: A backcross breeding method for transfering a single recessive gene to a recurrent parent.



Therefore a large population must be grown to ensure finding resistant plants with the desirable characters of the recurrent parent; and extreme care must be taken to ensure that uninfected plants are resistant and not escapees. Resistant plants are then crossed to the recurrent parents, the (susceptible) progeny are crossed again to the recurrent parent, and the progeny are selfed; the progeny of that self are grown under epiphytotic condition to find the 1/8 resistant progeny. When a sufficient degree of homozygocity is reached, the resistant progeny can be bulked and multiplied

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CHAPTER NINE

SEED PRODUCTION, TESTING AND BATTLING.

9.1 Introduction:

This chapter concerns the production of seed that will be used for planting in contrast to the production of soybean for utilization. The management practices are similar for the two uses, yet certain practices that are biologically and economically sound for the production of high quality planting stock may not be economically advisable for normal crop production.

9.2 Insect control:

For seed production it is important that pod sucking insects are kept under good control. While the economic threshold for pod sucking insects in production fields is generally considered to be between 1 to 3 insects per meter of row, it may be worthwhile to keep the insect population even lower for seed production. The fields should be carefully and frequently monitored for insects. For seed production chemical control of pod insects with thiodan is recommended.

9.3 Disease control:

For seed production there is merit in removing plants from the field that show symptoms of important seed-borne diseases. For example, it is often useful to remove all plants showing symptoms of soybean mosaic virus. If this is done every two weeks from planting date, one can greatly reduce the number of virus infected plants that will occur in the subsequent planting.

When plants are being rogued for disease, off-type plants should also be removed.

There are a number of seed pathogens that can cause severe reduction in seed quality, especially *Phomopsis sp.*. When producing seed with good vigor there are several practices that merit consideration. First, select a location or planting date that will permit the plants to dry-down in a relatively dry environment. If the relative humidity is high after seeds reach physiological maturity, deleterious pathogens will invade the seed and cause seed deterioration prior to harvest (field weathering of seed). A second practice is to harvest the seed very promptly. As soon as the pods are dry enough to thresh they should be harvested and the seeds should be dried down to at least 10% moisture. A third practice that can help minimize field weathering is to spray systemic fungicides, e.g. 1 kg/ha Benomyl, about every other week beginning at or just prior to flowering (McGee and Brandt (1979) If environmental conditions are humid when the pods near maturity it may be useful to spray the crop with paraquat which will greatly hasten drying. If this practice is used, one should spray when the pods are turning from yellow to brown. The rate of paraquat application need not be high to have a significant effect on plant drying. Two litres per hectare is generally adequate. After harvest it is very important that seeds are dried quickly before storage, 6-10% moisture is best. Drying temperatures should not exceed 35^{o}C. If one does not have equipment to test the moisture content a useful guide is to bite a seed. If the seed breaks, it is generally at least dried to 10% moisture.

For seed production several chemical applications may be useful; we already mentioned insect control, benlate fungicide application and possible applications of paraquat as a desiccant. Spraying a crop of soybeans late in the growing season is not easily done without damaging the plants. To facilitate spraying operations it may be useful to plant seed multiplication fields in strips so that spray equipment can have easy access. If all operations are to be done by hand, then the alleys need not be wide.

9.4 Harvesting procedures:

If the seed is very dry at harvest time it must be treated with great care to prevent cracking of seed and other less obvious forms of mechanical damage. Shelling is usually done when the beans are at 13-15% moisture content.

9.5 Storage conditions:

As mentioned earlier it is critical that seed is kept at less than 10% moisture content. This means that the relative humidity must be around 60% (Table 9.1). A general guideline is that for every 1% increase in moisture content, the storage life is reduced by one half. In the humid tropics, relative humidity is frequently from 75-95% and seeds will equilibrate at about 15% moisture and deteriorate rapidly. In some countries it may be possible to keep seed in parts of the country with lower humidity. For example, in Nigeria during the dry season the relative humidity is quite low in the middle belt and northern regions; and as such seeds can be kept between planting seasons with little risk.

Table 9.1: Moisture content of soybean seed at equilibrium with various levels of relative humidity (approximately (25°C).

	Relative humidity (%)					
	15	30	45	60	75	90
Moisture content	4.3	6.5	7.4	9.3	31.1	18.8

Seed storage in the humid, e.g. southern region in Nigeria is very difficult. If seed must be stored in humid regions then they must be properly dried and kept in either controlled environment facilities with low relative humidity or be kept in air tight containers. Heavy plastic bags, if well sealed can be used, but one must be very careful that the seed is well dried prior to sealing in air-tight containers.

The other environmental factor that can greatly influence seed longevity in storage is temperature. The general guideline for temperature effects is that for every 10°C increase in temperature, one will reduce the storage life by one half. One must remember, however, that when the temperature is reduced the relative humidity will rise unless a dehumidifying system is used. Moisture content is more critical than temperature in

maintaining good quality seed. In humid regions refrigeration systems that do not remove moisture from the air may cause more problems than they solve.

9.6 Assessing seed vigor before planting.

It is useful to monitor the quality of planting seed during storage and especially immediately before planting. Germination tests done under laboratory conditions do not always reflect seed vigor because as seeds lose vigor in storage they still may germinate under optimal conditions when they are too weak to emerge under field conditions. This problem has been the subject of considerable research by seed scientists. While there are numerous methods to assess seed vigor it is generally adequate to plant the seed in sandboxes at uniform depths and count the number of emerged seedlings after 7 days. The percentage emergence from sandbox conditions will generally be higher than one will observe in a field planting, but adjustments can be made in planting rates. If, for example, emergence from sandbox conditions is only 70%, then one might want to plant about 40% more seed than if emergence was 100%.

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Phomopsis in relation to time of inoculation. Plant disease Reporter

63 : 675 - 677

CHAPTER TEN

DISEASES OF SOYBEANS

10.1 Concept of disease in plants.

A plant is considered to be diseased whenever it is unable to perform any of its normal physiological functions of growth, development and reproduction to the best of its genetic potential owing to an interference by another biological agent or by an unfavourable environmental condition. A disease is therefore an abnormal and injurious physiological process that results from the interaction of some agent called the pathogen and the plant, commonly referred to as the host. It is any deviation from the normal growth or structure of plants. It is therefore extended to the deterioration of harvested products - seeds, tubers, bulbs, vegetables and wood. The ultimate effect of disease is a reduction in the quantity and/or quality of crop yield.

A disease is recognized by the external signs of the altered state of the affected plant or plant organ. This detectable response presented by the plant or its organ is called a symptom. Symptoms are usually characteristic of the disease and the causal agent involved. Examples of plant disease symptoms include leaf spotting or discoloration; rotting of root, stem or fruit; malformation of root, stem, leaves or fruits; wilting; dwarfing, etc.

10.1.1 Factors necessary for disease development.

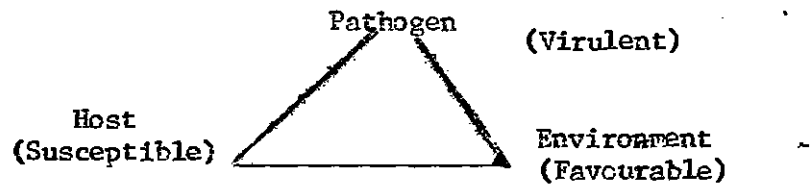
Three factors are involved in disease development namely:

(i) The pathogen or disease-causing agent

(ii) Host

(iii) Environment.

All three must be "in balance" for disease to develop, i.e. the pathogen must be virulent and the host susceptible in an environment favourable for infection. This balance is usually represented in the form of a diagram called Disease Triangle.



Let us briefly examine the three corners of the triangle.

10.1.2 Pathogen

Pathogens are disease-inducing agents. They include living and non-living agents. The living or biotic agents often referred to as parasites include many fungi, bacteria, viruses, mycoplasmas, nematodes, some insects and mites and a few flowering plants.

Fungi are plants which lack chlorophyll. Most of them are composed of threadlike filaments (hyphae) which are aggregated into a branched system (mycelium) from special parts of which spore - producing structures are formed, whose diversity and complexity provide the bases for classification. The vegetative body (thallus) of some fungi, however, is amoeboid and often in these instances the entire thallus is involved in the reproductive process. Fungi infect a plant by direct penetration of the cuticle, through natural openings or wounds. Resting bodies (chlamydospores, sclerotia, oospores) allow fungi to survive unfavourable conditions for long periods.

Bacteria are microscopic, one-celled plants, without chlorophyll, entering plants through wounds or small natural openings such as stomata or hydathodes. They are spread by man through cultivating and pruning in plant materials (seeds, transplants, nursery stocks), insects, splashing rain or flowing water. Once within the host, bacteria develop inter- and intracellulary, migrating through the plant. Bacteria survive in plant refuse, seed, soil or insect bodies. All plant pathogenic species are rod-shaped and do not form spores.

Viruses are submicroscopic, rod-shaped, spherical or polyhedral particles composed of nucleic acid and protein. They are transmitted either mechanically or by biological vectors, most importantly aphids, leafhoppers, and plant hoppers. A few viruses are seed-transmitted. In plants, the virus nucleic acid appears to redirect the metabolism of the infected cell to synthesize more virus particles. Viruses survive in perennial or biennial weed or crop plants or in insect bodies and induce a variety of local or systemic symptoms, including mosaics, stunting and ringspots. Micoplasmas differ from viruses in that they have a cell membrane and are particularly sensitive to the tetracycline group of antibiotics.

Nematodes are small, eel-shaped animals. They are usually 1 to 2mm long. Plant parasitic species feed by puncturing plant cells and extracting the contents with a hollow stylet. Nematodes are spread by infested soil, nursery stock or running water. Both males and females occur in most species. Eggs laid by females hatch into larvae and after several moults the larvae develop into sexually mature nematodes.

Examples of spermatophytes or seed plants that cause disease are (i) witchweed (*Striga spp.*) - root-invading parasites of maize, sorghum and other graminaceous crops. Its seeds remain viable in the soil and germinate only in the presence of secretions on the roots of the host plant. (ii) Dodder consists of white to orange coloured strands or vines that twine themselves around their hosts' branches and feed upon these branches and (iii) Mistletoes grow upon other plants. The seeds germinate and send feeding roots into the vascular tissue of the host.

Arachnids (spiders) and insects are responsible for some plant diseases. The red spiders bring about water deficiency in some plants while some plants are made to form galls owing to insect attack.

Non-parasitic or physiological diseases may be caused by any fluctuation in the environment beyond the normal for plant growth and reproduction. An excess of deficiency of air temperature, soil moisture, or soil nutrients often cause symptoms that may be confused with those caused by fungi, bacteria and viruses.

10.1.3 Host.

Plants which habour or support the activities of pathogens are called hosts or host-plants. The biotic pathogens at least for some stage obtain food from them. Some parasites such as *Pythium* rapidly kill the host tissues and succeed as parasites mainly because they are able to attack young seedlings of many species. By contrast other fungi, such as the smut fungus *Ustilago nuda* on wheat and barley, succeed as parasites because they induce few adverse changes in the host throughout the growing season.

Only at flowering does the pathogenicity of *U. nuda* become apparent in the replacement of the grain with fungus.

The growing of certain plants as crops by man has had two important effects on biotic pathogens. The selection and breeding of particular types (cultivars) of a plant species, to satisfy commercial requirements such as high yield, have led to the development of strains specialized in their ability to attack these cultivars. The monoculture of these cultivars then ensures a uniform population of hosts within which these strains can develop.

10.1.4 Environment:

This is the sum total of the factors that constitute the physical environment of the soil and air. Atmospheric and soil environments greatly modify disease development by affecting pathogen activity and host physiology. The most critical factors are air and soil temperature, relative humidity, dew, precipitation, soil reaction (pH) and soil fertility.

10.1.5 Stages in the development of disease (disease cycle):

The chain of events gone through in the process of disease development is known as disease cycle. It is composed of such steps as inoculation, dissemination and over-seasoning.

(i) Inoculation: The process of transferring inoculum to the infection court on or in the host. The inoculum which is the part of the pathogen that reaches the host may consist of the whole pathogen body as in the case of bacteria and viruses while other pathogens may form special structures for that purpose eg. spores (fungi), seed (parasitic higher plant) and larvae (nematodes).

(ii) Penetration. The movement of the pathogen into the host. It may be through natural openings like stomata, lenticels and hydathodes or through wounds or may be direct through cuticle into the epidermal cells. For an organism to be successful as a pathogen it must go beyond this.

(iii) Infection: The establishment of contact (feeding, etc.) with the host. In order to procure food, the pathogen parasite will have to kill and disorganize the host tissues in advance or feed "silently". Both lead to the disorganization of the structural integrity and the altering of the physiological processes of the host plant. A resistant crop variety would arrest this process while a susceptible one will succumb to it.

(iv) Incubation: The interval between infection and the appearance of symptoms on the host. This time is the function of the host-pathogen combination and the environment.

(v) Invasion: This is the extensive movement of the pathogen within the host. The movement may be intercellular (bacteria and most nematodes) or intracellular (viruses) or both (fungi); spread may be so extensive as to affect the whole plant (systemic disease e.g. maize streak virus disease) or restrictive (leaf spots).

(vi) Reproduction: Pathogens have great potentials for multiplying. For example, a bacterium unit produces an offspring in about 20 or 30 minutes which means that in 10 hours, that unit can produce about 1 million units.

(vii) Dissemination: Active movement of pathogen is restricted to those with organelles of locomotion (bacteria and zoospores). Viruses, higher plants and many fungi need passive dissemination (by wind, water, animals with plant products, etc.).

(viii) Overseasoning: Some pathogens thrive from one season to the other by remaining inside some perennial plants. Others produce special structures like weather-resistant spores, cysts (nematodes) and some, even overseason in the systems of some insects and in seeds.

10.1.6 Classification of plant disease.

Several criteria can be used to classify plant diseases. Disease classification may be based entirely on the type of causal agent or type of host. It may also be on the part of the plant affected *per se* or the function being performed by the affected organ. Briefly, below are some of the types of disease classification:

I. Classification based on type of causal agent.

A. Diseases caused by infectious agents (Parasitic diseases)

(i) Fungal diseases

(ii) Bacterial diseases

(iii) Viral and mycoplasmal diseases

(iv) Nematode diseases

(v) Seed-plant diseases

B. Diseases caused by non-infectious agents (Non-parasitic diseases). They are diseases caused by:

(i) Chemical excesses and injury e.g. fertilizer burn, herbicide damage or malformation (buggy-wip induced by 2, 4-D on maize) and nutrient excesses.

(ii) Nutrient deficiencies e.g. yellowing of leaf caused by nitrogen deficiency.

(iii) Environmental factors - drought, excess moisture, high or low temperature, low relative humidity, hail, strong wind, lightening, etc.

(iv) Air pollutants (a result of industrial by-products) e.g. ozone, fluorides, chlorine, sulphur dioxide etc.

(v) Genetic agents e.g. genetic stripe of maize

II. Classification based on plant part affected:

(i) Root diseases e.g. root rots

(ii) Stem diseases

(iii) Leaf (foliage) diseases

(iv) Floral diseases

(v) Fruit (pod) diseases

(vi) Seed (kernel) diseases

III. Classification based on stage of plant growth affected:

(i) Seedling diseases e.g. seedling blights

(ii) Mature plant diseases e.g. pustule

(iii) Storage diseases.

10.2 Fungal diseases.

Fungi are a diverse group of lower plants sharing many characteristics with the higher green plants, including transpiration, respiration and

assimilation of nutrients. However, fungi lack chlorophyll and they can not carry out photosynthesis.

Fungi acquire the nutrients they need to grow in several ways. Saprophytes uses organic matter derived from non-living sources. Parasites thrive only on living things. A large percentage of plant-pathogenic fungi are facultative parasites, that is saprophytes capable either of using nutrients released from decaying plant tissue or of infecting living tissue. Other fungi are highly specialized obligate parasites that grow and reproduce only in intimate association with a narrow range of living plant hosts.

Most fungi produce threadlike filaments, up to 100µm wide, called hyphae. The hyphae grow and branch to form the vegetative body or mycelium. The mycelium may be an interlacing tangle of hyphae, a loose wooly mass, or a compact body.

Typically, fungi reproduce, spread, and survive by means of asexual or sexual spores. In general, the asexual cycle is more important because very large numbers of spores are produced and the cycle may be repeated several times during the growing season. The spores are easily disseminated by air currents, splashing or flowing water, and the activities of people and animals.

Some fungi survive periods when growing conditions are unfavourable by producing resting (dormant) spores, such as chlamydospores and oospores. Other fungi do not produce spores, they multiply and over season by forming compact masses of hyphae (Sclerotia) or fungal fragments, and these are spread by water,wind, people and other agents.

Fungi enter soybean plants through natural openings such as stomata hydathodes, nectaries, and lenticels and through wounds made by blowing sand, wind, nail, people, insects, nematodes or other fungi. Some fungi use pressure or enzyme action or both to penetrate plants directly.

Infectious fungal diseases of soybeans include leaf spots and blights, root and stem decays, and pod and seed diseases . Disease symptoms result from the action of toxic or growth-stimulating metabolites, the depletion of host nutrients and the mechanical displacement of host tissues.

10.2.1 Anthracnose.

Soybean anthracnose causes considerable damage in both the tropics and subtropics. Anthracnose, caused by fungus *Colletotrichum truncatum*, has been isolated in Nigeria.

Symptoms:

Soybean plants are susceptible to anthracnose at all stages. Symptoms appear most often on stems, pods, and petioles as irregularly shaped brown areas. Pre-emergence and post-emergence damping-off may occur when infected seeds are planted. Dark brown, sunken cankers (lessions) often develop on cotyledons of emerging seedlings. These cankers gradually extend up toward the epicotyl and down to the radicle. In humid weather, one or both cotyledons become water-soaked, quickly wither, and fall off.

Anthracnose causes serious losses on maturing plants, particularly during rainy periods when shaded lower branches and leaves are killed. When soybean pods or pedicels are infected early, either no seed form or fewer

and small seeds develop. Mycelium of the anthracnose fungi may completely fill the pod cavity and seeds may become moldy, dark brown and shriveled.

Disease cycle and epidemiology.

Both anthracnose fungi can overseason as mycelium in infested crop residue or in infected seeds. Inoculum from infected seeds and debris may cause pre-emergence and post-emergence damping-off of seedlings. Mycelium may also become established in infected seedlings without symptoms developing until plants begin to mature. Infected embryos fail to germinate. Secondary stem and pod infection occurs during warm, moist weather.

Plants are susceptible to infection by *C. dematium* var. *truncatum* at each stage of development but particularly from bloom to pod-fill. Detailed information on environmental conditions that promote disease development is lacking. Conidia of the two fungi germinate and form appressoria at temperatures below 35°C when the plant surface is wet or when the raltive humidity is about 70%. Conidia are short-lived and sensitive to drying. Five hours of air drying can reduce germination by 98%.

Control measures.

(i) Sow seeds relatively free of the pathogen

(ii) Treat infected seeds with a recommended fungicide

(iii) Plough under crop residues

(iv) Rotate soybeans with other crops.

10.2.2 Soybean Rust.

The most destructive fungal disease in soybean is soybean rust caused by *Phakopsora pachyrhizi* Sydow. It is especially destructive on soybeans

growing in subtropical and tropical areas of the Orient. Yield losses of 3-5% are reported in the Yangtze River of the People's Republic of China, 10-40% in local cultivars in Thailand and complete losses on some imported cultivars and 23-90% in Taiwan (Sinclair, 1982). Soybean rust is conspicuously absent on the African continent.

Symptoms.

The most commonly observed symptom of soybean rust is the sporulating lesion on the lower surface of the leaf. At the early stages of development, the lesions may be confused with bacterial pustules. At the onset of the disease, chlorotic to gray-brown or reddish brown spots appear on leaves and enlarge to form polygonal lesions. Pimplelike uredia develop in the lesions and release uredospores through a central pore. More uredia develop on the lower surface than on the upper surface of the leaf. Uredia with lesions multiply over time. Under some conditions, groups of uredia develop in tissue that is not discoloured to form obvious lesions. The uredospores tend to stick together to form clumps, thus, the diseases is referred to as a sticky rust.

Soybean rust causes premature defoliation, early maturity, and low seed weight. Fewer pods and seeds may be produced when infection is early or severe.

Disease cycle and epidemiology.

Free water on plant surfaces is necessary for uredospore germination and direct penetration. Optimal temperatures for infection is about 18-21°C.

Uredospores germinate, usually by means of a single germ tube, over a temperature range of about 8-30°C, but 20°C is near the optimum. At 20°C, infected plants show chlorotic or tan-coloured flecks about five days after infection. In seven to nine days, uredia are differentiated and by nine to ten days, they begin liberating a new generation of spores. A single medium may continue to produce uredospores for weeks. Uredospores may remain viable for up to 40-60 days on leaf tissues depending primarily on temperature and moisture.

Control.

No satisfactory methods of control have been developed. Spraying with fungicides has been reported to reduce disease severity. Mancozeb is said to have proved effective.

10.2.3 Charcoal rot.

Charcoal rot is caused by *Macrophomina phaseolina*, is worldwide in distribution, is seedborne, can attack over 400 species of plants, and can live over in the soil as sclerotia for long periods of time. In tropical countries, where the pathogen causes a blight of emerging seedlings, plant losses up to 77% have been reported (Sinclair, 1982).

Symptoms.

The fungus causes a seedling blight, root rot, and lower stem decay. The disease is most severe under hot, dry conditions. The fungus is highly viable and the only above-ground symptoms may be yellowing and wilting of the foliage of infected plants. However, examination of the lower stem will

show a superficial lesion extending from ground level up the stem. When the plant is pulled back at the lesion small black sclerotia can be seen. The tissue has a silvery grey or charcoal appearance. The symptoms are brought about by an interaction of enzymes, toxins and intraxylem sclerotia.

Disease cycle and epidemiology.

Sclerotia and *M. phaseolina* may survive free in soil or embedded in host residue in dry soils for long periods. In wet soils, sclerotia cannot survive more than seven to eight weeks and mycelium no more than seven days. *M. phaseolina* is a poor competitor in soil. Growth in a soil phase is limited by the availability of nutrients. Populations of the fungus in soil increase when hosts are grown continuously in the same field, and the disease thus becomes more severe in successive crops.

Large numbers of seeds may carry the pathogen in the seed coat, particularly in tropical countries. Infected seeds either do not germinate or produce seedlings that may die soon after emergence.

The disease is not evident at low temperatures; the pathogen begins to grow and symptoms appear between 28 and 35 ^{o}C. Pathogen growth can occur early in the season, often infecting 80-100% of seedlings two to three weeks after planting. The rate of infection increases with higher soil temperatures. Low soil moisture further enhances disease severity.

Sclerotia germinate on the surface of roots and produce numerous germ tubes. The fungal hyphae first grow intercellularly then through the xylem and form sclerotia that plug the vessels. Sclerotia can be formed in green or juvenile tissues but are usually formed as a result of moribundity

and release of nutrients. *M. phaseolina* probably causes disease via mechanical plugging of the xylem by sclerotia, toxin production, enzymatic action and mechanical pressure exerted by penetration of the middle lamellae.

Control.

(i) Avoid excessive seeding rate. Crowding produces weakened seedlings which are more vulnerable to fungal attack.

(ii) Fertilize soybeans to encourage more vigorous growth

(iii) Irrigate, where possible, to keep soil moisture high, or flood fields for three to four weeks before planting.

10.2.4 Fusarium blight or wilt, root rot and pod and collar rot.

Fusarium blight or wilt occurs in most soybean-growing areas of the world, and is potentially destructive in the tropics and sub-tropics.

Symptoms.

(i) Fusarium blight or wilt.

At least three species of *Fusarium oxysporum* can cause blight or wilt. Symptoms appear about mid-season in hot weather, particularly on plants growing in sandy soils. The disease has not been reported on seedlings. The most characteristic symptom is browning or blackening of the vascular system in roots and stems which is evident when stems are split open. Leaves on affected plants may become chlorotic, wither and eventually drop.

(ii) Fusarium root rot.

Several *Fusarium* spp. may cause root rot which usually develops on seedlings and young plants in cool (14°C) weather. Older plants generally

are less susceptible than young ones when the disease is severe. Seedling emergence is slow and poor, and affected seedlings are stunted and weak. Infection is generally confined to the roots and lower stems. Cotyledons of diseased seedlings are chlorotic and later become necrotic. Infected plants beyond the seedling stage seldom die, but their seeds generally are small and shriveled. Although the pathogen is generally confined to the roots, nearly mature pods may be invaded under prolonged humid, wet conditions. Pod infection may result in seed transmission of the pathogen.

(iii) Pod and collar rot.

Fusarium semitectum causes pod and collar rot. Emerging or slightly older seedlings show depressed, water-soaked, cream coloured, serrated lesions on the cotyledons and hypocotyl. As seedlings mature, these areas turn dark brown to black and eventually coalesce to form large lesions.

Pods may dry prematurely, beginning at the pod tip and progressing toward the base. Pods eventually turn dark brown or black. Severely infected pods produce no seeds.

Disease cycle and epidemiology.

The *Fusarium oxysporum* group are soil inhabitants that readily colonize a variety of plant residues and overseasons as chlamydospores or mycelium in colonized substrates. Primary inoculum, therefore comes from the soil. Seedborne infection by *F. oxysporum* and *F. semitectum* has been reported and occasionally reduces seed germination.

F. oxysporum penetrates soybean plants through wounds. In early stages of infection, it is confined to the xylem vessels near the pith. Later most xylem vessels become filled with mycelium and parenchyma tissues are also invaded.

The soybean cyst nematode (*Heterodera glycines*), root-knot nematode (*Meloidogyne incognita*), and sting nematode (*Belonolaimus longicaudatus*) predispose seedlings and young soybean plants to infection by *F. oxysporum*. Seedlings growing in soil infected with *H. glycines* and *F. oxysporum* develop fusarium wilt symptoms. Predisposition of soybean plants by *M. incognita* is limited mainly to the root tip region and larvae migrate intercellularly, resulting in slight cellular destruction. Larvae of *H. glycines* however, invade more mature root tissue, migrate intracellularly, and cause extensive wounding, thus making soybean plants more susceptible to attack by *Fusarium* species.

Control:

(i) Grow cultivars resistant to both *Fusarium* pathogens and soybean cyst or root-knot nematodes.

(ii) Plant high-quality seed in warm, well-drained soil

(iii) Delay cultivation until soil moisture is adequate

(iv) Ridge soil around the base of plants to promote development of adventitious roots from the stem base.

10.2.5 Rhizoctonia root and stem decay.

Rhizoctonia solani causes damping off, root rot, stem decay of hundreds of plant species around the world. The fungus is soil borne and seedborne

in soybeans. Most reports describe pre-and post-emergence damping off as the major disease of soybean. However, *R. solani* and possibly in combination with *Fusarium* species and other soil-borne fungi cause severe losses to maturing soybeans in growing areas of southern Brazil. Large areas or patches within a field show progressive dying of plants throughout flowering to maturing. Losses up to 40 percent of potential yield have been reported (Sinclair, 1975). This appears to be a unique disease situation that developed after intensive soybean production was started in Brazil.

Purple seed stain.

Purple seed stain - also known as purple spot, purple blotch is caused by *Cercospora kikuchii* and is now found world wide. The disease does not reduce yields directly, but sometimes a high percentage of seeds are stained at harvest which reduces the grade and quality of the beans.

Symptoms.

Soybean seeds, pods, stems, and leaves can be infected. The disease is most conspicuous and easily distinguished on the seeds. Seed discolouration varies from pink or pale purple to dark purple and the discoloured areas range from specks to large irregular blotches that may cover the entire surface of the seed coat, cotyledons generally are not discoloured. Infected seeds cause reduced stands and often produce diseased seedlings.

Disease cycle and epidemiology.

Cercopora kikuchii overseasons in diseased leaves, stems, and seeds and infects soybean plants at flowering, earlier than many seedborne pathogens.

Unlike other pathogens, it does not increase in incidence during delayed harvest.

When infected seeds are planted, the fungus grows from the seedcoat into the cotyledon, gradually extending toward the radicle and rootlets. The seed coat of severely affected seeds, however, adhere to the cotyledons. Infected cotyledons remain attached or eventually fall. In either case, the fungus grows into the stem of only a small percentage of seedlings.

In warm humid weather, the fungus grows on cotyledons, stems, and leaves and produce conidiophores and conidia. Conidia are borne by wind and splashing rain to other leaves and stems, where they initiate seconday infections that produce conidia that infect other leaves, stems, and pods during warm, wet conditions.

The fungus grows through the mesocarp parenchyma of pods and then through the adaxial vein. From here, it spreads through the hilum into the seedcoat, where it produces the characteristic purple stain.

Planting purple-stained seeds may introduce the pathogen into a field. However, if the period during flowering is abnormally wet, the percentage of purple-stained seeds planted has little effect on the percentage of purple-stained seeds that develop.

Control:

(i) Plant high yielding, moderately resistant cultivars

(ii) Sow good-quality seed relatively free of the pathogen on the late side of the planting season.

The number and size of lesions vary with variety. A fluffy, gray, mold-like growth later develops on the underside of the spot. Seed from heavily infected plants may have a powdery dull white encrustation. Numerous physiological races are recognized. Varieties differ in their reaction to the several races of mildew.

10.2.8 Sclerotium blight.

This is caused by *Sclerotium rolfsii* Sacc; and is frequently observed on soybeans as well as in many other crops. A white mycelial growth occurs at the base of the plant and rather large brown sclerotia form on the outside of the mycelial growth. Sclerotium blight appears to be a secondary disease developing on plants weakened from other causes such as nematode or Phytophthora rot.

10.2.9 Fungal diseases affecting germinating seeds.

(i) Pythium rot. Pythium rot is caused by *Pythium debaryanum* Hesse, *P. ultimum* Trow, and *P. aphanidermatum* (Edson) Fitz. When soybean seeds are planted in cold soil, the *Pythium* fungus can cause seed decay or kill the young seedlings before they emerge from the soil. The seedlings that emerge often have well-developed cotyledons,with a dead growing point. A direct relation between the amount of carbohydrate exuded by germinating seeds and seed rot, caused by *Pythium* has been demonstrated. Disease resistant varieties are available in many localities and should be planted.

(ii) Phytophthora rot. Phytophthora rot caused by *Phytophthora megasperma* Drechs. *sojae* A.A. Hildeb., is a very destructive soil-borne disease,

(iii) Treat seeds with a fungicide

(iv) Rotate soybeans with a non-leguminous crop

(v) Plough under crop residues

10.2.6 Pod and stem blight.

Pod and stem blight are caused by *Diaporthe phaseolorum* var *sojae* (imperfect stage *Phomopsis sojae* Leh.).

Symptoms.

Stems, petioles, pods, seeds, and less frequently leaf blades may be infected. In warm, moist conditions, the fungus fruits on petioles of broken leaves or on dead soybean tissue on the ground as early as the first or second trifoliate stage.

Infected plants may be stunted. Many black pycnidia of the causal fungus develop on the lower portion of the main stem, branches and pods as plants reach maturity. Dead stems may be covered with speck-sized pycnidia usually arranged linearly or the pycnidia may be limited to small patches, generally near the nodes. Other fungus associated with dead stems are species of *Alternaria, colletotrichum, Diaporthe, Phoma* and *Septoria.*

Under field conditions, no definite stem lesions are produced. In a wet season pycnidia appear simultaneously over the entire plant. In dry weather, however, they are confined to limited areas on stems near the soil and generally are clustered close to the nodes.

Heavily infected seeds are badly cracked and shriveled and are frequently covered with white mycelium. Lightly infected seeds are often normal

in size and appearance. Severely infected seeds often do not germinate.

Disease cycle and epidemiology.

The pod and stem blight fungus overseasons as dormant mycelia in soybean or other host debris and in infected seeds. During the growing season, pycnidia or perithecia form large numbers of asexual spores, either of which can initiate primary infection. Initial infections can also result from planting diseased seed. Spores germinate in four hours if water is present. The fungus penetrates immature, senescent, or wounded tissue directly.

Prolonged wet periods during reproductive and maturation stages and warm temperatures (above 20°C) favour the spread and development of pod and stem blight.

Control:

(i) Plant high-quality seeds relatively free of the pathogen

(ii) Use a fungicide seed dressing

(iii) Harvest soybeans promptly at maturity. Crop rotation and a deep ploughing under of crop residues after harvest may also be beneficial.

(iv) Use a less susceptible cultivar. Soybean cultivars differ somewhat in resistance

(v) Grow cultivars that mature during periods of low rainfall.

10.2.7 Downy mildew.

Downy mildew caused by *Peronospora manshurica* (Naum) Syd ex Gaum is found wherever soybeans are grown. Small round yellowish-green spots first appear on the upper side of the leaves.

especially on slowly drained clay soils in humid regions. The disease may kill seedlings before they emerge or at any other time during the growing season, or it may only reduce vigour. Under certain conditions, the fungus causes pre-emergence damping-off of the germinating seeds. When this occurs, gaps of various lengths may appear in rows, and the stand of plants may be so sparse that replanting is necessary. The fungus can survive in the soil for long periods of time in the absence of soybeans, and once soil is infected by the fungus, use of resistant varieties is the only adequate means for disease control.

10.3 Bacterial Diseases.

Bacteria are procaryotic organisms, most of which lack chlorphyll and are saprophytic. Several hundred species cause diseases of plants or animals or both. Common genera of plant pathogenic bacteria include *Agrobacterium, Corynebacterium, Erwinia, Pseudomonas,* and *Xanthomonas*.

Bacteria are found in air, water, and soil and on or in all plants and animals, including man. They vary remarkably in their characteristics and are widely adaptable. They commonly persist in mixed populations.

Bacteria generally have a rigid cell wall, but some recently discovered bacteria lack a firm outer wall. These organisms are generally referred to as mycoplasmalike organisms or cycoplasmas. Another group, called spiroplasmas, lack a cell wall and are bounded by a trilaminar membrane. Spiroplasmas,howver, characteristically grow as mobile, helical filamentous cells.

Classifying and identifying bacteria can be difficult. Soybean pathogens are identified by host symptoms, cell and colony morphology, host specificity, and reaction to a wide variety of serologic and biochemical tests.

Plant-pathogenic bacteria normally are unicellular rods up to 3μm long that do not form spores. Many species have one to several flagella that aid in motility via rotary motion. Spiroplasmas move by a gliding motion. The most common types of bacteria divide by binary fission; populations of the resulting cells may separate or form associations of cells. In a warm, moist environment, large numbers of new cells can be produced within a few hours.

Bacteria that cause plant diseases are disseminated by people transporting diseased plant material and performing a wide range of cultural practices, by other animals (including insects, mites, and nematodes), by splashing or flowing water, and by wind blown sand or soil. Bacteria enter plants through wounds produced by adverse weather, insects, nematodes, or human activities or through natural openings such as hydathodes, lenticels, nectaries, stomates, and leaf scars. Water-soaked tissues often predispose plants to invasion by bacteria. Free moisture and moderate-to-warm temperatures are generally required for pathogen and disease development.

Bacteria multiply rapidly inside plants, where they cause death of cells (necrosis), abnormal growth (tumors), blockage of water-conducting tissue (wilting), or breakdown of tissue structure (soft rots)

Bacteria may migrate throughout the plant and become systemic. They are pathogenic primarily through the action of enzymes or toxins that produce chlorosis, water-soaking, and other symptoms.

When conditions are unfavourable for their growth and multiplication, bacteria remain dormant on or in living or dead plants, soil, tools and equipment, or the bodies of insects and other animals. Most plant-pathogenic species die quickly in high temperatures (10 minutes at 51°C), dry conditions, and sunlight. Few pathogenic bacteria survive in the soil - many are ingested by soil protozoa, and few have the biochemical function necessary to compete for soil nutrients.

10.3.1 Bacterial blight.

Bacterial blight occurs world wide and is the most common bacterial disease of soybeans, especially during cool, wet weather. It is caused by *Pseudomonas syringae* PV *Glycinea* (Coerper).

Symptoms

These are small angular, usually water soaked lesions on leaves. These lesions may also form on stems and pods. Bacterial blight development appears to be favoured by cooler temperatures than are optimum for bacterial pustule. Heavy dews which permit water droplets to remain on leaflets for several hours also favour development. Varieties differ in degree of susceptibility.

Disease cycle and epidemiology:

P. syringae PV *glycinea* over-winters in crop residues and in seeds. Seeds can be infected through the pods during the growing season, or may be invaded during harvesting. Primary infections of cotyledons may be a major source of inoculum that causes secondary lesions on seedlings.

The bacterium is spread during windy rainstorms and during cultivation while the foliage is wet.

Bacteria enter the plant through stomata and multiply in the intercellular spaces of the mesophyll where they produce a toxin that inhibits chlorophyll synthesis. Bacterial slime and fluids fill these spaces, and typical water-soaked lesions form within five to seven days.

Control.

(i) Avoid planting high susceptible cultivars in areas where the disease is a potential problem.

(ii) Plant seeds that are relatively free of the pathogen

(iii) Rotate soybeans with crops not susceptible to the pathogen

(iv) Do not cultivate when the foliage is wet.

10.3.2 Bacterial pustule.

Bacterial pustule has been reported from most soybean growing areas of the world where warm temperatures and frequent showers prevail during the growing season. It is caused by *Xanthomonas campestris* pv *phaseoli*.

Symptoms:

Early symptoms are minute pale green spots with elevated centres on either or both leaf surfaces. Later, a small, raised light coloured pustule forms in the centre, usually in lesions on the underleaf surface. Spots vary from minute specks to large, irregular, mottled brown areas that arise when smaller lesions coalesce.

Symptoms of bacterial pustule may at times resemble those of bacterial blight. However, pustule lesions are not water-soaked in the early stages of development and usually have minute raised pustules in the centres.

Disease cycle and epidemiology.

The bacterium overseasons most commonly in soybean seeds but also in soybean crop debris and in the rhizosphere of wheat roots. The bacterium spreads via splashing water or wind-blown rain and during cultivation when the foliage is wet.

The bacterium enters the plant through natural openings and wounds and multiplies intercellularly. Bacterial pustule, unlike bacterial blight, is not checked by high temperatures. New infections may occur throughout the growing season whenever wet or rainy conditions prevail.

Control.

(i) Use resistant cultivars

(ii) Follow control measures suggested for bacterial blight.

10.3.3. Wildfire.

Wildfire, a disease of tobacco (*Nicotiana* spp) has been reported on soybeans in the United States and Brazil. It is caused by *Pseudomonas syringae* pv *tabaci* (Wolf and Foster) Young.

Wildfire occurs naturally only on plants first infected with bacterial pustule, and usually in areas of a field rather than on an entire field.

Symptoms are a large yellow halo surrounding a pustule. Development of wildfire will magnify yield reductions appreciably. All varieties resistant to bacterial pustule are resistant to wildfire.

10.4 Virus Diseases.

More than 600 viruses - macromolecules composed of either ribonucleic acid (RNA) or deoxyribonucleic acid (DNA) surrounded by a protective protein or lipoprotein coat - are known to infect plants. Virus particles, can multiply only within living cells and thus are obligate parasites. Viruses may be long rigid or flexuous rods, or spherical, (isometric), or bacilliform (elliptic). They range in diameter from 10 to 70nm, and rod lengths can exceed 2μm. To observe virus particles requires a high-resolution electron microscope.

Viruses are transmitted to plants by pollination, through wounds created by animal (mainly arthropods and nematodes) or fungal vectors; by parasitic plants; by mechanical inoculation; and by deliberate or accidental human activities, such as planting infected seed and propagating plants by cuttings, grafts, or budding.

Viral symptoms range from latent infections to plant death. Viruses may induce stunting, mosaic patterns, yellowing or reddening of the foliage and necrosis. The action of two or more viruses in a single plant multiple infections can be additive, synergistic, or cross-protective (one strain preventing infection by another strain of the same virus).

Viruses are identified by host specificity; particle morphology, mode(s) of transmission; and biochemical, physical, and serologic properties. The types of symptoms of indicator plant hosts also aid in identification. Most plant viruses are named for the original or major host attacked and the

symptoms they produce. Plant viruses are grouped taxonomically by type of nucleic acid, size and shape, mode of transmission, serology, and antigenic properties.

At present, identifying virus and viruslike diseases in the field is more an art or a game of chance than a science. Indistinct symptomatology, the occurence of several viruses in the same area, the existence of virus strains, the presence of singly and doubly infected plants, and inadequate symptom characterizations confound disease diagnosis in the field. Moreover, symptoms of virus infection may be confused with those caused by mycoplasmas or mycoplasmalike organisms. Satisfactory clinical techniques, however, are available to identify many viruses. Genetic and nutritional abnormalities may be ruled out if a causal agent is transmitted from diseased to healthy plants, electron microscopy of diseased tissue reveals virus particles that are absent in healthy plants, or serologic tests detect relationships with known plant viruses.

More than 50 viruses or virus strains have been reported to cause diseases of soybean throughout the world. All viruses that infect soybean contain RNA. Several virus diseases are not known to occur in nature but have been induced under experimental conditions (Sinclair, 1982).

10.4.1 Soybean viruses.

Soybeans are susceptible to a number of virus diseases but in tropical Africa rarely do more than two cause economic damage in any one area during a season. In soybean growing areas in Africa soybean mosaic virus and cowpea mosaic virus may be found.

Mixed virus infections often occur in nature with possible adverse implications beginning to be realized. For example, certain viruses can be transmitted from a single infection. Also, certain mixed infections of unrelated plant viruses result in a synergistic interactions of unrelated plant viruses resulting in a synergistic interactions where the symptoms and other measures of infection are more severe than the sum of the effects of single virus infections.

10.4.2 Field spread of soybean viruses.

Clearly, field spread of soybean viruses occurs. Although epidemics of soybean viruses have been unusual, well-designed studies of the spread of endemic viruses must be made to provide information on the potential for future epidemics especially in Africa.

10.4.3 Vectors:

Insect vectors are known for all but one important soybean virus (Table 10.1), thus they are of primary importance in understanding the spread of soybean viruses. The aphid is the most important vector of soybean viruses, transmitting soybean mosaic virus, cucumber mosaic virus, bean yellow mosaic virus, alfalfa mosaic virus, peanut mottle virus and other viruses.

Most aphid-transmitted viruses of soybeans are stylet-borne or non-persistent; they are rapidly acquired during probing or feeding, and then can be immediately transmitted, but the exact mechanism is unknown. Retention of ability to transmit is usually less than one hour which limits the likelihood of long-distance spread.

Other viruses are transmitted by aphids in a persistent or circulative manner. Soybean dwarf virus is acquired by its aphid vector *Aulacorthum solani*, during a 30- to 60 minute feeding. After a latent period of 15 to 27 hours, it can then transmit the virus to healthy plants for up to 20 days. Ability to transmit is retained through the molt, but not through the egg (Tanada, 1970).

Transmission of bean pod mottle virus and cowpea mottle virus by beettles can occur immediately after feeding on an infected plant. Usually, the ability to transmit is retained for one or two days, depending on many incompletely understood factors. Why certain viruses are beetle transmitted and others are not is unknown, but evidence suggests that more than a simple contamination of the beetle's mouthparts by virus is involved (Walters, 1967).

Whiteflies also transmit soybean viruses. They retain the ability to transmit virus-like pathogens of soybeans for many days or weeks. Detailed knowledge is lacking, but it appears the whitefly-virus relationship is similar to the persistent or circulative aphid-borne viruses (Costa, 1969).

10.4.4 Aphids.

Most aphid vectors are host-alternating, insuring their wide dispersal. They spend the winter in the egg stage on a primary host, always woody. Eggs hatch and alatae (winged forms), fly to secondary hosts where colonies of apterae (wingless forms) establish, the number of generations depending on seasonal and meteorological conditions. Crowding and short days stimulate alatae formation, allowing them to return to the primary host to lay eggs.

Aphids generally fly immediately after a molt before feeding again. Newly-molted alates crawl upward for flight departure, partly because they are attracted to blue, violet, and ultraviolet light. Flight is upward until it enters moving air where currents provide transportation. Light, temperature, wind speed, turbulence, and humidity determine flight distance and duration. Aphids from nearby vegetation alight near the edge of the field, while those from more distant vegetation enter at greater heights and are thus more evenly distributed. There is no evidence that flying aphids recognize stands of suitable hosts and alight when they arrive at the edge of the field. Aphids are attracted toward green, yellow, or orange light, but once attracted they alight before host selection occurs.

10.4.5 Leafhoppers:

No soybean viruses are known to be leafhopper-transmitted, even though leafhoppers are prevalent in temperate soybean-growing areas. The biological relationship between plant viruses and their leafhopper vector is persistent, requiring acquisition and incubation periods of several days; the vectors retain the ability to transmit for many days or weeks. Some viruses multiply in the leafhopper as well as in the plant hosts.

10.4.6 Beetles.

Among beetles, only members of the family Chrysomelidae transmit plant viruses (Walters, 1969). Beetle-transmitted viruses are stable, highly titered, mechanically transmissible, 25 to 30mm diameter polyhedrons.

Table 10.1: Major insect vectors, seed transmission, and distribution of soybean viruses (Ford and Goodman, 1976).

Virus	Insect Vectors	Seed Transmission	Geographic Distribution
Cucumber mosaic (Soybean stunt)	*Myzus persicae, Rhopalosiphum prunifoliae, Aphis glycines*	No	U.S. and Japan
Bean yellow mosaic	*M. persicae*	No	U.S., Europe and East Africa
Peanut mottle	*Aphis craccivora*	No	U.S., Australia, Africa
Peanut stund	*M. persicae, Aphis craccivora*	Yes	Southern U.S., Japan, East Africa
Soybean dwarf	*Aulacorthum solani*	No	Japan
Soybean mosaic	*Acrythosiphon pisum, Aphis fabae, M. persicae*	Yes	Wherever soybeans are grown
Bean pod mottle	*Cerotoma trifurcata Diabrotica undecimpunctata Howardi*	No	Southern U.S.
Cowpea mosaic	*C. trifurcata*	No	Southern U.S., Puerto Rico, Africa
Southern bean mosaic	*Atrachya menetris*	Yes	U.S., Japan and on cowpeas in West Africa
Tobacco ringspot	*Thrips tabaci*	Yes	Midwestern U.S.
Soybean yellows	*Bemisia tabaci*	No	Asia
Yellow stunt	*B. tabaci*	No	Puerto Rico, South America
Tobacco streak	-	Yes	U.S., Brazil

Beetles acquire viruses in a few minutes and then transmit without a latent period, retaining transmission ability up to 20 days. Those viruses transmitted by beetles that infect soybeans are southern bean mosaic virus, soybean mosaic virus, cowpea mosaic virus and bean pod mosaic virus.

10.4.7 Whiteflies.

Whiteflies are important virus vectors, especially in the tropics, where various yellow mosaic diseases are serious problems on beans and soybeans (Bird and Sanchez, 1971). Whiteflies acquire the presumed virus after reaching the adult stage, generally within 24 hours from initial feeding and then transmit for 10 to 12 days. The incubation period between acquisition feeding and ability to inoculate a plant is four to eight hours. For successful inoculation, a 10-minute to 1-hour feeding time is required following incubation The female is a more efficient transmitter than the male (Costa, 1969).

10.4.8 Grasshoppers.

Grasshoppers (*Melanoplus differentialis*, *M. mexicanus*, and *M. femur-rubrum*) transmitted tobacco ring-spot virus (TRSV) to soybeans from tobacco and soybeans. Best transmission occurred with insects allowed only one bite of leaf tissue. Grasshoppers are not considered important as vectors ofTRSV in nature (Dunleavy, 1957).

10.4.9 Thrips.

TRSV was transmitted by nymphs, not adults, of *Thrips tabaci* from soybeans to soybeans. Groups of 10 thrips transmitted at the rate of 26 percent, and retained the virus 14 days. Neither *Frankliniella tritici* nor *Sericothrips variabilis* transmitted TPSV (Messieha, 1969).

10.4.10 Other vectors.

Mites (*Tetranychus* sp) transmit tobacco ring-spot virus from soybeans (Thomas, 1969), but they are probably not economically important as vectors. Several vectors of plant viruses are known outside the insect kingdom, including nematodes, fungi, mammals, and possibly others. Unfortunately, the amount of data available for soybean viruses is meager. Soil-borne viruses transmitted by fungi or nematodes usually occur in circular patches due to limited mobility of the vector. No fungal-transmitted viruses have been reported on soybeans.

10.4.11 Seed transmission.

Three important viruses are seed-borne in soybean (Table 10.1). Thus, the distribution of infected seed by man is an obvious first step in the "epidemiological" pattern of these viruses. Soybean mosaic virus occurs everywhere soybeans are grown apparently because of seed transmission.

10.5.1 Soybean mosaic.

Probably the most common virus of soybeans around the world is soybean mosaic virus (SMV). It is transmitted non-persistently by several species of aphid, and it is also transmitted through the seed. Moreover, it can be readily transmitted mechanically. The symptoms of infection by SMV vary widely, depending upon soybean varieties, weather, time and inoculation, and the strain or isolate of the virus (Ross, 1969). Mild strains of SMV in tolerant varieties growing under ideal conditions cause little loss of yield, although

maturity of the plants may be delayed. In warm climate (above 30°C) infected plants may even grow normally with few or no foliar symptoms. Highly susceptible or moderately susceptible varieties infected with severe strains of SMV show a yellow veinclearing symptom in the first systemically infected leaves. This is followed by a characteristic mosaic and rugosity. Severely affected plants may be stunted with short internodes and downwardly curled leaves, and the pods may contain fewer than the normal number of seeds.

Yield reductions of 50 percent or more have been reported from experiments in which all plants in the field were artificially inoculated. Losses of 80 percent occurred when plants were doubly infected with SMV and bean pod mottle virus (Ross, 1968). In tropical areas where aphid vectors are plentiful and seed-born virus is available as primary inoculum, rapid spread of the virus can be expected. It is conceivable, and in some cases has already been found, that 100 percent infection by SMV can occur. In such cases significant yield losses are expected. Soybean mosaic virus is seed-transmitted and is therefore known in every country where soybeans are grown (Dunleavy, 1973). Most commercial seed lots of soybean contain some SMV-infected seeds; some varieties have a very high level of seed transmission (Dunleavy *et al.*, 1970). The host range of SMV is relatively narrow compared with other legume viruses, but a number of varieties of *Phaseolus vulgaris* (L.) and *Lespedeza* sp. are systemically infected and are potential sources for spread of the virus in areas where soybeans are grown near these other legumes.

In addition to possible deleterious effects on plant growth and yield, SMV can also cause other problems. SMV-infected soybeans of many varieties produce a high proportion of mottled seeds, i.e. seed with an irregularly pigmented seed coat. This is an undesirable character in the soybean seed industry and can result in discounting on domestic and world markets. Also some investigators have reported reduced germinability of seeds from SMV-infected plants compared with seeds of the same variety from healthy plants (Quiniones *et al.*, 1971; and Galvez, 1963).

It is theoretically possible to control SMV by planting non-infected seeds of resistant varieties and also by controlling insect vectors, but in practice, control of insect vectors is not effective. No agronomically suitable varieties resistant to SMV have been put into wide use, and even the cleanest seed lots of soybeans available on commercial markets can contain a low percentage of virus-infected seed. In addition to serching for virus-resistant lines to use in breeding programs to produce virus-resistant varieties, research at the International Soybean Program is directed toward finding lines that do not transmit the virus to their seed. If a non-transmission character were found in the soybean germplam, it could be used to create new varieties which, while they may be infected with the virus, do not produce seeds that are infected. Since the major source of inoculum for spread within the field is believed to be infected seedlings arising from infected seed, the elimination of infected seed should provide a successful means of controlling SMV infection.

10.5.2 Bud blight.

Two viruses can cause bud blight disease of soybeans. Tocacco streak virus (TSV) causes a severe bud blight disease in Brazil (Costa and Carvalho, 1961) and the United States (Fabgenle and Ford, 1970; Ghanekar and Schwenk, 1974). The more common bud blight disease in the United States is caused by tobacco ringspot virus (TRSV). Both TSV and TRSV have wide host ranges. No insect vector is known for TSV, and the means of spread of this virus in soybeans is so far unknown. Field spread of TRSV usually occur in a pattern suggesting spread of the virus from outside the field by an aerial vector. TRSV is known to be transmitted by thrips (Messieha, 1969), grasshoppers (Dunleavy, 1957), and nematodes of the genus *Xiphinema* (Bergeson *et al.*,1964), although in no case is the transmission of TRSV to soybeans very efficient. Transmission by thrips is the most likely means of spread in soybeans, but laboratory studies show that only the relatively sedentary thrip larvae are capable of transmitting the virus (Messieha, 1969). Therefore the effective vector of TRSV in soybean fields is also unknown. Both TSV and TRSV are seed-transmitted in soybeans (Ghanekar and Schwenk, 1974).

Symptoms of TSV and TRSV infection in soybeans are identical. The growing tip in young, infected plants curves downward, becomes brown, and dies. The plants are stunted and produce little or no seed. Leaves of the infected plants often show a red flecking symptom. Plants that become infected by TRSV during or after flowering produce poorly developed pods that often show dark, irregular markings. As with soybean mosaic virus, TRSV causes

infected soybeans to mature later than healthy plants so that at the end of the growing season when healthy plants lose their leaves, virus-infected plants remain green.

10.5.3 Bean yellow mosaic.

Another legume virus that has been reported as a pathogen of soybeans in several countries is bean yellow mosaic virus (BYMV). The English terminology in current use for various yellow mosaic virus diseases of bean is confusing. Yellow mosaic diseases that are not caused by BYMV, but by a whitefly-transmitted, virus-like pathogen, have been reported in India, Brazil, and Puerto Rico. Bean yellow mosaic virus is a flexuous, rod-shaped virus that can be readily purified. It is transmitted in the fields by aphids and can also be easily transmitted mechanically, but it is not seed-transmitted in soybeans. BYMV has been reported to infect soybeans in the United States and Japan. The virus is widespread in legumes, especially in species of *Phaseolus*, and will undoubtedly appear in soybeans in areas where its other hosts are grown (Goodman and Nene, 1976).

Soybeans infected by BYMV have yellow mottled foliage or chlorotic vein-banding. Red necrotic areas occur on mature leaves. There are no records on yield loss caused by BYMV, and usually infected plants are not significantly stunted. However, various strains of BYMV are known, and the potential for a more severe disease of soybeans caused by BYMV should not be ignored.

10.5.4 Beetle-transmitted viruses.

Bean pod mottle virus BPMV) and cowpea mosaic virus (CPMV) are transmitted to soybeans by leaf beetles (Patel and Pitre, 1971; Ross, 1963; Walters, 1964). Soybeans singly infected by BPMV are usually not seriously affected, but double infection with BPMV and SMV can result in severe losses (Ross, 1963). In addition to yield losses, seed size may be reduced in plants affected by BPMV. The foliar symptoms of BPMV include mild chlorotic mottle, which may be more severe at higher temperatures. The virus has a narrow host range, but it includes several other useful bean crop in the genus *Phaseolus*. Isolates of CPMV from Trinidad, Puerto Rico, and the United States can cause a very serious disease in soybeans, (Goodman, and Nene, 1976). The symptoms include transient vein chlorosis, followed by an intense yellow-green mosaic. Leaves are distorted, often assuming a cup-like shape during the acute stage ofthe disease. During the chronic stage of the disease the leaves tend to be narrowed, occasionally straplike, and show a pronounced mosaic pattern. CPMV-infected soybeans produce few or no flowers. Occasionally flower buds and even vegetative buds turn brown and die, and the plants do not mature.

10.5.5 Soybean dwarf.

Yet another soybean virus of importance in some areas is soybean dwarf virus (SDV). The disease caused by this virus was first reported from Japan (Tamada, 1970). The known host range of the virus is restricted to legumes. SDV is transmitted mechanically and is apparently not seed borne. There is evidence that SDV may be a phloem-restricted virus. All 45 soybean varieties tested by Tamada (1970) were susceptible to SDV.

10.5.6 Other diseases:

Alfalfa mosaic virus, cowpea chlorotic mottle virus, peanut mottle virus, and broad bean mosaic virus are other naturally occurring soybean viruses that may become important in new soybean growing areas but are of no known consequence in soybeans today. Alfalfa mosaic virus (AMV), for example, has been reported naturally infecting soybeans in Japan, South Africa, and the United States (Dunleavy, 1973), but the symptoms are generally very mild. AMV has a wide host range among legumes (Klesser, 1961) and is probably a common virus in tropical areas where soybeans may become an important crop. Since AMV is transmitted by aphids, there is a real possibility that in certain tropical areas a severe strain of AMV may become widespread in soybeans.

10.5.7 Soybean yellows.

Perhaps the greatest threat to soybean production in the tropics is the group of virus-like pathogens of legumes that are transmitted by whiteflies. Unlike the viruses discussed above, the whitefly-transmitted, virus-like agents have not been fully characterized, but they are serious and cause a lot of damage in Asia.

10.6 Control methods.

Much remains to be learned about the epidemiology of soybean viruses and their control. While there is considerable knowledge about vectors of known soybean viruses, few studies have been done which characterize the virus-vector-host relationships in the field especially so in Africa. The need for knowledge of soybean virus spread will increase as soybean culture is

introduced in new areas in Africa, and as production expands in the current soybean producing areas. Some varieties e.g. Buffalo and Sable are resistant to most strains of SMV. Removal of virus infected plants from seed production plots is helpful.

10.7 Noninfectious diseases.

Noninfectious diseases of soybeans are caused by an excess, a deficiency, or an imbalance of soil nutrients or water; extreme soil acidity or alkalinity; extreme temperatures; air pollutants; pesticides, and mechanical or other injury. Severity and type of injury vary with the stage of plant maturity when the disturbance occurs and the plant part involved. Symptoms of non-infectious diseases are often confused with symptoms caused by bacteria, fungi, nematodes, and viruses.

10.7.1 Crusting or soil compaction:

When heavy rain falls on fine-textured soil, a hard crust may form and prevent germinated soybeans from emerging. The stems of such seedlings become thickened, and in severe cases, the hypocotyl arch is cracked or broken. Rotary or hand hoeing to break up the surface crust may aid emergence. Minimum tillage practices eliminates much of the crusting problems.

10.7.2 Sunburn:

Minor sunburn damage appears as small, interveinal, brick red spots on both leaf surfaces. In severe cases, the discoloration spreads over and along the veins. The spots later develop brownish centers that may crack.

Sunburn damage on petioles and stems appears as elongated, brick red lesions that may be confused with bacterial infection. On pods, brown spots

appear, spread, and are often colonized later by saprophytic fungi, such as *Alternaria* and *penicillium* spp.

10.7.3 Water damage:

Soybeans flooded or submerged in water for a long time will die. How long plants can survive in such conditions depends on the temperature and whether the water is still or moving. If not submerged, soybeans can withstand flooding relatively well, although some cultivars are more flood-tolerant than others. Death of soybeans in low areas may be caused by Phytophthora rot rather than water damage. Herbicide injury may also be more serious in wet areas.

10.7.4 Air pollutants.

Ozone and sulfur dioxide are the major pollutants known to cause foliar injury. Soybeans are more sensitive to both pollutants than are barley, maize and sorghum and are about as sensitive as alfalfa, clovers, and groundnuts. Foliar sensitivity is related to genotype, cultivar, and environmental conditions. Environmental conditions that promote good plant growth also contribute to maximum foliar injury from air pollutants.

Hydrogen fluoride peroxyacetyl nitrate have not been considered detrimental to soybean production. Accidental releases of ammonia, chlorine and hydrogen chloride into the air have caused foliar injury but, as air pollutants, they pose no widespread threat to soybean production

Chemicals used as herbicides, insecticides, and miticides can produce foliar symptoms on soybeans similar to those caused by air pollutants.

Air pollution symptoms are also easily confused with such stresses as nutritional imbalances, insect damage, viruses, drought, and temperature extremes.

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CHAPTER ELEVEN

11.1 Insect pests and their control;

Possibly because soybean is a new crop, serious yield losses due to insect pests have not been reported in Africa except in localised situations.

Insects may feed on soybean from when it is planted until physiological maturity is reached. Damage results from insect feeding on seed, seedlings, roots and nodules, stems, foliage and fruiting structures. Feeding may occur in stored beans, although this is rare under good storage conditions. Certain phytophagous species also provide access for disease organisms or transmit them directly to plants. Soybean may withstand considerable reduction of plant stands and damage to foliage and fruiting structures without loss in yield or quality.

Insects have been recognized as important pests of soybean and in recent years greater attention has been given to pest species identification, the action threshold and degree of injury necessary to cause an economic reduction in yield, and ways of managing the pest population.

Several means of control are now available, such as the use of insecticides and varietal resistance. Defoliation studies have shown that a moderate level of defoliation does not reduce seed yield. If insecticides must be used, it should be in connection with other control methods so as to cause minimum damage to the environment and natural enemies. Considerable backgroumd information must therefore be accumulated on insect pests and biological control agents and the effect of various insecticides on them.

11.2 Major insect pests of soybean.

11.2.1 Green stink bug (*Nezara viridula*)

The *Nezara* species occur in large numbers where soybeans are grown in Africa. In Nigeria the green stink bug is found to occur in large numbers at about 11 weeks after planting and continues to build up until harvest (Ezueh and Dina, 1979).

The Stink bug feeds on a variety of crop plants including cotton, castor, tomato and various legumes. The adult stink bug can reach a length of 13mm and is about 8mm broad. There is some variation in the colour pattern from plain green to green with yellow stripes, or yellow with green dots. The nymphs are a brownish-black with yellow or white markings. In their first stage they are in groups of fifty to sixty on the undersides of leaves (de Pury, 1968) where eggs are normally laid. Later nymphs and adults can feed on any soft parts of the plant, but usually prefer developing seeds or fruit.

Stink bugs may affect soybeans through direct damage to fruiting structures or indirectly by transmiting the causal organism of the yeast spot disease, *Nematospora coryl* (Turnipseed and Kogan, 1979).

Damage is done by piercing and sucking by stink bugs on soybean pods and seeds. This ranges from nearly imperceptible punctures with minor discolourations or stained areas, to completely shrivelled seeds. The degree of damage is dependent upon the developmental stage of the seed at the time of damage.

Seeds that were very young when pierced became completely shrivelled, whereas seeds attacked after they were completely formed would likely show only slight puncture marks.

In general, stink bug damage to soybean may affect seed quality significantly resulting in lower percent germination, decreased seedling vigour, smaller seed size, reduced oil content, slightly increased protein content, and reduced storage stability. The location of stink bug punctures is probably more important than the number of punctures, one puncture in the radicle-hypocotyl axis ofthe embryo can prevent germination; whereas several punctures on the cotyledons may affect vigour of the seedling but not germination (Jensen and Newsom, 1972).

11.2.2 Golden wing moth (*Plusia orichalcea*)

This moth belongs to the family *Noctuidae*, and its caterpillars are semi-loopers, their first two pairs of prolegs are much reduced and therefore they move in much the same way as the true loopers of the *Geometridae*.

The adult moth has bright golden forewings, with brown borders on them, and grey-brown hindwings. The pale green caterpillars are found eating the leaves of flax, grain legumes, cabbages, turnips, chicory and other vegetables and they will also sometimes attack wheat and grasses. They sometimes show some tendency towards an armyworm effect.

In Zimbabwe *Plusia orichaloea* caterpillar is a serious pest of soybean. These larvae damage the crop by feeding on the foliage and, in some cases they may also chew into developing pods. Studies have been conducted

in Zimbabwe on the biology of *Plusia* species, prediction of outbreaks, and control measures (Tattersfield, 1975).

Egg laying usually starts at the end of December and may continue in waves until March. The intensity of egg laying appears to be negatively correlated with the incidence of rain in September.

Plusia activity can be detected by the presence of the moths in light traps. When large numbers of these are caught, radio warnings to farmers are broadcast so that they can spray. Damage can be avoided if control measures are applied before larvae commence extensive feeding. The timing of insecticide applications is greatly improved by regular scouting of the crop for the presence of eggs and larvae. Insecticides are then applied when the larvae are very small, before the third instar.

Control measures rely on the use of insecticides. The most common of the species, *Plusia orchalcea*, can be killed with a number of insecticides including DDT, Monocrotophos, Endosulfan, Trichlorfan, Malathion and Carbaryl (Tattersfield, 1975). DDT is very effective and relatively cheap but its use is discouraged due to contamination problems.

In Zimbabwe, field tests have indicated some degree of success in the use of a virus to reduce the *Plusia* population. This virus may have general use as a control measure but more information is necessary on the method of its collection, storage, method of application and rate and reliability of its spread under different environmental conditions.

11.2.3 *Maruca Testulalis* Geyer.

Maruca testulalis is regarded as one of the most important pests of cowpeas in Nigeria (Singh, 1978) and has also been reported on soybeans in Nigeria (Ezueh and Dina, 1979). The association of this pest with soybeans is however not fully established. It attacks soybean stem, leaves and pods. The larvae bore into the stem and causes die-back of the affected branch on the plant. Although older larvae have been observed feeding on flowers, damage seems to be concentrated mainly on foliage. It is not yet known to what extent the plant can compensate for this injury (Dina, 1978).

11.2.4 Aphids (*Aphis glycines* Mats.).

This group of relatively small, winged and unwinged insects infests several crops throughout the humid and sub-humid tropics in Africa in different seasons. The insects in this group are vectors of many diseases, especially the disease commonly known as soybean mosaic virus (SMV) transmitted through feeding on plants.

Both nymphs and adults suck the cell sap from the tender plant parts, such as the young leaves and shoots. The infected plants are generally stunted and show leaf rolling, discolouration, and etiolation.

Both the alate and apterous aphids can reproduce parthenogenetically and viviparously. A single apterous female gives birth to between 10 and 20 young daily.

Effective control of the pest can be achieved by spraying with systemic insecticides. Dimethoate and Pirimor have been reported to be quite effective. Other soil systemic insecticides such as carbofuran applied in the furrow during planting can provide adequate protection for about six to eight weeks.

11.2.5 Leafhoppers (*Empoasca* Spp.)

Like aphids, leafhoppers (*Jassids*) are found on several other crops in Africa and are a serious pest of cotton. They attack the underside of cotton leaves and prefer leaves which have just reached maturity. The nymphs grow to about 2mm long and the adults are about 2.5mm. All stages are pale green in colour.

The damage is caused by the toxic saliva which the insect injects, this interferes with the function of the vessels in the leaves, which turn first yellow and then red. There can be up to eleven generations in a year, for the complete life cycle takes only three to four weeks. Numbers tend to increase during the second half of the rains as the weather gets warmer (de Pury, 1968).

They have many alternate hosts and these include both crop pests and weeds. They can be controlled by several systemic/contact insecticides.

11.2.6 American Ballworm (*Heliothis armigera* Hubn)

This is one of the major insect pests of cotton but will also attack soybeans, beans, maize, citrus, sorghum, tobacco, sunflower, tomatoes,

pigeon peas and carnation flower buds.

The larva is usually green when it hatches, but as it grows it shows a great variation of colours, it can stay greenish, or it may turn brown with blackish spots or stripes along its sides. The fully grown larva is about 4cm and pupates in the soil.

The larva bores into the pod and feeds on the seed. If the seed has not yet formed, the larva feeds on the young pod, primarily at the base of the pod, which eventually falls off. The pest then feeds on the flowers and then finally the leaves. The pest can be effectively controlled by three or four applications of toxaphene - DDT.

11.2.7 Army worm and lesser army worm (*Soodoptera exempta and Spodoptera exigua*)

These two moths are very similar in appearance and habits at all stages. The young caterpillars are at first pale-bodied with dark heads, but when they begin to feed they become greenish, and during the later instars they develop their characteristic stripes, only the underside of the body is green, there is a black stripe along the centre of the back, and on each side of this is a pale stripe of broken lines on a grey-green background. The sides have a thick, black, longitudinal stripe and then a yellow line between this stripe and the green underside of the body. This appearance is typical of the caterpillars during a gregarious phase. They feed voraciously upon the leaves of grasses, cereal crops and soybeans if planted early. The older caterpillars are very destructive.

In East Africa outbreaks of swarming *Spodoptera* occur about every two years and they are probably caused by a particular combination of climatic conditions. Outbreaks occur only if rains continue, or are delayed, into what is normally the dry season of the year between December and March (de Pury, 1968).

There is only a period of about ten days in which the pest can be controlled on any patch of ground. Control is made all the more difficult because outbreaks are often not noticed until the caterpillars are quite large and ready to pupate. If conditions are known to be favourable a close watch should be kept on grasslands and young crops, so that the caterpillars can be found and destroyed in their early stages.

Persistent insecticides, usually in spray form, such as Endrin and DDT are effective against armyworms. There are many birds which prey on the caterpillars. These include storks and kites. Parasitic wasps and tachinid flies also parasitize them, and there is also a virus disease which causes the contents of the caterpillar to liquefy, and the empty skins of those which have been attacked by the virus can be found hanging from vegetation.

11.2.8 Cutworms (*Agrotis segetum* and others).

Cutworms belong to the family *Noctuidae* and are a group of lepidopteran larvae which attack the stems of young seedling plants at ground level. They can be fairly serious as nursery pests and will attack seedlings of maize, other cereals, beans, soybeans and cabbage. In the southern highlands of Tanzania they are also important pests of tobacco.

The adult moths are night flying or nocturnal and are dull coloured with brown or greyish forewings and creamy-coloured hindwings. The young caterpillars will feed on the foliage of plants but older caterpillars are more inclined to cut stems. They feed at night and either take a bite out of the side of the stem at ground level, causing the plant to fall over, or they will cut completely through the stem. In the early morning, after damage has been done, the cutworm larva may often be found just below the surface of the soil close to the damaged plant. Soybean seedlings have been protected by dusting around the base of the stems with DDT or BHC dust.

11.2.9 Termites (*Odontotermes* spp.)

There are about four hundred different species of termites in Africa (de Pury, 1968),. They are often loosely called "white-ants", but in contrast to the complete metamorphosis of the true ants, termites have an incomplete metamorphosis, and they are more closely related to the cockroaches in structure and life cycle than they are to any other group.

Termites can be a serious pest of soybeans especially during a dry spell. The termite that attack soybeans are subterranean and feed continuously upward from the tap root into the stem. The infested plant withers, although even after the plant dies, the termite remains inside the stem. Aldrin applied to the soil gives effective protection against termite attack. Other insecticides are also effective.

11.7 Soybean insect pest studies at IITA

The common pests observed so far at IITA are Borombia beetle, *Taeniothrips* and *Nezara viridula*. During the second season of 1976 (IITA, 1976)

a preliminary assessment of leaf feeding by two lepidopterous larvae of *Trichoplusia* spp.and *Plathypena* sp. was made on 114 lines in replicated trial plots. The frequency distribution based on the highest score in any replication is presented in Table 11.1.

Table 11.1: Frequency distribution of leaf damage score by two insect species, *Trichoplusia sp.* and *Plathypena* sp.)

Score	Leaf damage (%)	Frequency
1	0 - 5	0
2	0 - 10	7
3	11 - 25	45
4	26 - 50	49
5	> 50	43

Pod sucking hemipterans recorded in the study included *Nezara viridula*, *Acrosternum sp.*, *Aspavia armigera*, *Piezodorus sp.*, *Cletus sp.*, and *Captosoma* sp. These insects damage young pods, causing them to shrivel and prevent seed development. Cultivars reacted differently to insect damage, and some early and late maturing cultivars appeared to escape damage.

11.3.1 Control.

The most commonly observed pod sucking insects are stink bugs. Although the composition is complex, three stink bugs are frequently encountered in Nigeria i.e. *Nezara sp.*, *Piezodorus guildinii* and *Aspavia.* sp. has been extensively studied. The insects have a wide host range, and a reservoir population is maintained on many wild leguminous plants and other

weeds. They normally migrate into a soybean field in relatively small numbers, but population rapidly increases as the insect breeds in the crop. One female can lay as many as 600 eggs, and the nymphs start feeding on soybean pods approximately two weeks later.

Experiments at IITA have used early-maturing soybeans or other legumes which form pods earlier than the main soybean as a trap crop which can be sprayed with endosulfan to kill the stink bugs. This study is still preliminary but experiments to verify the results are planned.

Important consideration is that the initial insect population that concentrates on the trap must be controlled. Failure to spray the trap properly can be devastating as the population on the trap multiplies and serves as a reservoir for invading the main soybean crop.

There may be some advantage in using cowpeas as a trap. There is evidence indicating a preference by stink bugs for cowpeas over soybeans (IITA, 1980). The use of cowpeas as a trap may be a very economical method for growing cowpeas. Cowpeas must be sprayed for control of pod sucking insects regardless of whether they are used as a trap or grown in monocultures.

Consequently, by growing the cowpeas on the edges of the soybeans, one is effectively controlling the stink bugs in the soybeans "free of charge". Such a system produced yields of 1,564 kg/ha of soybean as compared to yields of no cowpeas and 225 kg/ha of soybean when not sprayed (Table 11.2).

Table 11.2: Pod damage at physiological maturity and yield of soybeans grown under various methods of insect management (IITA 1980)

Management Method	Insecticide applied	% of pods without seeds	Yield kg/ha	% yield loss due to insects
Soybean monocrop	None	75.0 (6.0)	225 (45)	85
Soybean monocrop	Sprayed throughout pod development	4.6 (1.0)	1688 (79)	0
Soybean "trap"	Only "trap" sprayed	3.7 (0.5)	1545 (55)	8.5
Cowpea "trap"	Only "trap" sprayed	6.0 (1.0)	1679 (53)	0.5

Values are means followed by standard error of mean in parenthesis.

11.4 Other insect pests.

Foliage-feeding insects like thrips and *Spodoptera* species may occur throughout the growing season and are effectively controlled by applications of Lindane, Endosulfan, or Dimethoate, singly or in combination, (Rachie and Silvestere, 1977). Flower and pod-borers like *Laspesia* spp. are well controlled by gardona in experiments carried out in Southern Nigeria (IITA, 1973).

Robertson (1969) identified the following insects as forming the pest complex in soybean growing areas in Tanzania.

Cryptophlebia semilunana Saalmuller *Heliothis armigera*, *Spodoptera littoralis* Boisduval, *Spodoptera exigua* Hubner *Diacrisia investigatorum* Karsch *Sylepta derogata*	Lepidoptera
Brachyplatys testudo - nigra De Geer, *Coptosoma spp.*, *Agonoscelis versicolor* Fabricius, *Acrosternum acutum* Dallas, *Malydicoris scorula* Dallas *Piezodorus pallescens* Germar, *Dalsira costalis* Germar, *Anoplocnemis curvipes* Fabricus *Mirperus jaculus* Thunberg, *Riptortus* spp. *Clavigoalla tomentosicollis* Stal. *Clavigoalla Shadabi* Germar	Hemiptera

The damage done by each insect species was not estimated in this study but taken together these species caused serious damage. Feeding took place on stems and leaves, but more usually it was concentrated on growing points, developing buds and pods. This reduced the vigour of the plant and must have caused loss of yield by the loss of fruiting points, because the attacked buds dried and fell. A major loss of yield was also probably caused by the attack on developing pods, some of which failed to develop. Others continued to develop with little external sign of damage, but at harvest contained few or damaged seeds.

Experiments on the control of this pest complex carried out in Eastern Tanzania by Robertson (1969) during 1965-7 showed that two applications of endosulfan 35 F.C. applied at 1.4*l*/ha gave economic control of the soybean pest complex in that area.

On the basis of the little available data it appears that there is an urgent need to intensify the effort to catalogue and classify the insects associated with soybeans in Africa. The initiation of any pest management scheme will be greatly protracted in the absence of adequate biological and ecological information on the insect fauna. Currently there is a strong consensus among developing countries to employ pest management schemes instead of relying completely on chemical pesticides, but the basic foundation needed is not available.

11.5 Management and control of pest species

Present soybean insect control is primarily concerned with the temporary suppression of insect outbreaks that approach or exceed economic injury thresholds. The use of chemical insecticides constitutes the only presently available tool that afford sonsistent and satisfactory suppression of such outbreaks. These chemicals must be applied at minimum effective rates and oly only when necessary to avoid economic loss to the crop.

(i) Chemical insecticides. Conventional chemical insecticides are necessary to control pest outbreaks on soybeans. However, broad-spectrum chemicals are often being applied unnecessarily and frequently at excessively high rates. The action of such materials against many potentially beneficial non-target organisms has been reviewed (Newsom, 1967). Some of these insecticides give considerable residual kill of predators and parasites while affording only initial effectiveness against certain pest species. This may lead to a later resurgence of the pest in greater numbers than existed when the insecticide was initially applied (Bartlett, 1964). Recent research

(Turnipseed, 1973) has indicated that low rates of certain insecticides afford adequate pest control and allow survival of beneficial species.

Insecticidal research on soybean must be encouraged in Africa and should include studies on minimum effective rates of selected chemicals in integrated programs designed to conserve natural enemies of pest species.

Recommendations concerning the timing of insecticidal applications, the type of insecticide to be used, and rates of application may vary considerably from one region to another. Species may differ and actions of insecticides may vary with different climatic conditions. For these reasons chemical controls should be applied only in accordance with current recommendations of local extension services.

(ii) Predators and parasites. Published accounts of the effectiveness of predators and parasites against pest species in soybeans in Africa are limited. Ezueh and Dina (1979) indicated that a number of predaceous insect species occur in Nigeria (Table 11.3). These observations should be borne in mind when chemical control measures are envisaged in order to prevent a serious disturbance of the agro-ecosystem which might result from indiscretional use of pesticides. This is particularly significant when managing the cereal-soybean intercrop systems practiced in many parts of Africa because of the potential value of such crop mixtures in promoting biological control.

Table 11.3: Insect predators associated with soybean pests in Nigeria

Coleoptera:
Cydonia lunata F.
Cydonia vicina Mulsant
Exochomus flavipes Thunbert
Hyperaspis pumila Mulsant
Hemiptera:
Macrorhaphs infuscata Walker
Geocoris ambillis Stal.
Rhinocoris bicolor F.
Rhinocoris sp
Nagusta sp.
Hymenoptera:
Belanogaster junceus F.

(iii) Insect diseases.

The most commonly observed diseases of insects on soybeans are caused by fungi *Spicari rileyi* (Farlow). A bacterial disease organism, *Bacillus thuringiensis* Berliner, has been mass cultured and artificially diseminated with some success against several lepidopterous larvae.

(iv) Cultural practices.

Cultural practices that avoid or reduce insect losses are frequently used by farmers, in many instances without their awareness. Delayed planting in certain areas may speed germination and growth, reducing possible damage from insect pests. Appropriate rotations may reduce numbers and damage done. Use of early maturing varieties may decrease chances of late season damage from pests.

(v) Resistant varieties.

The greatest potential tool for effective management of soybean insect pests is available through development of resistant varieties. Excellent reviews of examples and mechanisms of insect resistance in plants were published by Painter (1951, 1958) and later reviewed by Beck (1965). Pathak (1970) indicated that insects on resistant plants are often restless and less vigorous rendering them more susceptible to environmental variations, predators, and insecticides.

11.6 INSECTICIDES:

Insecticides are poisons which will selectively kill insects more than any other form of life when used at recommended doses. Many insecticides are unstable compounds and therefore present storage problems. Most are insoluble in water. Manufacturers therefore, prepare them in forms which remain stable and can readily be diluted in water or mineral oils to give strength of solution required for field use.

The manufacturer's finished product is called a formulation. This usually contains a stabiliser to prevent chemical degradation. The real insecticidal content of the formulation is known as the active ingredient (a.i.) or active material (a.m.). Most formulations contain only a single insecticide but some formulations contain two different insecticides. Formulations may be either solid or liquid.

(a) Solid formulations.

(i) Dusts: These are fine powder formulations usually containing 5-10 percent of the actual insecticide. The rest is made up of an innert material

(filler) which may be some form of powdered clay or talc. Dusts are unsuitable for use under conditions of high wind, heavy rains or very dry conditions. They are also easily degraded because of the small amount of the insecticide contained. They do not require further dilution and so are applied as formulated.

(ii) Grannules: The insecticide is mixed with filler materials so as to form large grannules about 840 microns in size. Grannular formulations are more durable as the insecticides are only slowly released and are suitable for soil application. The insecticidal content is also between 5-10 percent.

(iii) Wettable powders (W.P.). These preparations are not soluble in water. Active insecticidal substance is dissolved in a carrier material which is a fine dust. This preparation is then treated with an emulsifier which enables the particles to disperse evenly when mixed with water. Some manufacturers use the term dispersible powders as an alternative. Wettable powders range between 40 percent and 80 percent in insecticidal content.

(b) Liquid formulations.

(i) Emulsifiable concentrate. (E.C.). The active insecticidal ingredient is dissolved in an appropriate solvent and an emulsifier is added. The preparation usually forms an emulsion when mixed with large volumes of water. The emulsifier also acts as a stabiliser which ensures that the emulsion remains long enough to allow the operator to apply the chemical.

It is often necessary to stir the mixture during applications. The usual strength of Emulsifiable Concentrates lies between 40 percent to 80 percent.

(ii) Solutions. The active ingredient is water-soluble and therefore requires no emulsifiers but a stabiliser may be added to prolong its storage life.

(iii) Oil preparations. Oil miscible liquids (o.m.l) are emulsifiable concentrates prepared for dilution in mineral oils instead of water. Examples of mineral oils used as solvents are kerosene, naptha and turpentine.

(iv) Fogging concentrates. These are very concentrated formulations meant for application with hot oil vapour droplets as the carrier instead of water or mineral oil. These are usually applied with special motorized or powered machines.

(v) Ultra low volume preparations (U.L.V.). These refer to high concentrates of insecticides suitable for use with atomizing machines. They are formulated for use without dilution in water.

Types of insecticides.

The following chemical classes of insecticides are known (i) Chlorinated hydrocarbons, (ii) Organo phosphorus compounds, (iii) Carbamates, (iv) Mineral oils, (v) Plant extracts, and (vi) Inorganic substances.

(i) Chlorinated hydrocarbons. Chlorinated hydrocarbons are insoluble in water but soluble in fats and liquids. As a result some of these compounds are stored in fatty tissue when ingested by humans and snimals. DDT is stored at a level which is 6 to 28 times the dietary intake, and is slowly metabolized and excreted over biological half-life of about one year. This is basis for

concern over ecological pollution when some of these compounds are introduced into aquatic food chains (Brooks and Gates, 1972).

Aldrin and dieldrin are stored more readily than DDT and their toxicity is greater, yet residues of these compounds are generally found at much lower levels in the environment. Chlordane, lindane, endrin, heptachlor, toxaphane and methoxychlor are stored on a lower level of magnitude than DDT.

Many chlorinated hydrocarbon insecticides have been subjected to basic toxicological re-evaluations in various test animals. These studies were conducted to measure chronic effects, including effects on reproduction and carcinogenicity. Studies of aldrin, dieldrin, endrin, heptachlor and chlordane in animals have not shown those chemicals to produce significant toxicological effects at dosage levels under 1 ppm in the diet, although they produce reversible adaptive responses of the liver at dosage levels of 1 ppm or higher.

The chlorinated hydrocarbons are quite specific in their action, being highly poisonous to insects in certain groups and comparatively ineffective in killing others. Resistance to these insecticides has developed in a growing number of pests during their period of use. Resistance to one chlorinated hydrocarbon is often followed by resistance to others.

(ii) The organo phosphate insecticides. Organic phosphates have a wide range of insecticidal effectiveness. They are contact insecticides. Many have fuming action. The organic phosphates act as inhibitors of the enzyme cholinesterase. Often the effect is not immediate and a worker may be exposed to the poison on successive days without apparent ill effects. However, grave symptoms appear when the critical level of the enzyme is damaged.

The phosphates as a whole do not have long residual action. This makes some undesirable where a long period of protection is needed, but many of the phosphates are most important where residual tolerances limit the choice of available insecticides, and in control of insects resistant to chlorinated hydrocarbons.

(iii) The carbamate insecticides.

The carbamate insecticides, like the organiphosphorus insecticides, are very active inhibitors of the enzyme cholinesterase, a vital component of the neuromuscular system of insects. However, the carbamates differ from the phosphates, in that they are competitive rather than irreversible inhibitors of this enzyme.

The carbamates act by contact or stomach poisoning and are not fumigants or vapour toxicants. Carbamates provide residual protection against most piercing and sucking pests upwards to 10 weeks when applied as a granule in soil applications. Absorption and uptake of the toxicant by the plant roots may be noted within 24 hours. Tests indicate that systemic activity diminished as plants mature. Translocation is upward into the vegetative tissues, with very little, if any downward movement.

(iv) Mineral oils. Highly refined petroleum oils mostly used against small insects and mites.

(v) Plant extracts. Extracts from plants which have insecticidal properties include: Rotenone, nicotine and pyrethrin.

(vi) Inorganic substances. This include arsenates and sulphur but are not commonly used now.

11.7 Making up insecticidal solutions.

It is important to know how to make insecticidal dilutions in order to apply the actual recommended dosages in the field. Most dilutions are in the range of 0.1-1 percent or 1-2kg/ha (hectare).

When an overdose of the insecticide is given the plants may show signs of toxicity such as stunted growth, chlorosis (marginal discolouration, yellowing) leaf distortion and burns. An underdose of course will not protect the plants (Fzueh, 1978).

When interpreting formulations, the following guidlines must be used. A 50 percent solution contains 50 ml. of active ingredient in 100 ml. of formulation volume (v/v). A 50 percent wettable powder contains 50 gms. of active ingredient in 100gms. of formulation weight by weight (w/w). Dose rates of insecticidal applications are usually given in grams or kilograms per unit area (hectares).

1. To determine the quantity of a formulation (X) required to apply the recommended amount of active ingredient per hectare (A) with a formulation containing B percentage active ingredient.

$$\frac{A \times 100}{B} = X$$

Example: Apply 0.25 kg ai/ha of 5 percent carbofuran granules

$$\therefore \quad \frac{0.25 \times 100}{5} = 5 \text{ kg granules/ha}$$

2. To determine the quantity of active ingredient (Y) required to mix with a known quantity of diluent (Q) to obtain a given concentration to spray

$$Q \times \frac{\text{percent concentration required}}{\text{percent concentration of active ingredient}} = Y$$

(a) Example: Mix 100 litres of 0.5 percent active ingredient (a.i) using 50 percent wettable powder

$$100 \times \frac{0.5}{50} = 1 \text{ kg of wettable powder}$$

(b) Example: Mix 2 litres of 5 percent active ingredient (a.i) using 75 percent wettable powder

$$2000 \times \frac{5}{75} = 133g \text{ of wettable powder.}$$

Given an insecticide of 75 percent w.p. formulation and required to be sprayed at the rate of 0.2 percent a.i. This means that the dilution should be 0.2g a.i./100 ml of water or 2g of a.i. in 1000 ml or 1 litre of water., i.e. = 800g in 400 litres of water per hectare. But the formulation is only 75 percent.

$\therefore$ The actual amount required is $\frac{100}{75} \times \frac{800}{1}$ g

$$= \frac{3200g}{3} = 1066.7 \text{ g/ha}$$

If to be applied on $\frac{1}{5}$ of an hectare

then we have $\frac{1.067}{5}$ kg in $\frac{400}{5}$ litres of water = 0.213kg in 80 litres of water or 213 g/8 litres of water.

11.8 Health hazards in the use of insecticides

Insecticides are essentially poisons and will kill other forms of life if carelessly used. Since they are invariably applied by humans, it is necessary to consider the toxic effects and safety measures to be taken.

'Toxicity is an expression of the quantity of that material which will kill or injure a living organism'. Humans can be poisoned by insecticide through direct inhalation, contamination on body, oral ingestion or by drift on crops which are likely to be eaten by them. When small amounts of contamination occur over a long period, its effect is known as cumulative poisoning or chronic toxicity. Acute poisoning or toxicity results from exposure to a single lethal dose of the insecticide.

Some insecticides remain active for a long time (persistent) and give rise to toxic residues - i.e. deposits on food or forage products remaining poisonous to humans and animals at the time of consumption. Mammalian toxicity expresses the effect of insecticides on humans and other mammals. The standard method of assessing this is by means of its median lethal dose - MLD or LD_{50} - which is the lowest dose of the chemical capable of causing death in 50 percent of the individuals of a given group of animals treated or exposed to it. It is measured in relation to body weight, - milligrams of poison/kilograms of body weight (mg/kg). It will require a smaller dose to kill an animal of 1kg than a man weighing 75kg. Female rats are usually used in the bioassary of chemicals to determine toxicity levels. The more toxic a substance is the lower will be the LD_{50}.

11.9 Observe these precautions when using insecticides:

(i) Always read the label before using insecticides. Note ingredients, uses, directions, warnings, and cautions each time before opening the container.

(ii) Keep all insecticides out of the reach of children, pets, and irresponsible people.

(iii) Always store insecticides in the original containers and keep them tightly closed.

(iv) Never smoke or eat while spraying or dusting.

(v) Avoid inhaling sprays or dusts. When directed on the label, wear protective clothing and masks.

(vi) Do not spill sprays or dusts on the skin or clothing. If they are spilled, remove contaminated clothing immediately and wash thoroughly.

(vii) Wash hands and face and change to clean clothing after spraying or dusting. Also wash clothing each time before reuse.

(viii) Cover food and water containers when treating around livestock or pet areas. Do not contaminate fish ponds.

(ix) Use separate sprayers for applying herbicides in order to avoid accidental injury to susceptible plants.

(x) Always dispose of empty containers so that they create no hazard to humans, animals, or wildlife.

(xi) Observe label directions and cautions to keep residues on edible portions of plants within limits not injurious to mammalian life.

(xii) If symptoms of illness occur during or shortly after spraying or dusting call a physician or get the patient to a hospital immediately.

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CHAPTER TWELVE

NEMATODES AS PESTS OF ECONOMIC PLANTS

12.1. Introduction.

Soil inhabiting nematodes being more numerous than any other animal of similar size must be considered an important segment of the soil fauna. They must be seriously considered in gaining an understanding of soil biology Nematodes are a well defined group of invertebrates ranked as phylum or a class in the animal kingdom. Nematode is a word derived from nematoid meaning 'like a thread' and is used with other common terms such as eelworm, threadworm or roundworm. Nematodes are widely spread and often occur in great numbers wherever food and moisture are present. Nematodes can be grouped according to their life style as parasites of animals, insects, plants, fungi or as free living in the soil or fresh or marine waters.

Nematodes or the diseases they cause in man, animal and plants have been known for centuries and are mentioned in some biblical accounts. J.T. Needham recorded observations on the first plant-parasitic nematode in 17[illegible] when he disected 'smutted corn' and found dormant second stage juveniles of what is now known as the wheat gall nematode (*Anguina tritici*). He recognized the juveniles as worms when they began to move when moistened. This nematode is a serious pest of wheat and can cause considerable losses in yield if crop rotation and other control measures are not employed. The wheat gall nematode also attacks rye, emmer and spelt. Other species of the genus attack grasses and much less commonly some dicotyledonous plants.

The Rev. M.J. Berkeley in 1855 found the galling on greenhouse cucumber in England was caused by the root-knot nematode (*Meloidogyne* sp.). The

root-knot group of nematodes must be placed high on the list of most serious plant pests because of their adaptability, pathogenicity, worldwide distribution in temperate and tropical climates and an extensive host range that includes most economic plants. The nature of nematodes as pests of agricultural crops was not generally recognized until the latter part of the last century. Scientists began to study crop losses in the sugar beet and potato industries caused by the sugar beet nematode (*Heterodera rostochiensis*), respectively.

These early workers found that certain crop rotations reduced crop damage and the concept of limiting losses through chemicals (carbon disulphide) applied to the soil was introduced. It was not until 1943, however, that an effective and economic chemical for the control of soil inhabiting plant-parasitic nematodes was discovered. D-D soil fumigant (1.3-dichloropropens and 1,2-dichloropropane) made nematode control on a field scale feasible. Growers, plantation managers as well as research workers could now compare crop growth, visually as well as statistically, in nematode infested land with areas in which plant-parasitic nematodes had been effectively controlled by soil fumigation. Nematode control in agriculture by the use of chemicals is now generally accepted worldwide and has developed into an industry of great importance. Succeeding developments have brought on the market additional soil fumigants and contact, systemic and non-phytotoxic nematode control compounds.

Closely following the general use of soil fumigants was the demonstration that a group of nematodes living almost exclusively in the soil

could be of great importance in limiting crop production. Prior belief was that a parasitic nematode had to enter a plant root (or other plant part) to cause injury and ectoparasitic nematodes were pretty much ignored. These groups of nematodes are now recognized as serious pests on many crops in almost all soils and have devastating devitalizing effects on root systems.

The plant parasitic nematodes could have a causative role in a plant disease complex involving fungi, bacteria or viruses was eventually realized. Plant cultivars bred for resistance to certain plant disease lost this resistance or had it greatly reduced in the presence of certain plant-parasitic nematodes. Control of the nematodes in the soil also controlled the disease in subsequent resistant crops.

12.2 Nematode loss estimates in agricultural crops:

Accurate yield loss data are not available for most crops in many nations of Africa. Non or limited studies have been made to define the extent of damage or its prevalence caused by plant-parasitic nematodes. Investigations on tomato, maize and cowpeas have shown yield reductions of 28 to 64% leaving no room for doubt of the destructiveness of plant-parasitic nematodes and the importance of their role in agricultural production.

Nematodes are frequently subtle and insidious crop pests and yield reductions of a few to 20 or 30% can pass undetected unless carefully managed control plots are introduced to observe differences.

This is especially true of crops as maize, cowpeas, sorghum, sugarcane, citrus and certain vegetables. In certain root and tuber crops nematode damage and disfiguration may cause serious losses due to consumer rejection.

12.3 Gross plant symptoms of nematode infection.

Plant-parasitic nematodes are obligate parasites as they are unable to reproduce without sustained feeding on live cells of a host plant. Lacking the presence of a suitable host plant, the parasitic nematodes will, over a period of time, gradually deplete the stored energy reserves within their bodies. A more favourable environment will encourage nematode activity and food reserve consumption while the stress of drought or cold will restrict nematode activity. Once food reserves are exhausted nematodes will die greatly reducing population numbers. Depending on the nematode species involved and the environment, the time needed for this to occur can be a few months to several years. Some species have built in survival or protective mechanisms of one kind or another which will help preserve the nematode population during period of stress.

Depending on the life style and stage of development of a nematode species, various parts of the host plant will be attacked. The majority of plant-parasitic nematodes feed on roots or other underground organs of higher plants such as tubers, root tubers, rhizomes, bulbs and corms. Some plant-parasitic nematodes, although they survive in the soil, infect above-ground plant parts attacking developing young buds of stems and flowers. Some forms feed externally or may penetrate shoots, stems or leaves and feed

and reproduce inside the above-ground portions of the plant.

12.4 Above-ground plant symptoms of nematode attack.

Above-ground symptoms due to nematode attack are difficult to distinguish from those caused by other plant pathogens, low fertility, drought or moisture excess or other adverse conditions of the environment. Nematode attack may result in a root system inadequate for the plant to make normal growth and this damage would be reflected in the above-ground plant parts. This may be expressed as reduced top growth, attendant lower yields, general lack of vigor, less resistance to drought conditions, early wilting during the heat of the day and in soils deficient in some necessary element the plants tend to develop symptoms of the mineral deficiency. Certain above-ground symptoms are specific for nematodes that attack the aerial portions of plants. These can be expressed as crown and stem swellings, leaf, stem and seed galls and crinkling and distortion of leaves with attendant leaf spots and lessions.

12.5 Below ground plant symptoms of nematode attack.

Below-ground symptoms of nematode attack can also be easily confused with the activities of other pathogens or environmental factors. A field diagnosis is therefore chancy and open to error. The plant parts and some adjacent soil need to be adequately examined in a laboratory by an experienced technician. However, some nematodes can be seen attached to roots of affected plants as cysts may be formed or the length of the nematode may permit detection with the unaided eye. The cyst-forming nematodes (*Heterodera* sp) and needle nematodes (*Longidorus* spp) are examples.

Feeding by the various species of plant-parasitic nematodes, both endo-and ectoparasites are known to cause a general reduction in the root system, root pruning, root galls (or knots), lesions on the root surface or in depth, excessive root branching, injured root tips causing short, stubby clusters of roots, an open root system devoid of rootlets and c oling of the root tip.

Gross symptom expression is generally related to the number of plant-parasitic nematodes attacking the plant. An unthrifty plant will have smaller yield and a poorer quality product at harvest.

12.6 Feeding sites and plant-parasitic nematodes:

The plant-parasitic nematodes that attack plants are numbered in the hundreds. It is assumed that every plant wild or cultivated, is host to a nematode parasite if not a nematode pathogen. Frequently several plant-parasitic nematodes will occur in any given soil. All plant parts are liable to attack by one kind of nematode or another, including roots and other underground organs, stems, leaves, buds, flowers, tree trunks and replacement of developing seeds with galls. Most known plant-parasitic nematodes are root feeders and live and reproduce entirely within the soil or root tissue or tubers. Some forms wholly enter the root where they can further develop and reproduce. Endoparasite is the term applied to these nematodes.

A large number of soil inhabiting nematodes feed on roots without penetrating and are known as ectoparasitic nematodes. Nematode forms with

attenuated stylets can feed on cells of the cortex or stele while the body of the nematode remains outside in the soil. Ectoparasitic nematodes are frequently larger and better adapted for external feeding.

The feeding activities of some plant-parasitic forms lie somewhat midway between endo- and extoparasitic nematodes. These nematodes partially enter the root tissue with the anterior part of their bodies. They are rarely found wholly within root tissue.

A smaller group of nematodes are parasites and pathogens of aerial parts of the plant. Primarily these forms infect and damage the tissues of above-ground plant parts.

12.7 The typical life cycle of a plant-parasitic nematode.

Typically in plant-parasitic nematode development there are four juvenile stages with each being terminated by a molt. The first stage juvenile develops within the egg shell and the first molt takes place within the shell. The second stage juvenile leaves the egg shell and is free in the soil or plant tissue. The second stage nematode feeds and develops through the third and fourth stages each ending with a molt and the nematode entering adulthood after the fourth molt. In the interval between molts further growth and development occurs. The most obvious change is the growth of the reproductive systems in the male and female. With a suitable host plant as a food source the mature female nematode lays eggs and the life cycle is repeated. The male nematode is essential in many species as reproduction will occur only after copulation and fertilization of the eggs by male sperm. The other

species the male form does not occur or is rare and eggs develop without fertilization by the male. Reproduction is parthenogenetic or hermaphroditic with the female gonads producing both eggs and sperm. In nematode species where the male is necessary the sex ratio is generally 1:1.

12.8 Distribution: Where nematodes are found.

Nematodes occur just about every place there is food and moisture. Some nematode species have adapted to extremes of temperature and moisture. Plant-parasitic nematodes have been found in all areas surveyed. Many genera of plant-parasitic nematodes have a worldwide distribution while other genera and species occupy a restricted area or region. The activities of man have been responsible for introducing many plant-parasitic nematodes into area distant from their place of origin. These nematodes have adapted to a new or similar environment and often host plants as well. One function of plant quarantine measures is to prevent nematode pathogens from being carried to areas free of that particular kind of nematode. Depending on the kind of nematode and its innate survival mechanisms, nematodes can be transported by shipment of roots, tubers, stems and other plant parts and also in the soil adhering to them. Nematodes capable of surviving desiccation can be transported in plant material used as packing, in or mixed with seeds or dried mud of vehicles. Local spread can be on boots, feed of man and animals, from tools, wind and the washing of rain water.

12.9 Nematode injury to plants.

The injury to plants due to the feeding and presence of plant-parasitic nematodes extends from simple mechanical damage to highly involved

nematode-plant interactions. Endoparasitic nematodes cause injury or destruction to individual cells by direct feeding which may involve complex host-pathogen interactions from chemicals introduced by the nematode resulting in a physiological change in the host or chemical substances produced by the plant in response to nematode attack.

12.10 Root-knot nematodes (*Meloidogyne* spp): Cause the formation of knots or gall on the roots of many kinds of plants. The root galling symptom is well known as the galls are large enough to be easily seen and the nematode is widespread. The attack by second stage juveniles of the root-knot nematode involves a host response involving the development of giant cells in vascular tissue of the root which are used as food source by the nematodes. Root swelling and the gall formation results from a rapid increase in the size and number of adjacent cells.

12.11 Root-lesion nematodes (*Pratylenchus* spp.): Cause lesions by feeding on and killing root cells. Usually large numbers of root lesion nematodes in all stages of development are found in the cortex in a limited area where feeding kills the cells resulting in the formation of a lesion that ordinarily involves secondary invaders. The nematodes are generally found at the periphery of the damaged tissue and gradually enlarge the lesion by feeding on healthy cells.

The stem nematode (*Ditylenchus dipsaci*) feeding on cells of bulbs above-ground plant parts results in the disolution of the middle lamella of cells in that area. The salivary secretions carry a pectinase which works

on the middle lamellae. Freed cells often become rounded causing the plant structures to become swollen and puffy. Infected stems may be twisted and distorted and leaves wrinkled and curled. Middle lamella dissolution appears to be a necessary host plant reaction for the survival and reproduction of the nematode. This reaction does not occur in unsuitable host plants.

The cyst nematodes (*Heterodera spp*). Also cause the formation of giant cells in root tissue. Ordinarily little mechanical damage is done to host plant roots. At maturity the female body undergoes physiological changes that turn her cuticle into a resistant cyst filled with eggs. These cysts are readily seen with the unaided eye. Above-ground symptoms are stunting, lack of plant vigor and other general symptoms resulting from an inadequately functioning root system. In tropical regions the most serious threats to crop production are probably the soybean cysts nematode, the rice cyst nematode and the sugarcane cyst nematode.

12.12 Miscellaneous nematodes. Of various kinds may cause injury in the form of cessation of root-tip growth, root pruning or root proliferation. Any and all of these can result in retarded plant growth and reduced yield.

12.13 Plant-nematode disease complex/

Plant disease can be caused by the interactions of nematodes with other pathogens. Fungi and bacteria are common to soils and certain nematodes obtain a virus from an infected root and are capable of infecting a healthy plant when feeding on root cells. Crop developed from resistance to certain soil-borne fungal or bacterial pathogens have shown a loss or reduction in

resistance in the presence of plant-parasitic nematodes. When the nematodes are controlled the plants are again resistant to the fungal or bacterial disease. In some bacterial diseases the invading nematodes merely provide an infection court for the pathogen. The role of the nematode is more than simple wounding of root cells in some plant-fungus-nematode complexes as ordinarily the fungus is capable of penetrating an unwounded root. Nematode invasion predisposes root cells to fungal attack through an alteration in the physiology of root tissue.

12.14 Control of plant-parasitic nematodes.

Control of plant-parasitic nematodes will continue to be of great importance as population growth places an increased demand on arable land. Shortened crop rotations coupled with the more frequent planting of economic crops, particularly near large centers of population, favor the build up and maintenance of large soil populations of plant-parasitic nematodes.

All control principles are based on the imposition of certain stress factors on nematode populations. These imposed conditions affect the nematode's ability to feed, reproduce and survive as a population. Some cultural practices reduce nematode populations over various periods of time in contrast to a quick population kill by the use of heat or chemicals. Control is relative to the crop and kind of nematode involved. And satisfactory economic control may change with the price of the marketable produce. Control of plant-parasitic nematodes is also achieved where cultural practices

prevent their initial increase to damage causing levels.

12.15 Fallow to control plant-parasitic nematodes.

The principle here is to keep the land free of living plants by plowing or otherwise disturbing the soil or by use of herbicides. Nematodes deprived of a food source eventually starve to death. The length of time necessary to achieve a significant reduction in a nematode population level will vary with the kind of parasite involved. There are several objections to using fallow for nematode control:

(a) freeing land of vegetation is laborous and time consuming,

(b) mixed populations of nematodes do not die at the same rate,

(c) the soil is exposed to erosion by wind and rain and soil structure may be altered, and

(d) fallow land does not earn money for the farmer.

12.16 Soil desiccation to control plant-parasitic nematodes.

Certain kinds of nematodes are readily killed by drying. In areas with a hot, dry season tilling of the soil to eliminate vegetation and facilitate drying will control nematode populations in the layer of soil treated. Nematodes at lower depths usually survive and eventually re-infect subsequent crops.

12.17 Crop rotation to control plant-parasitic nematodes.

The planting of two or more crops in a sequence is a widely used agricultural practice. When crops suitable as host plants for plant parasitic nematodes are alternated with less suitable host plants or non-host

plants a singnificant influence can be made on population levels of nematodes. High population levels can be reduced below the economic threshold and/or population levels can be prevented from increasing to an economic level. Shifting cultivation practised in much of Africa is a form of crop rotation where the land is allowed to revert to wild plant species many of which are poor or non-host plants for the nematodes. The number of any favourable host plants for the plant-parasitic nematodes are diluted by intraplant competition and population levels per unit area are reduced.

Limitations to crop rotations: (a) alternate crops may be of low economic value, (b) resistance to nematode populations can vary between cultivars, (c) the alternate crop might suppress one population of plant-parasitic nematodes and increase another, (d) adequate knowledge of the nematode-plant resistance relationship is often unavailable and (e) the recommended rotation crop may not meet with farmer acceptance.

12.18 Cover crops to control plant-parasitic nematodes.

Cover crops are commonly grown to help reduce soil erosion, moderate soil temperatures, influence insect populations, provide forage for livestock, improved soil fertility and increase the organic matter content of the soil. Cover crops, like rotation crops, can affect plant-parasitic nematode population levels depending on their suitability as host plants, the sequence with other crops and the length of time they are grown.

12.19 Intercropping to control plant-parasitic nematodes.

Intercropping is a traditional farming practice in many areas of the

tropics. The basic principles of crop rotation and growing cower crops apply. Plants that are not suitable hosts would tend to reduce nematode populations and plants that are favourable hosts would be diluted in numbers per unit area thus plant-parasitic nematode population levels be held to a minimum.

12.20 Time of planting to control plant-parasitic nematodes.

Certain kinds of plant-parasitic nematodes are susceptible to dessication and the high soil temperatures associated with the dry season common in many tropical areas. However, plant-parasitic nematodes in the deeper levels of the soil and those surviving on or in the roots of weed hosts would be present to attack the economic crop. Early planting, commensurate with the arrival of dependable rains, would allow the development of a root system better able to withstand attack from nematodes migrating up from lower soil levels and those feeding on early weed growth.

12.21 Sanitation to control plant-parasitic nematodes.

Some annual crops continue to live and grow after being cut for harvest or are left in the field after the produce has been picked. The remaining root systems continue to supply food to the nematodes which may develop one or more additional generations before the plant dies, is removed or plowed under. Prompt destruction of the living crop residue is necessary to limit population development. In addition, if the plants can be uprooted and their roots exposed to the elements the nematodes concentrated in the roots and the adjacent soil will be killed by dessication.

12.22 Organic matter and mulches to control plant-parasitic nematodes.

Numerous studies indicate that the severity of plant-parasitic nematode attack is reduced by creating conditions favourable for the development of microorganisms already in the soil. Organic matter and mulches added to the soil increase food supply which create cycles of microorganisms growth and activity. Plant-parasitic nematode populations are usually reduced by the biotic competition and increased soil fertility from the organic matter which allows a healthier plant to make rapid growth thus minimising the effects of nematode attack.

12.23 Trap crops to control plant-parasitic nematodes.

The principle in using a trap crop to control plant-parasitic nematodes is the planting of a favourable host crop where the roots are invaded by the second stage juvenile nematodes. The trap crop is allowed to remain on the land just long enough for the second stage juveniles to begin development and become immobile within the root tissue. The trap crop is then destroyed along with the 'trapped' juvenile nematodes by plowing under or uprooting. This practice is effective against those genera which become sessile when they develop beyond the second stage. The root-knot and cyst-forming nematodes are examples.

Certain crops can be effectively used as trap crops as they are highly susceptible to invasion by second stage juveniles but the nematodes are unable to mature and they die without laying eggs. Crotolaria and in some areas groundnuts have been used successfully to reduce populations of certain

root-knot nematode species. Objections to using trap crops as a control practice are that the crop must be destroyed before the nematodes start egg laying which may not always be possible and the expense and labor in planting and destroying a crop with no direct economic return to the farmer.

12.24 Antagonistic crops to control plant-parasitic nematodes

Plants whose roots secrete into the soil substances toxic to some kinds of nematodes are said to be antagonistic. *Tagetes spp.*, *Cynodon nlemfuensis* and *Asparagus officinalis* are examples. Objections to using antagonistic plants to control nematodes are the unavailability of seed, lack of precise knowledge about the host-nematode interaction in any one particular field, and farmer resistance at growing a crop that may not bring him a direct economic return.

12.25 Mitigating plant stress to control plant-parasitic nematodes.

The damaging effects of nematode attack can be offset to some degree by altering the environment in favour of the plant as much as possible. More frequent application of fertilizer, avoiding rapid moisture and temperature changes with a soil mulch, timely irrigation and protection from other pests and pathogens tend to lessen nematode damage. Although such practices do not really reduce nematode populations they allow some measure of yield to be taken. In the long term a fundamental program of nematode control practices would provide more satisfactory return and frequently would be essential.

12.26 Clean planting stock to control plant-parasitic nematodes.

Exclusion of plant-parasitic nematodes through the use of nematode-free planting stock is an effective practise to limit nematode spread. Transplants can be frown in grown beds freed of nematodes by heat or chemicals tomato, tobacco and pepper are examples. Tubers, bulbs and seeds can be heat treated to kill the nematodes and in certain instances chemicals are also available. Yams, garlic sets and rice seed are examples.

12.27 Resistant plants to control plant-parasitic nematodes.

Resistant plants have certain qualities or characteristics that make them unsuitable as host plants. The quality that makes a plant resistant is not necessarily the same in each case. Some roots are less attractive than others and the roots of some plants are freely invaded by nematodes. The invading nematode's inability to obtain food through the development of specialized cells makes some roots unsuitable sites for reproduction. Complex physiological factors probably determine the degree of resistance or susceptibility in plants. The relatively slow rate of reproduction and mutation of nematodes and their slow spread in the field makes the search for resistant cultivars economically attractive. The availability of a resistant cultivar would simplify a farmer's overall nematode control program but should not replace it.

12.28 Biological control of plant-parasitic nematode.

Certain fungi are known to capture, kill and consume nematodes in the soil. Certain protozoans infect and kill nematodes. Predatory nematodes

attack and devour other nematodes. While there has been much interest and many studies made attempting to apply these phenomena, little of practical or economic value has emerged.

12.29 Physical factors to control plant-parasitic nematodes.

Heat can give excellent control of plant-parasitic nematodes in large and small quantities of soil. Small amounts of soil can be heated in an oven or over an open fire. Brush pilled on seedbeds will satisfactorily control nematodes to a limited depth. In permanent installations tile or pipes can deliver steam from a boiler or buried electric cables can heat bulk soil. These applications can be economical for the production of certain high value crops such as vegetables, tobacco and rootstock. Carefully controlled heated water can rid infected plants and bulbs of nematodes. Electric shock, radiation and soil compaction have very limited application to special situations.

12.30 Exclusion to control plant-parasitic nematodes.

Many kinds of plant-parasitic nematodes are already widespread in local areas as well as worldwide. However, many regions, areas and fields are free of certain species of nematodes and their careless introduction would complicate control measures and increase the economic burden on both farmer and consumer. A mildly parasitic nematode in a new environment or on a new crop may become a serious pest. Also, the long term accumulative effects of nematode infested land could be debilitating to both farmer and nation.

Plant quarantine helps to exclude plant pathogens from areas where they are not present.

12.31 Chemicals to control plant-parasitic nematodes.

The development of an effective soil fumigant for use against soil nematodes in the 1940's made possible nematode control on a field scale. Prior to this, control attempts were limited to greenhouse, nursery soils and seedbeds. Fumigating soil for control of nematodes reduces the nematode population level below a damage causing threshold resulting in an increase in yield and quality of crops grown. Crops planted in soils thus treated are able to form a strong and well developed root systems to support vigorous top growth. Generally there is also a reduction in other root problems caused by fungi and bacteria. A strong, well developed root system allows the plant to make maximum use of water, fertilizers and mineral elements in the soil. Perhaps of equal importance derived from controlling nematodes is the protection of the overall investment in the crop of seed, labour, time, pest and disease control measures and irrigation. Were plant-parasitic nematodes not controlled weakened plants would be unable to produce to their full potential and produce less than full profit for the farmer.

12.32 The general structure of a nematode.

Nematodes are animals. They develop from three germ layers, are bilaterally symmetric, unsegmented, and lack a coelom. Their usual shape is serpentine being more less cylindrical, varying from fusiform to roundish in some mature female forms. The mouth is anterior and surrounded by lips

bearing sensory organs. Following the mouth is the stoma, esophagus, intestine and a rectum terminating in an anus in females or a cloacal opening in males. The body covering is termed a cuticle. Beneath the cuticle lies the hypodermis and a single longitudinal layer of muscles. The male reproductive system opens into the cloanca. The female reproductive system terminates in a ventrally located vulva. Internal fluid movement in response to body activity is apparently involved in both circulatory and respiratory functions as both systems are lacking in nematodes. Figures 12.1 to 12.34 show the anatomy of the various organs of a typical nematode.

12.4 Nematode disease of soybean.

More than 20 genera of plant-parasitic nematodes involving about 50 species have been found associated with soybean production or shown to be pathogenic. World demand for the soybean has brought about a more intensive cultivation and the planting of new land to the crop. This intensive growing has often allowed the build-up of nematode soil populations with the resulting affect of lower yields. In the United States alone, estimates place the loss at about 4 million metric tons annually.

Unhealthy appearing soybean roots may suggest nematode damage but are not necessarily conclusive and a laboratory analysis of soil and roots is essential for confirmation. Nematodes feeding on soybean roots may cause root lesions, surface necrosis or the reduction in total root volume by causing stubby roots, root galling or the killing of fine feeder roots resulting in a course root appearence.

Above-ground symptoms are essentially those caused by other conditions that deprive the plant of an adequate and properly functioning root system. The degree that stunting, chlorosis, wilting or plant death occurs is dependent on nematode population density, plant susceptibility, soil and climate effects, and the interplay of other pests and pathogens, particularly fungal root pathogens. Good weather and a high soil fertility could ameliorate nematode damage while drought and low soil fertility could accentuate the damage. Under favourable conditions of moisture, temperature and food supply (roots), female nematodes of the various species can produce several dozen to several hundred eggs in each generation. With 3 or 4 generations often occurring in one season, nematode soil population densities can reach high levels.

The soybean cyst nematode, *Heterodera glycines*, is a serious production problem in Asia and the United States. The "yellow dwarf" disease of soybean was first reported from Japan in 1915. The nematode was reported in the United States in 1954 and now affects soybean production in several mid-western and southeastern states.

Above-ground symptoms are typically nonspecific and only appear when soil populations of the nematode are high. Here the plants are chlorotic and stunted giving rise to the name of "yellow dwarf". The nematode can severely restrict the development of *Rhizobium* nodules resulting in a nitrogen deficiency and chlorosis. Nematode feeding and the host plant responce of cell and tissue alteration severely disrupt the movement of water and nutrients to the above ground plant parts. Heavily infected plants may defoliate earlier than

plants with a lighter infection. Depending on the intensity of nematode attack, crop susceptibility, race of the nematode, prevailing environmental conditions and soil fertility, yield losses vary from insignificant to a near total loss. The presence of other soil pathogens may intensify the disease.

An abundance of lateral roots may result from a light to moderated cyst nematode attack. A heavily attacked plant's root system is severely reduced in size and extent with necrotic lesions and a greatly reduced number of *Rhizobium* nodules. Upon careful lifting and washing of roots the white to yellowing females and the brown mature cysts can be seen with the unaided eye on the root surface. Cyst size is generally slightly smaller than a pinhead.

Within the species, biological variation is demonstrated by the occurrence of four races identical in morphology. Race effect on many cultivars varies significantly. The cyst is non-living, brown, lemon-shaped and about 700µm long and about 500 µm in diameter. The second stage juveniles which emerge from the egg are the infective forms which migrate and penetrate the plant root. Root invasion is near the root tip and the nematode moves primarily intracellularly and becomes established as a parasite in the undifferentiated cortical and stelar tissues. Salivary secretions of the second stage juvenile initiate the formation of syncytis or nurse cells for the nematode. The nematode becomes sedentary, feeds on the nurse cells and begins to enlarge. The juvenile undergoes a second molt (the first molt is within the egg) which is followed by a third and then the fourth and final molt to the adult stage. By this time the female body has swollen and broken through the root

epidermis with the neck and head within the root. The female nematode generally produces 200 to 500 eggs before dying. Many of the eggs remain within the female and are protected by the cyst when it develops from the female body wall but 30 to 40 percent of the eggs are deposited external of the body in a gelatinous matrix. The externally laid eggs hatch within a few days and the second-stage juveniles become second-generation parasites on the same or adjacent soybean plants.

The lemon-shaped female is white to off-white and the body wall is transformed into a brown cyst filled with eggs at death. The cyst is highly resistant to decay and desiccation and the eggs within are well protected and survive for extended periods of time. When conditions are favourable most eggs will hatch, leave the cyst and seek its host plant. Generation time from egg to egg is about 24 days at 23°C. Thus it is possible to have several generation cysles in one cropping season with the attendant build-up of nematode populations to very high levels.

Second-stage juveniles have limited dispersal powers on their own, being able to move through soil only a few centimeters in each generation. The parasite is moved within the field and over longer distances by any agent capable of transporting soil or plant material. Contaminated equipment and clothing are primary means of local spread. Poor cleaned seedlots may contain cysts in soil peds with some eggs that may survive up to 22 months. Birds may contribute to soybean cyst nematode dissemination as the cysts, eggs

and second-stage juveniles can pass through the digestive tract of blackbirds and remain viable. In the absence of a host plant, eggs within the cysts may remain viable up to eight years under conditions favourable to the nematode.

Soybean cyst nematode attack is most serious in dry, sandy, light-textured soils low in fertility and deficient in organic matter. Symptom expression and yield loss are accentuated by the reduced nodulation that results from nematode attack on the crop.

The soybean cyst nematode is an obligate parasite that has a host range of over 1,100 plant species. Soil populations of the nematode quickly increase to damaging levels under continuous soybean or other favourable host cultivation but decline significantly the first year under a non-host crop. Control measures of planting resistant cultivars (except where race 4 is present) and a rotation of one to five years with non-host crops give satisfactory yields.

Root-knot nematodes, *Meloidogyne incognita, M javanica, M. arenaria* are cosmopolitan throughout the tropic zone and maximum damage occurs on sandy, light-textured soils. Yield losses on the more susceptible cultivars range from 30 to 90 percent. Symptoms are stunted plants with yellow leaves and a tendency to wilt under moisture stress. Root symptoms are knots or galls of varying size.

Root-knot nematode species identification can only be done with aid of a microscope. Second-stage juveniles are the infective forms and they penetrate the root near the tip. Nematode feeding induces gall formation by

initiating hypertrophy and hyperplasis of infected and adjacent tissues. The main and branch roots become infected. Gall sizes range from minute to 20mm depending on the root-knot nematode species present, their number and cultivar host suitability. In infected tissues the vascular elements are disrupted and water and nutrient movement to the top of the plant is restricted. In heavy infections the root system is reduced and feeder roots do not develop thus inhibiting the plant's ability to absorb needed water and nutrients. Compared to non-infected plants the root weight is greater and top weight is reduced in infected plants.

At maturity the female is 1 to 2mm in length, pear-shaped or globose in form. The female may produce from 500 to 2,000 eggs which are laid outside the body in a gelatinous matrix. The eggs and matrix are usually outside of the root. The eggs hatch within a few days and the second-stage juveniles may infect the same gall or seek a new root tip. The generation time from egg to egg is about 30 days so that a number of generations can occur during one growing season.

Root-knot nematodes have extensive host ranges and often occur as mixed populations in the same field which greatly complicates control by crop rotation. Usually soybeans can be grown once in a three-year rotation with non-host crops.

The reniform nematode, *Rotylenchulus reniformis*, is also widely distributed in the tropic zone. Yield losses on soybean usually occur only when population levels are relatively high.

Heavily infected plants are stunted and leaves are chlorotic. There may be many thousands of males, vermiform females and juveniles in the soil about the roots. Eggs hatch in one day and with little or no feeding molt three times in the soil and become adults with males and females in about equal numbers. After a few days of feeding on epidermal cells the female invades the root, becomes semiendoparasitic, partially embedding herself in root tissue and forms a permanent feeding site in the cortex and phloem. The posterior portion of the female outside the root enlarges to the characteristic kidney shape. Eggs are laid outside of the root and are less than 100 in number. At a soil temperature of 29°C the life cycle is completed in 19 days. Control is gained by judicious use of resistant cultivars in a suitable crop rotation program. A few cultivars are available that are resistant to the soybean cyst nematode, root-knot nematodes and the reniform nematode.

A number of other plant-parasitic nematodes occur in soybean fields. Some species may cause reductions in yield but little is known of the host-parasite relationship. Field symptoms cannot be differentiated from those caused by other organisms that invade and restrict plant root system development.

Some of these genera are the sting nematodes, *Belonolaimus spp.*, the ring nematodes, *Criconemoides spp.*, the stem nematode, *Ditylenchus dipsaci*; the spiral nematodes, *Helicotylenchus spp.*, *Rotylenchus spp.*, the lance nematodes, *Hoplolaimus spp.*, the pin nematodes, *Paratylenchus spp.*, the root-lesion nematodes, *Pratylenchus spp.*, the stubby-root nematodes, *Trichodorus spp.*, *Paratrichodorus spp.*, the stylet nematodes, *Tylenchorhynchus spp.*, and the dagger nematodes, *Xiphinema spp.*

12.5 Techniques in Nematology:

12.5.1 Sampling soil and plants for plant-parasitic nematodes.

Soil and plant roots are sampled to determine which species of parasitic nematodes are present and to estimate their numbers. Ectoparasitic nematodes (nematodes living outside the roots and in the soil) are concentrated in the vicinity of the small feeder roots. The roots contain endoparasitic nematodes (nematodes that spent most or all of their lives feeding and reproducing within plant roots). About 200 cm^3 of soil and about 5g of roots are adequate and convenient for examination for the presence of plant-parasitic nematodes. Soil should be taken from the root zone of the plant and a portion of the root system can be taken without damage to the whole plant. The very nature of nematodes concentrates them at points of food supply. This applies to nematodes that are free living as well as plant parasites. This fact results in an uneven or spotty distribution of nematodes in the field resulting in the need to take several samples at different locations.

A variety of tools can be used for collecting samples. These include soil augers, soil tubes, spades, digging forks, mattocks, machettes, garden trowels and even a stick if nothing else is available. Plastic bags are useful for collecting and storing samples as they prevent drying of soil and roots. Care should be taken to keep collected samples in the shade at all times as excessive heat will kill the nematodes. Samples should be processed as soon as possible but can be stored for a few days if kept from drying and in a cool place.

12.5.2 The isolation of nematodes from soil and root samples.

The isolation of plant-parasitic and other nematodes from samples is the separation of the nematodes from soil and plant tissue so they can be seen., identified and numbers estimated. Several procedures have been developed to accomplish this separation. No one procedure is perfect as all methods have advantages and disadvantages.

Baermann Funnel Method.

The Baermann funnel method was described by Dr. G. Baermann in 1917 and has been widely used with various modifications ever since. A modification by Whitehead and Hemming in 1965 overcame a disadvantage of poor oxygenation and is the procedure described here.

A filter of facial tissue, table napkins with "wet strength" nylon or terylene cloth, paper towels or similar material is supported by plastic mesh or a plastic sieve (metal objects may be toxic to nematodes) in a plastic tray or basin. Soil is thinly spread on the filter and water is added to the tray sufficient to wet but not flood the soil. The soil is left overnight or longer. The tray should not be disturbed to avoid turbidity. Most nematodes, by means of their activity, will migrate through the filter and, being heavier than water, will sink to the bottom of the tray. The plastic sieve must be removed carefully and quickly to obtain a clear nematode-water. suspension. Do not drain the plastic sieve into the tray as this will add silt and trash to the nematode-water suspension. The water suspension from the tray containing the nematodes is poured into a plastic tumbler and left standing

for about four hours for the nematodes to settle. Excess water is carefully decanted or siphoned leaving the nematodes in about 10ml of water. To use the settling-siphon method (Caveness, 1975), the water is poured into a wash bottle with a spout and internal tubulation to the bottom of the bottle. After a minimum of five hours a 45-cm length of rubber tubing of 3mm inside diameter filled with water to form the siphon is slipped over the wash bottle spout. The waste water will drain away in about six minutes. To increase the speed of draining will only result in the loss of nematodes with the water. When the draining is completed the siphon will break automatically. The nematodes can now be examined under a microscope or preserved.

Nematodes can be isolated from plant roots (and other plant tissues) by using the same procedure and same equipment. If a blender is available the plant tissue can be comminuted for 5 to 15 seconds depending on tissue softness then poured onto the filter. Avoid overloading each single tray as the excess organic matter will encourage bacterial growth and deplete the oxygen supply thus slowing or stopping the activity of the nematodes. Good results can be obtained by cutting roots into 3 to 5mm segments and placing them on the filter.

12.5.3 Storage of nematode suspension.

Most nematodes can be stored in a refrigerator for days without deterioration or contamination. Growth of microorganisms can be retarded by adding 3 drops of 5 percent streptomycin sulphate solution for each 5ml of nematode suspension. The best procedure is to examine them promptly or kill, fix and preserve them.

12.5.4 Killing and fixing nematodes.

Concentrate the nematodes in a few ml. of water by allowing them to settle in a glass vial or similar vessel and decanting the excess water. Plunge the vial into a beaker of water heated to 65°C for about 3 minutes. After the nematodes are dead add an equal volume of fixative. Most nematodes can be stored satisfactorily in fixative for an indefinite period.

Nematodes can be fixed and preserved in formalin or TAF solution:

Formalin fixative: (For long term storage)	formalin (40 percent formaldehyde)	8ml.
	Calcium carbonate ($COCO_3$)	92ml.
	pinch distilled water	
TAF Fixative: (For short or intermediate term storage)	Formalin (40 percent formaldeyhade)	7ml.
	Triethanolamine	4ml.
	Distilled water	89ml.

12.5.5 Identification of nematode specimens.

Precise identification of nematode species requires the skill and experience of a qualified scientist. The use of a high quality light microscope and sometimes a scanning electron microscope is required. Contact the departments of Plant Pathology, Entomology, Botany or Biology at your local university as to whether nematode identification services are available. The Commonwealth Agricultural Bureaux in England offers an identification service worldwide to all countries. Write to the following address for information on submitting nematode specimens and costs:

CAB Identification Services
Commonwealth Institute of Helminthology
The White House
103 St. Peter's Street
St. Albans, Herts
England AL1 3EW.

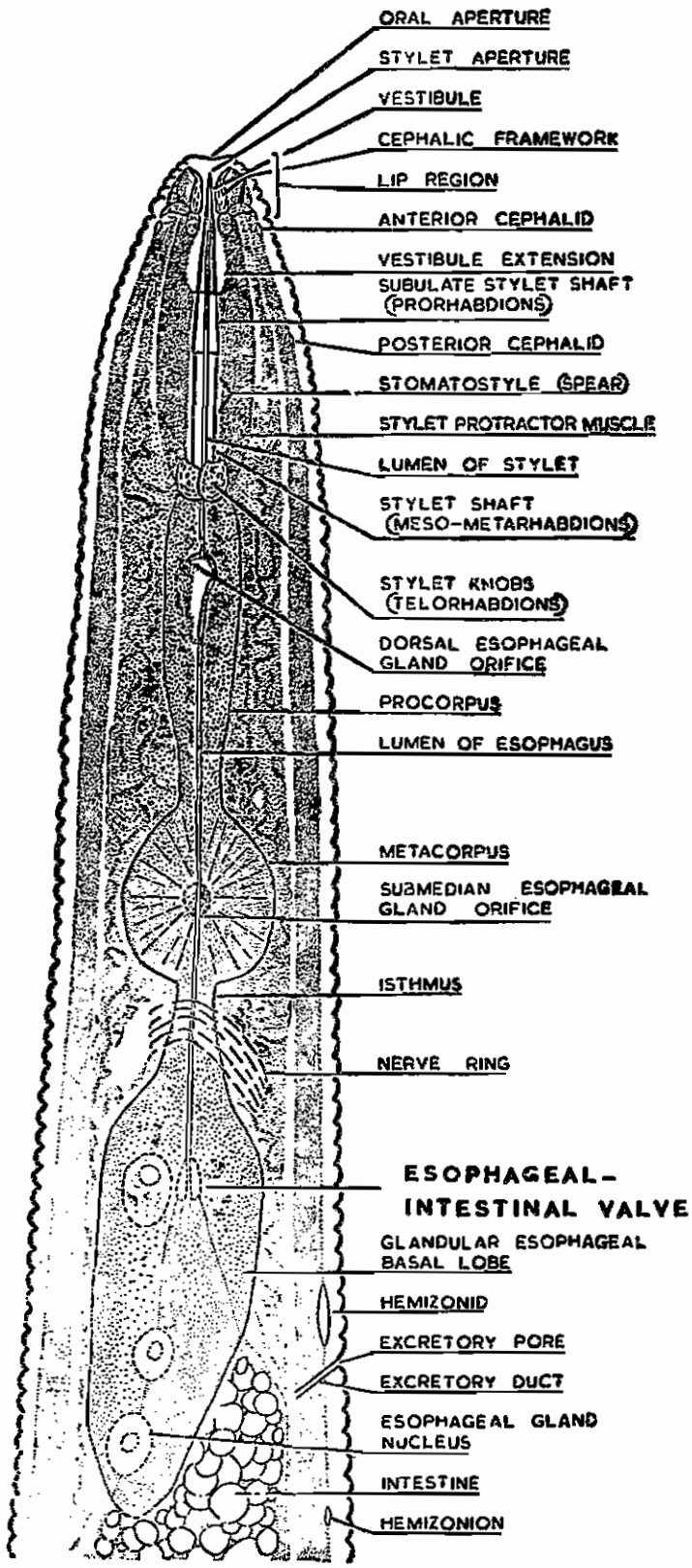

ORAL APERTURE
STYLET APERTURE
VESTIBULE
CEPHALIC FRAMEWORK
LIP REGION
ANTERIOR CEPHALID
VESTIBULE EXTENSION
SUBULATE STYLET SHAFT (PRORHABDIONS)
POSTERIOR CEPHALID
STOMATOSTYLE (SPEAR)
STYLET PROTRACTOR MUSCLE
LUMEN OF STYLET
STYLET SHAFT (MESO-METARHABDIONS)
STYLET KNOBS (TELORHABDIONS)
DORSAL ESOPHAGEAL GLAND ORIFICE
PROCORPUS
LUMEN OF ESOPHAGUS
METACORPUS
SUBMEDIAN ESOPHAGEAL GLAND ORIFICE
ISTHMUS
NERVE RING
ESOPHAGEAL-INTESTINAL VALVE
GLANDULAR ESOPHAGEAL BASAL LOBE
HEMIZONID
EXCRETORY PORE
EXCRETORY DUCT
ESOPHAGEAL GLAND NUCLEUS
INTESTINE
HEMIZONION

Fig.12 .1

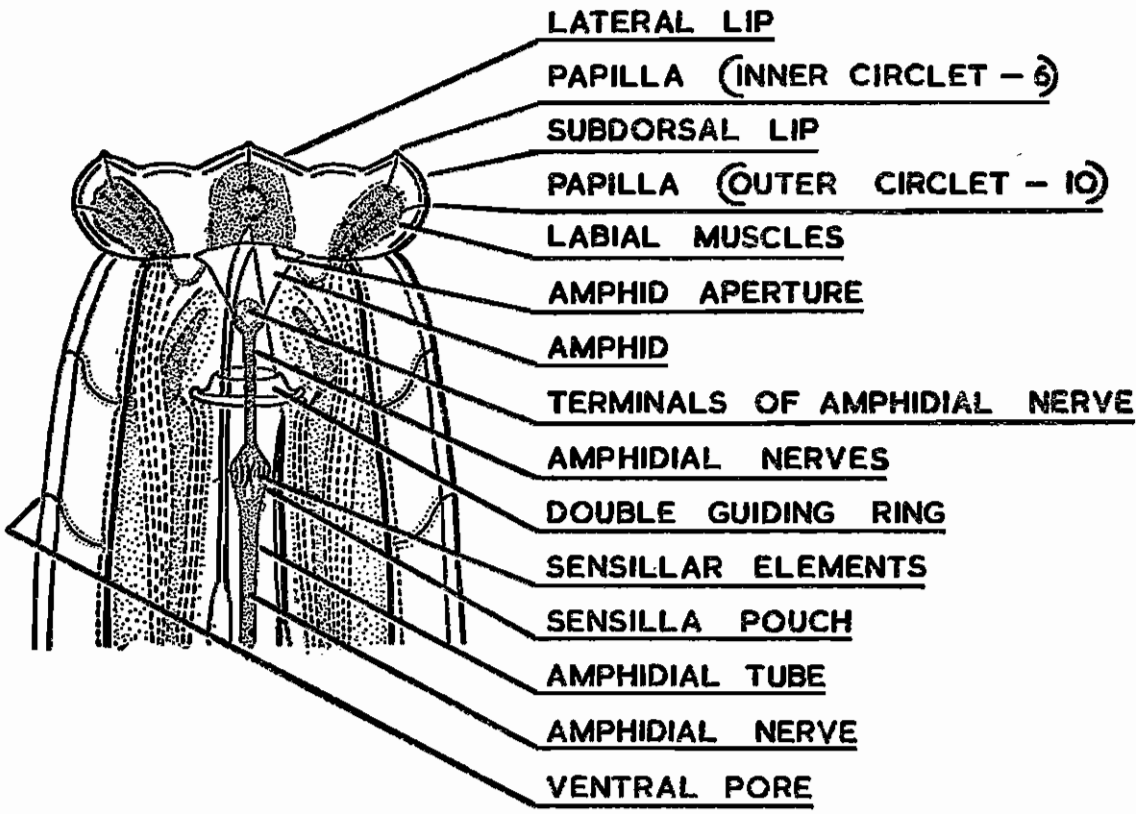

LATERAL LIP
PAPILLA (INNER CIRCLET – 6)
SUBDORSAL LIP
PAPILLA (OUTER CIRCLET – 10)
LABIAL MUSCLES
AMPHID APERTURE
AMPHID
TERMINALS OF AMPHIDIAL NERVE
AMPHIDIAL NERVES
DOUBLE GUIDING RING
SENSILLAR ELEMENTS
SENSILLA POUCH
AMPHIDIAL TUBE
AMPHIDIAL NERVE
VENTRAL PORE

Fig. 12.2

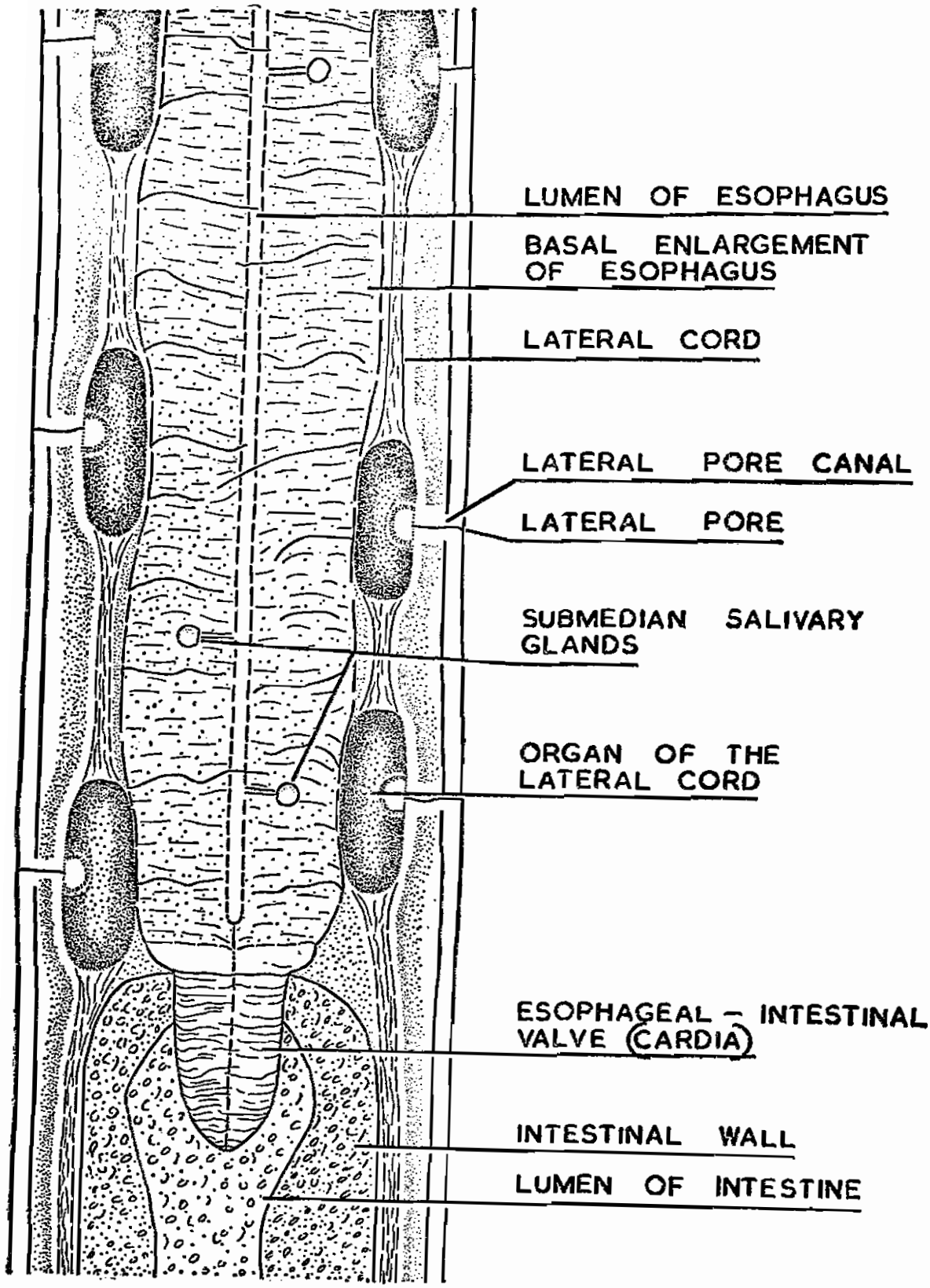

LUMEN OF ESOPHAGUS
BASAL ENLARGEMENT OF ESOPHAGUS
LATERAL CORD
LATERAL PORE CANAL
LATERAL PORE
SUBMEDIAN SALIVARY GLANDS
ORGAN OF THE LATERAL CORD
ESOPHAGEAL – INTESTINAL VALVE (CARDIA)
INTESTINAL WALL
LUMEN OF INTESTINE

Fig. 12 .3

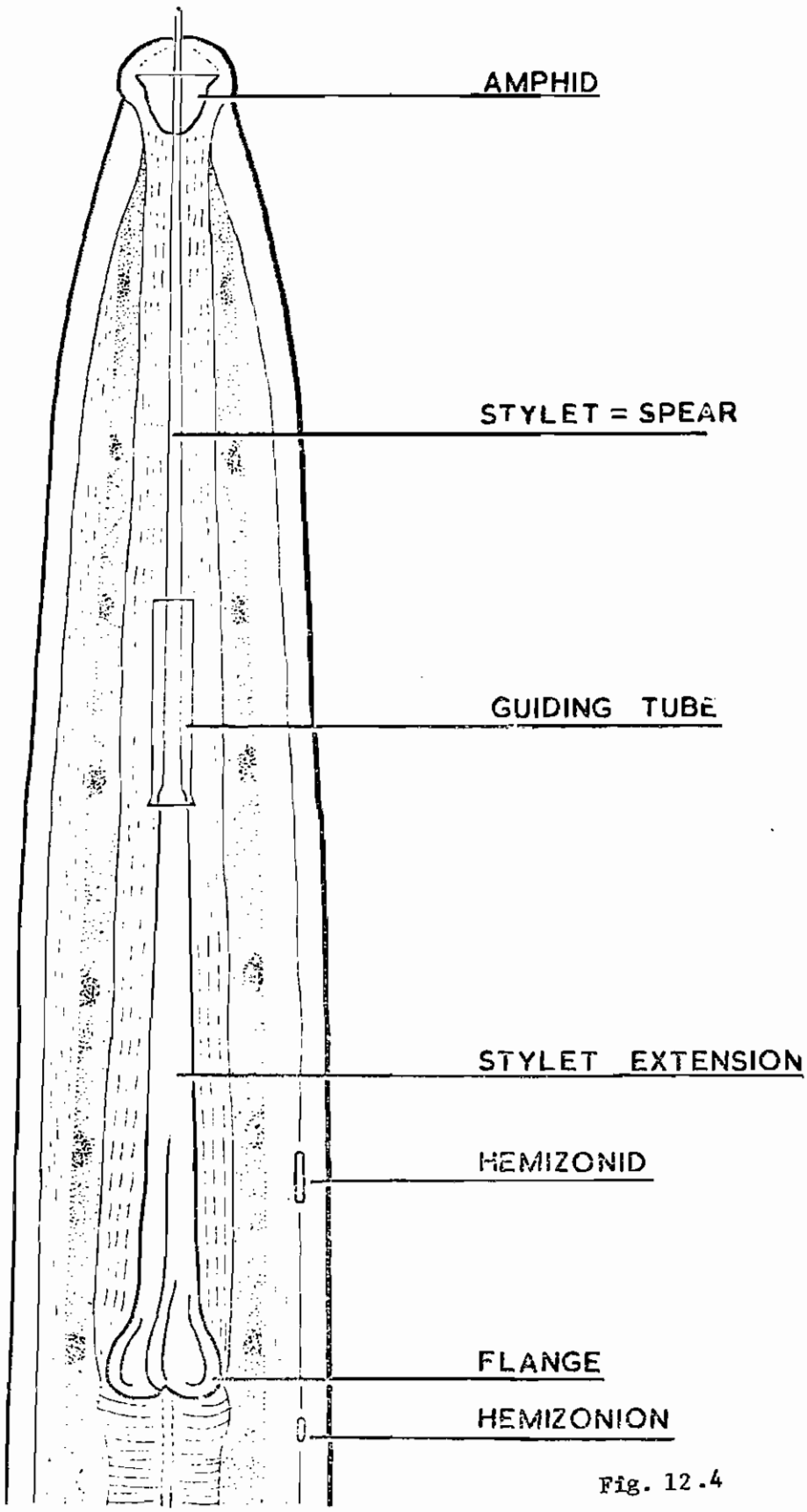

AMPHID
STYLET = SPEAR
GUIDING TUBE
STYLET EXTENSION
HEMIZONID
FLANGE
HEMIZONION

Fig. 12.4

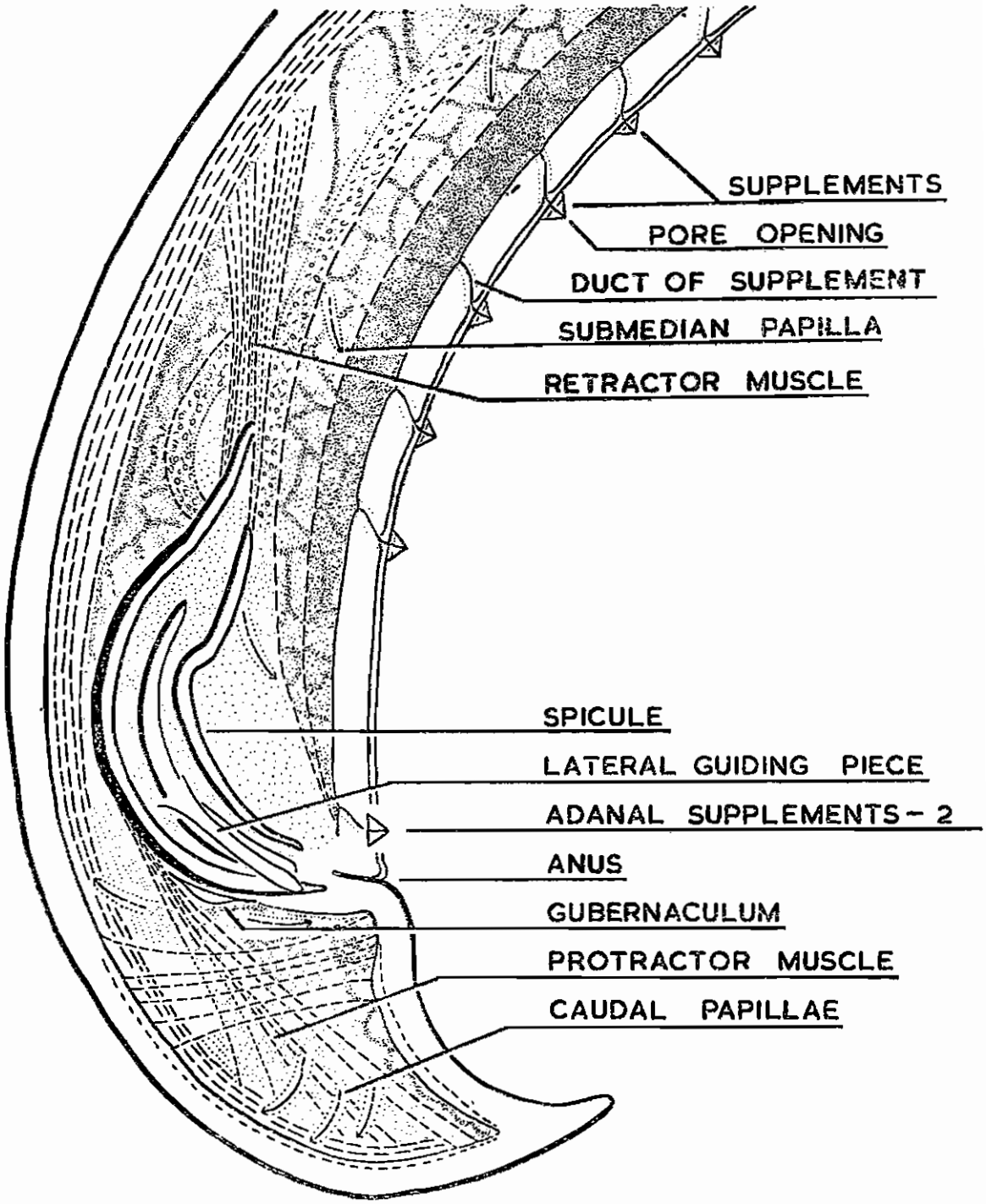

SUPPLEMENTS
PORE OPENING
DUCT OF SUPPLEMENT
SUBMEDIAN PAPILLA
RETRACTOR MUSCLE
SPICULE
LATERAL GUIDING PIECE
ADANAL SUPPLEMENTS - 2
ANUS
GUBERNACULUM
PROTRACTOR MUSCLE
CAUDAL PAPILLAE

Fig.12 .5

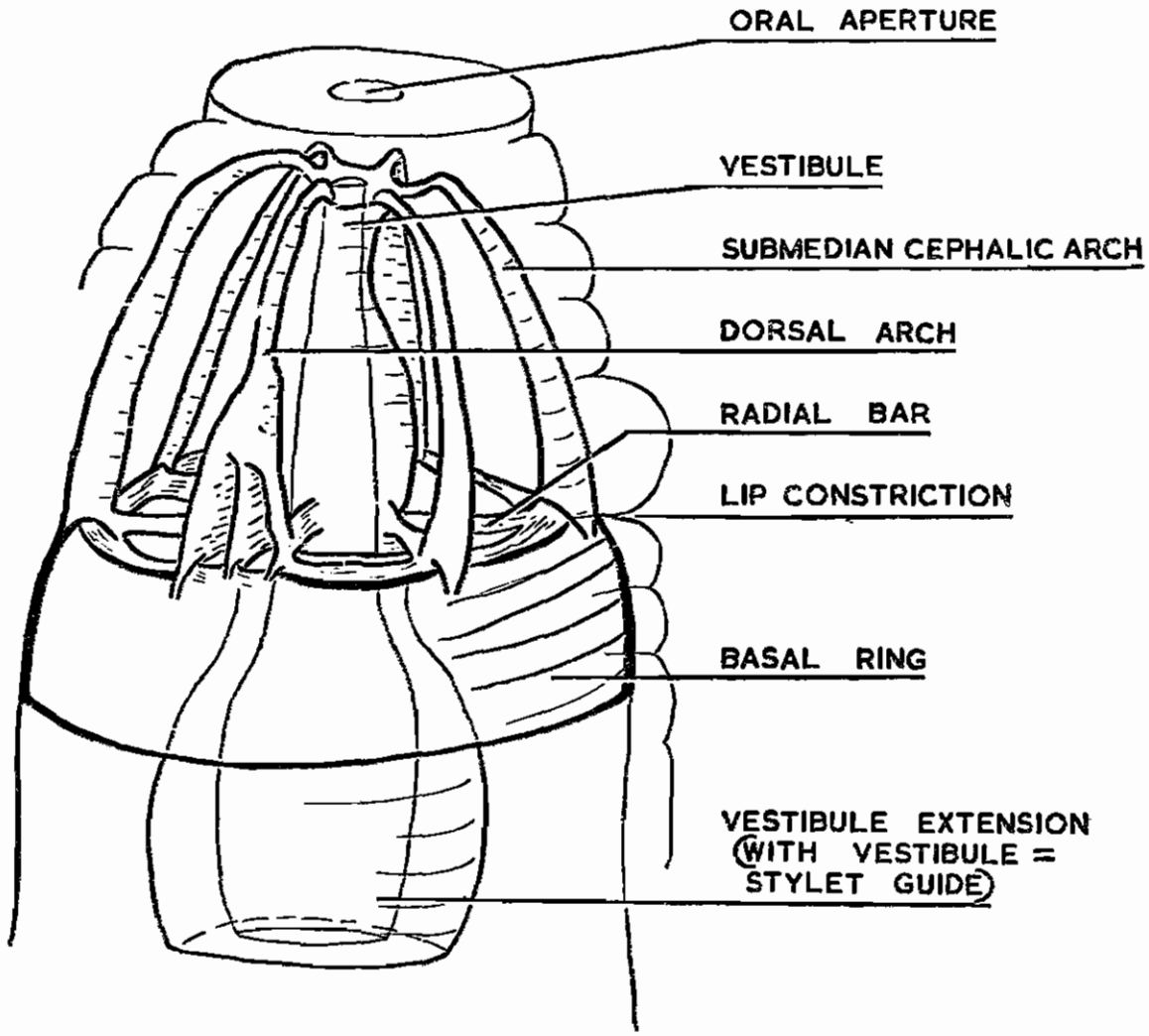

ORAL APERTURE
VESTIBULE
SUBMEDIAN CEPHALIC ARCH
DORSAL ARCH
RADIAL BAR
LIP CONSTRICTION
BASAL RING
VESTIBULE EXTENSION
(WITH VESTIBULE =
STYLET GUIDE)

Fig. 12 .6

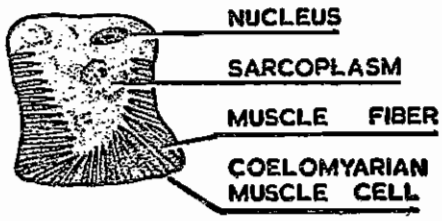


Fig.12 .9

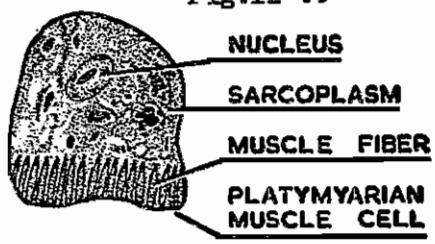


Fig.12 .8

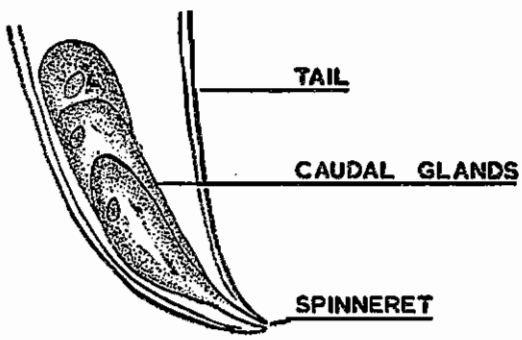


Fig.12 .7

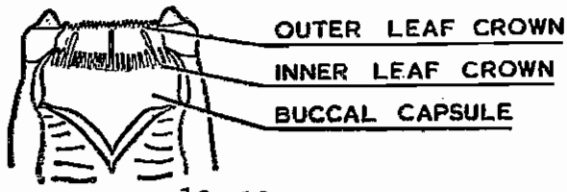


Fig. 12..12

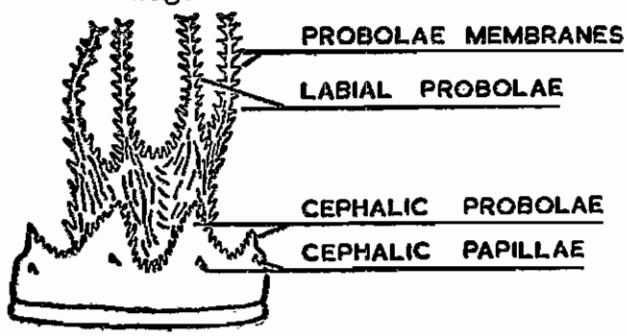


Fig. 12.11

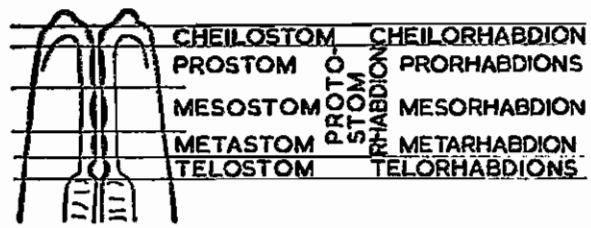


Fig. 12.10

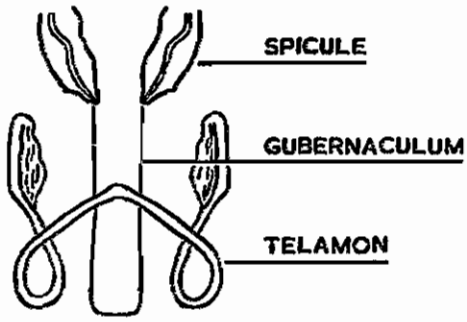


Fig. 12 .14

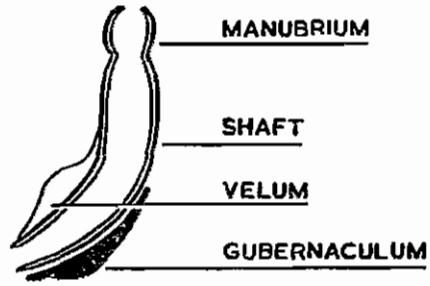
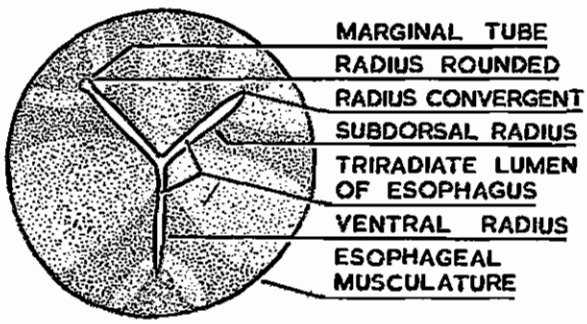


Fig. 12.16



CROSS SECTION OF ESOPHAGUS PRECORPUS

Fig. 12 .13

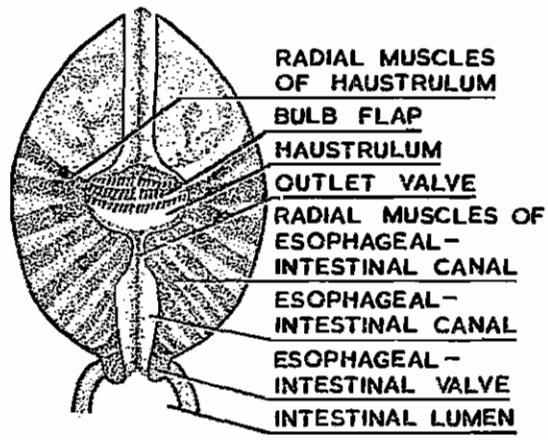


Fig. 12 .15

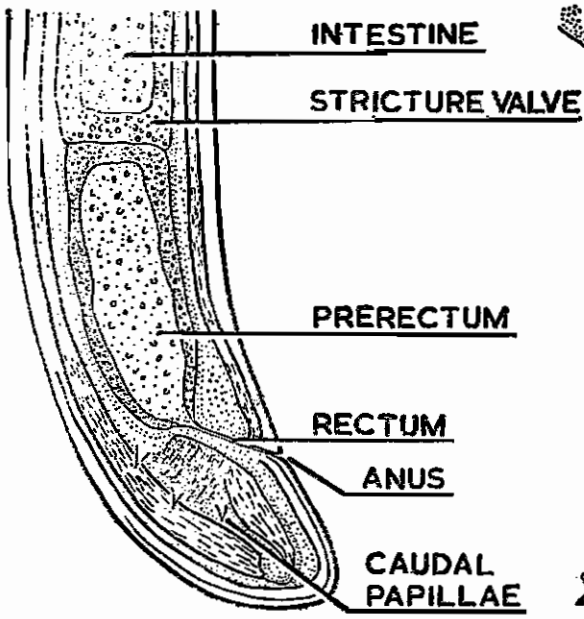


Fig.12 .18

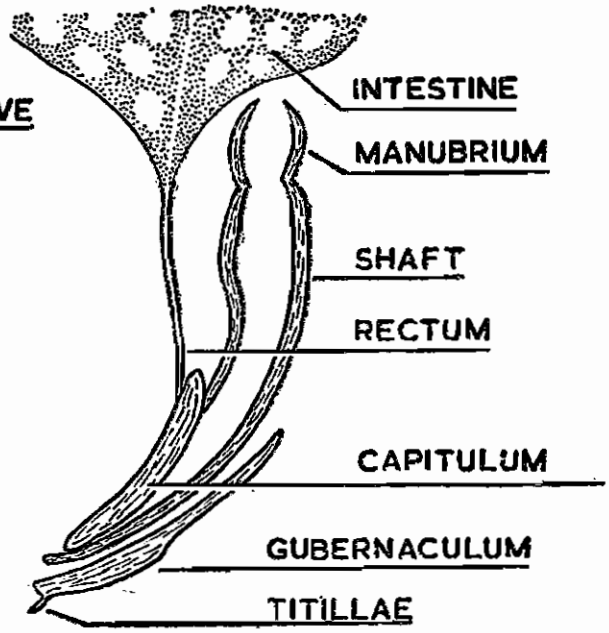


Fig. 12 .20

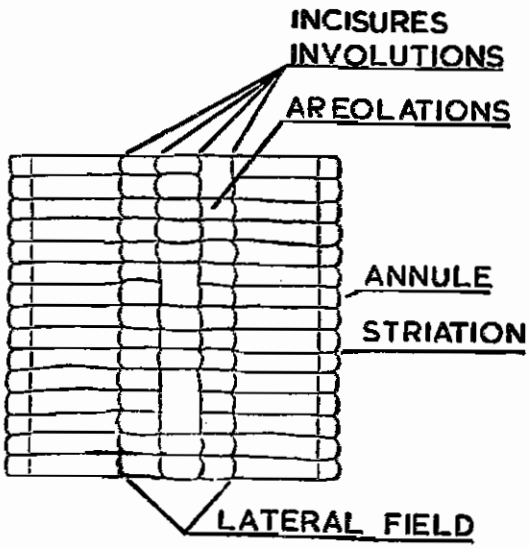


Fig. 12.17

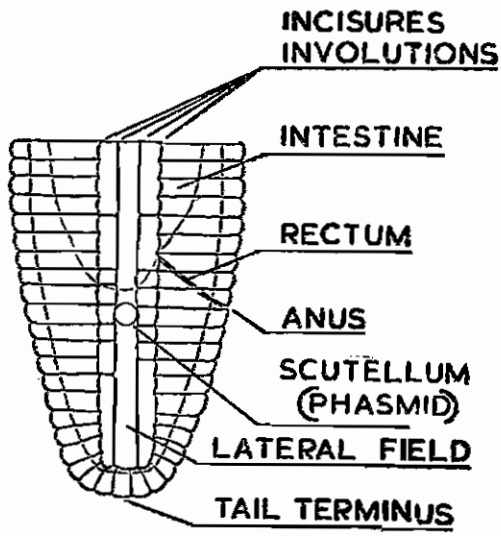


Fig. 12 .19

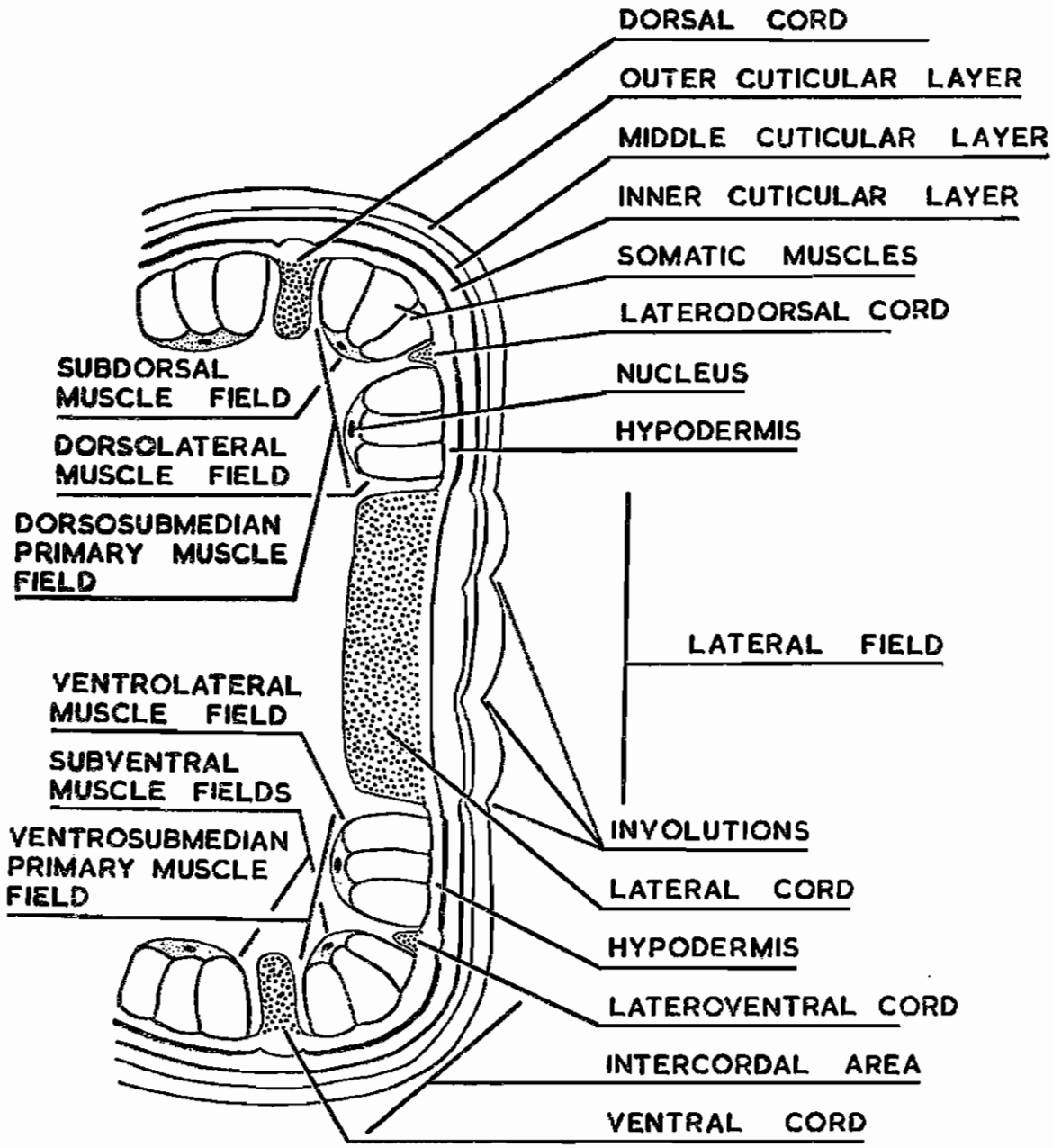

DORSAL CORD
OUTER CUTICULAR LAYER
MIDDLE CUTICULAR LAYER
INNER CUTICULAR LAYER
SOMATIC MUSCLES
LATERODORSAL CORD
NUCLEUS
HYPODERMIS
SUBDORSAL MUSCLE FIELD
DORSOLATERAL MUSCLE FIELD
DORSOSUBMEDIAN PRIMARY MUSCLE FIELD
LATERAL FIELD
VENTROLATERAL MUSCLE FIELD
SUBVENTRAL MUSCLE FIELDS
VENTROSUBMEDIAN PRIMARY MUSCLE FIELD
INVOLUTIONS
LATERAL CORD
HYPODERMIS
LATEROVENTRAL CORD
INTERCORDAL AREA
VENTRAL CORD

Fig. 12.21

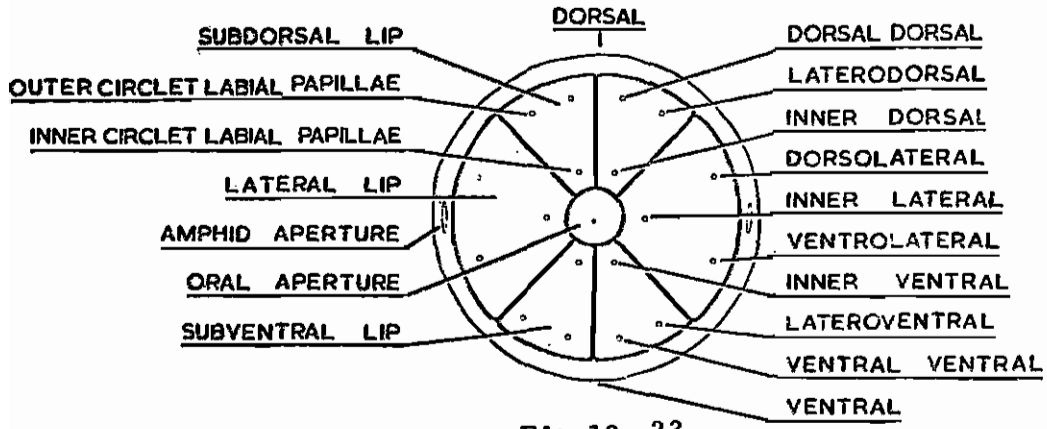


Fig. 12 .23

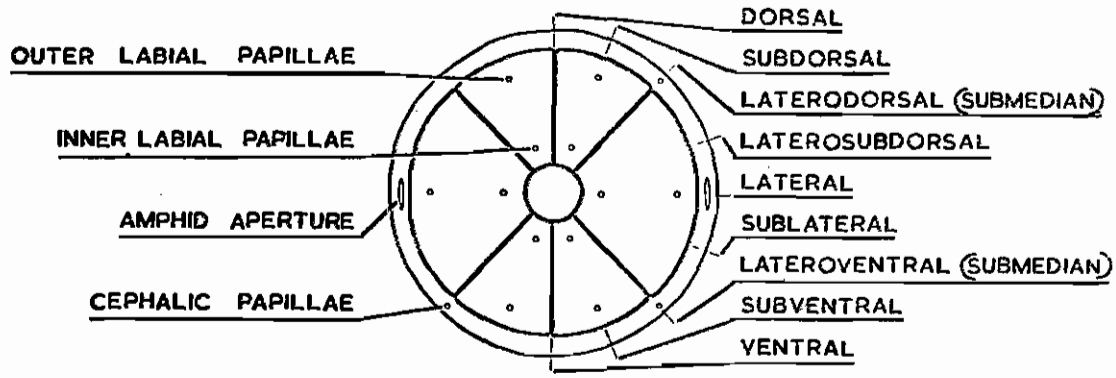


Fig. 12 .22

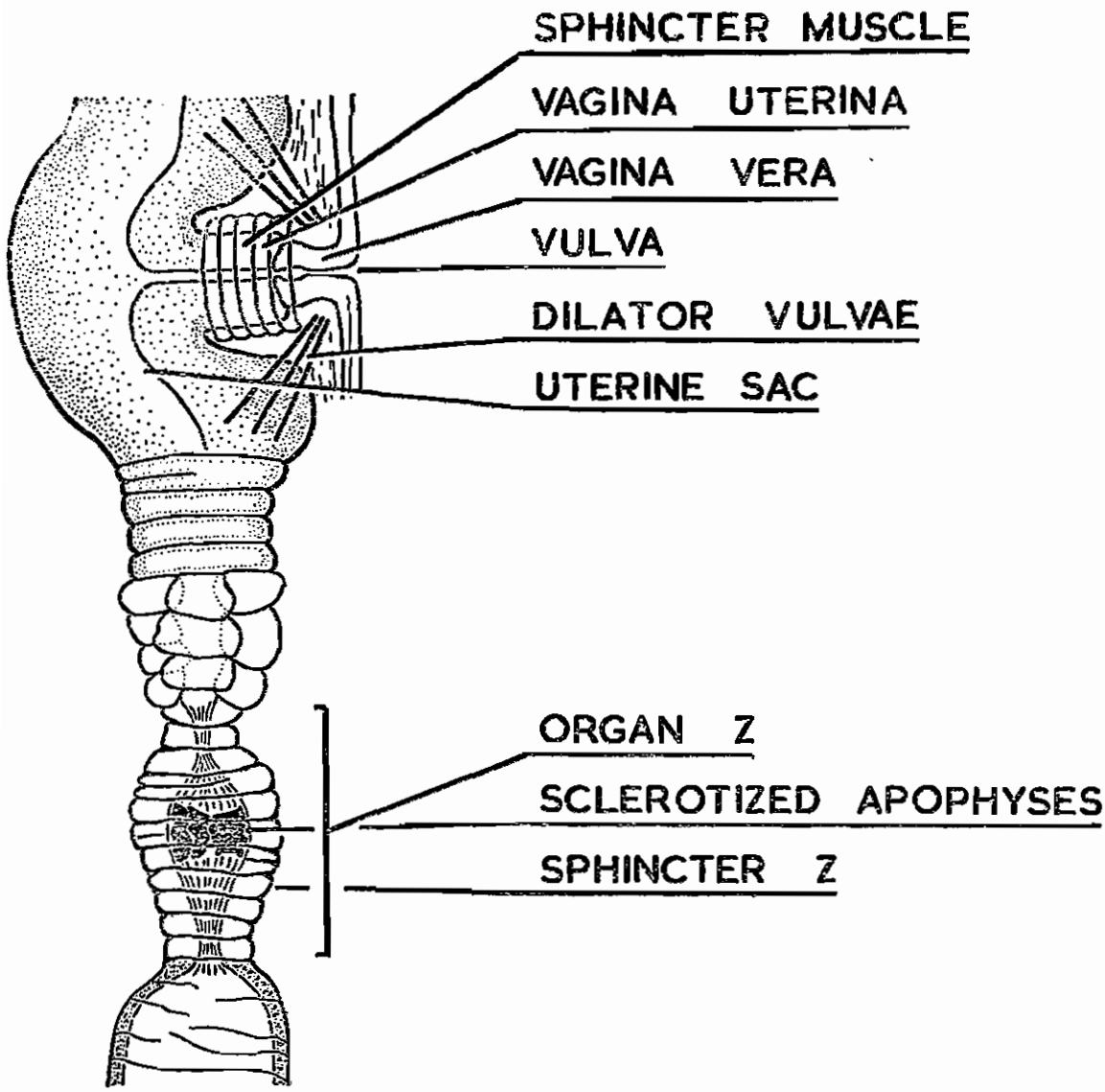
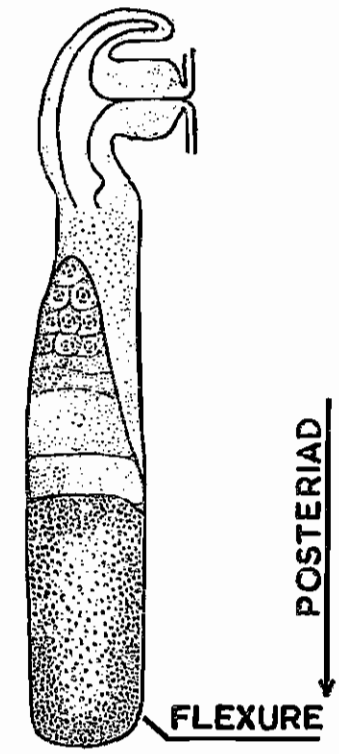
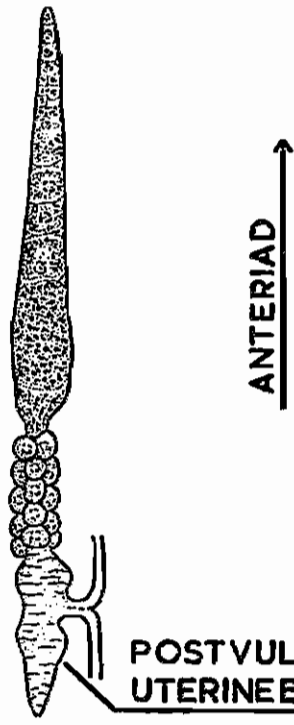

SPHINCTER MUSCLE
VAGINA UTERINA
VAGINA VERA
VULVA
DILATOR VULVAE
UTERINE SAC
ORGAN Z
SCLEROTIZED APOPHYSES
SPHINCTER Z

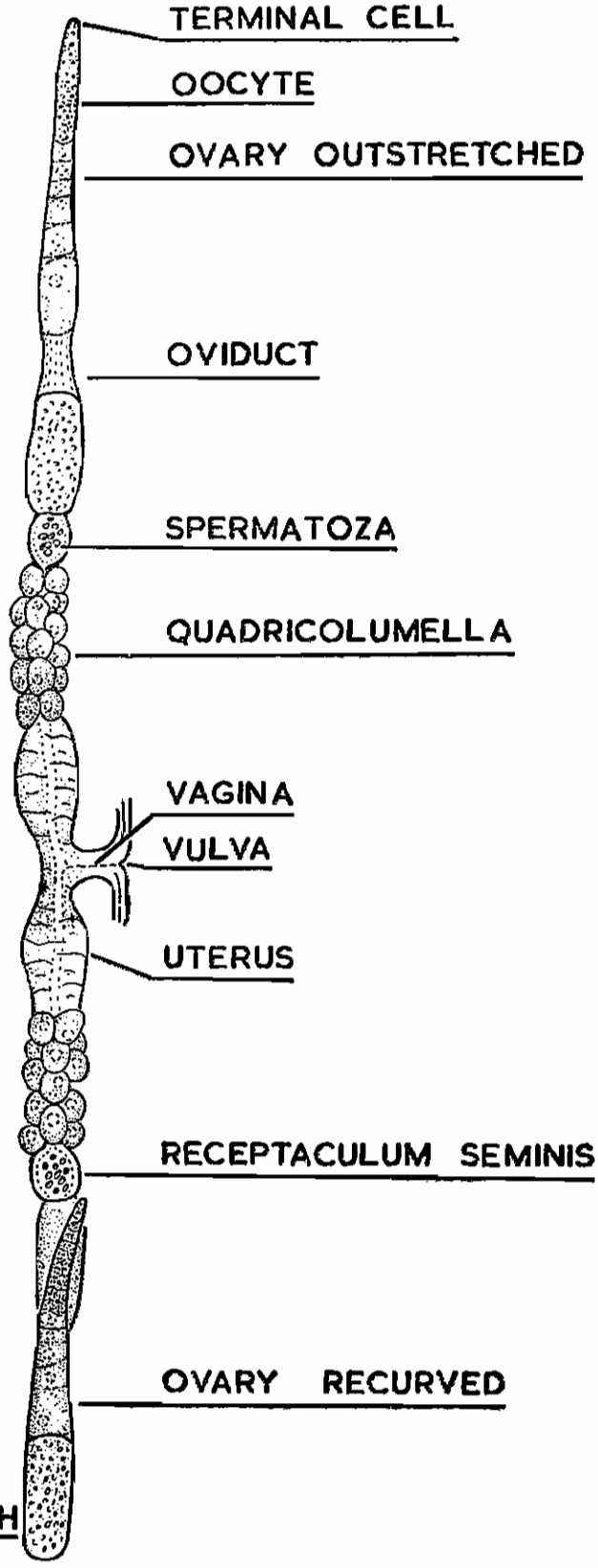
Fig. 12.24



MONODELPHIC
OPISTHODELPHIC
Fig. 12 .26



MONODELPHIC
PRODELPHIC
Fig. 12.25



DIDELPHIC
AMPHIDELPHIC
Fig. 12 .27

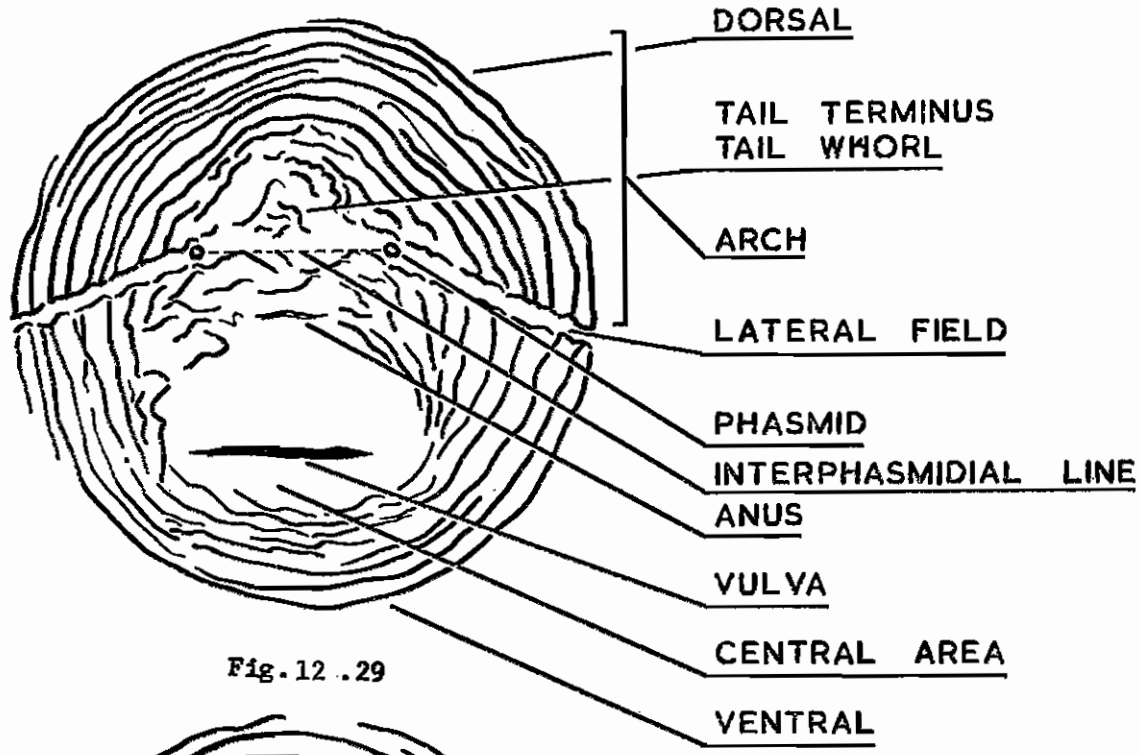


Fig. 12.29

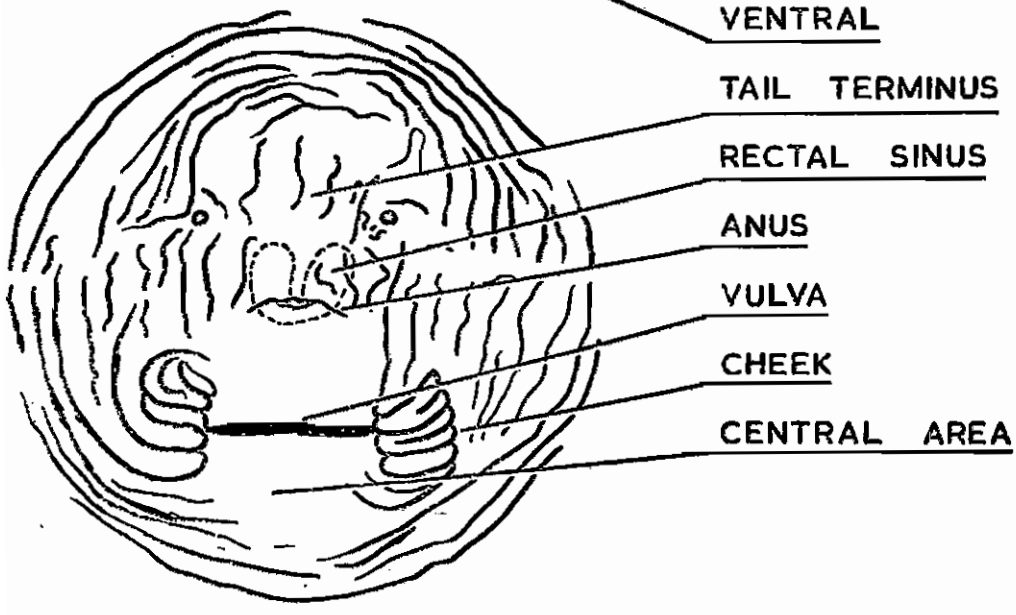
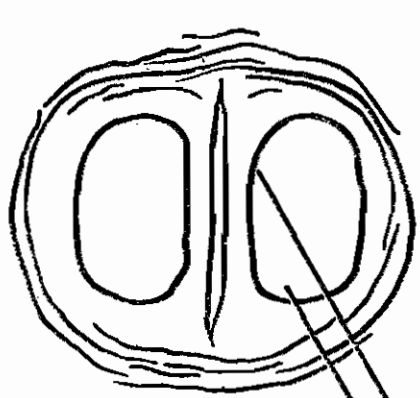
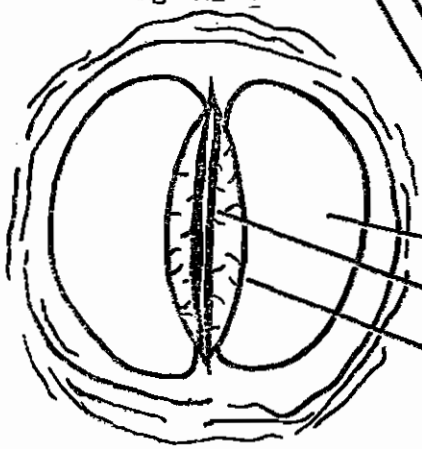


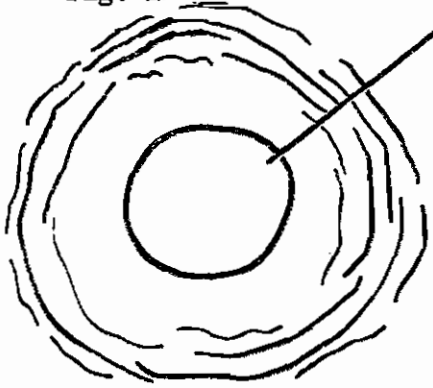
Fig. 12.28



BIFENESTRATE
Fig. 12.32

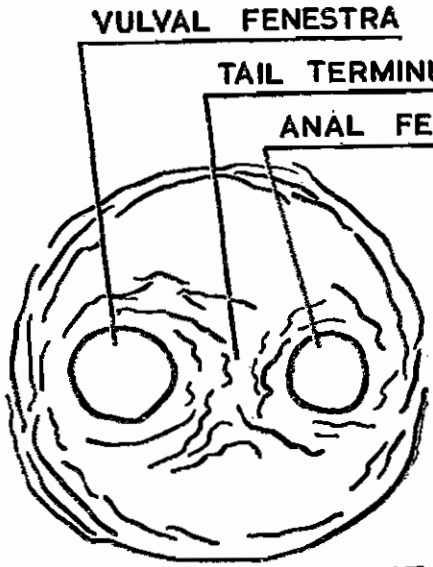


AMBIFENESTRATE
Fig. 12. 31

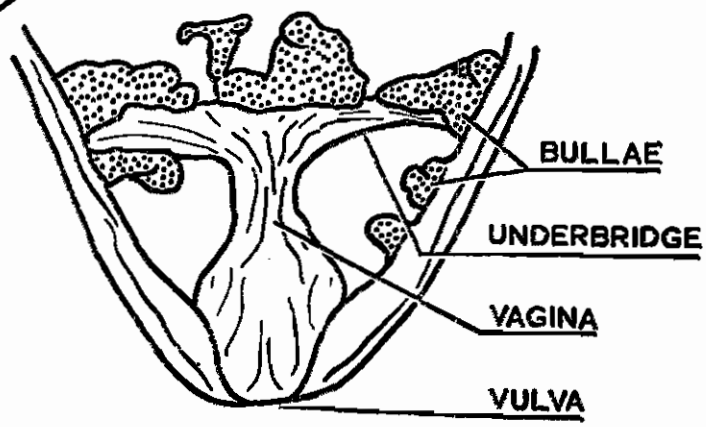


CIRCUMFENESTRATE

Fig. 12.30



TERMINAL VIEW OF CYST
Fig. 12.34



CYST VULVAL CONE
Fig. 12.33

VULVAL FENESTRA
TAIL TERMINUS
ANAL FENESTRA
BROAD VULVAL BRIDGE
SEMIFENESTRAE
VULVAL SLIT
WALL OF VAGINA
FENESTRA
BULLAE
UNDERBRIDGE
VAGINA
VULVA

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CHAPTER THIRTEEN

HARVESTING AND SEED STORAGE

13.1 Introduction.

Harvesting operation includes the cutting of matured plants or pods, threshing and winnowing (separation of seed or bean from chaff). These three stages can be done simultaneously by a combine, or separately with small machinery but generally, in the tropics, by family or hired labour. In harvesting soybean for seed, two aspects have to be considered: (a) the time of harvest, and (b) threshing method.

Soybean is generally ready for harvest when most of the leaves have dropped off and about 95 percent of pods have ripened. This guide is by no means precise since in some cultivars many of the leaves are still retained or more than 10 percent of the pods are still green even though most pods have matured. This is particularly true when soybean matures during wet weather. Prompt harvest is essential in soybean, when harvesting is delayed, the pods may shatter resulting in yield losses and/or deteriorate due to alternate wetting (by rain or dews) and drying.

In a study conducted at Ibadan, Nigeria, with four American cultivars, delaying harvest after optimum maturity increased percentage purple stained, discoloured and cracked seed in the major season and only cracked seed in the minor season (Nangju, 1977). Wilcox, *et al.*, (1974) found that delayed harvest increased the occurence of internally seed-borne *Diaphorte phaseolorum* var. Sojae (*Phomopsis* sp.) and other fungi.

Work in Pueto Rico indicated highly negative correlation between percent *Phomopsis* or total fungi and percent germination in 24 cultivars harvested at 0, 2 and 4 weeks after maturity (Anon, 1977). In work conducted at IITA, some cultivars were found to be more adversely affected by delayed harvest than others indicating the importance of selecting cultivars which are resistant to weathering and fungal infection in the field since prompt harvesting is seldom possible in the tropics. Hot, dry weather during harvest adversely affects both the physical and physiological quality of soybean seed and thereby reduce seed quality (Green *et al.*, 1966).

13.2 Harvesting and threshing.

A three year study conducted by Green *et al.*, (1966) showed clearly the influence of threshing method on soybean seed quality. They found that the percent split and cracked seed coats, and abnormal seedlings was greatly increased as combine cylinder speed was increased from 500 to 900 rpm. Hand-harvested seed lots had a much higher viability than machine harvested lots of the same cultivar, the difference being ascribed to differences in seed coat damage. In Nigeria and much of elsewhere in Africa where soybeans are grown, farmers thresh soybean by beating the whole plants on hard surfaces of by beating pods enclosed in a jute sack with a stick. Nangju *et al.*, (1978) compared hand threshing and a combine threshing and found that the traditional method of beating pods in a bag was highly satisfactory, whereas the combine threshing increased breakage and reduced germination and emergence.

Seed moisture content decreases rapidly when good drying weather prevails during the normal harvest time, or following a rainy period. In such cases seed moisture may drop to 10 percent or less before harvest and threshing can begin or are completed. Very often the result is substantial seed injury even though harvest is done as carefully as possible.

Soybean seed becomes very brittle and susceptible to injury from mechanical forces when moisture content drops below 12 percent. Germination of soybean seed at 12 percent moisture or less can be immediately reduced as much as 10 percent by the force of an impact resulting from a 1.6m drop on to a metal surface, while a 6.25m drop onto the same surface has no immediate or latent effect on seed at 14 percent moisture content. The mechanical forces generated in the threshing section of a combine and in certain types of conveyors are much greater than those resulting from a 1.6m or even 3.2m drop (Delouche, 1975).

The most favourable seed moisture content for harvest of soybeans is a subject which has been under discussion for sometime. Available data (Green *et al.*, 1966, and Monti, 1972) suggest, however, that there is a rather narrow range of seed moisture contents that are optimal for harvest, between about 13 and 15 percent. Seed cracking and splitting increases sharply as moisture content decreases below 13 percent, while seed bruising and other less visible-- but not less detrimental-- injuries increase at moisture contents above 15 percent (Delouche, 1975).

A few rules for harvesting as related to maintenance of seed quality are advanced below:

i) Weed free, uniform stands facilitate adjustments of harvesters to minimize seed damage.

ii) Commence harvesting when seed moisture content first drops below about 15 percent.

iii) Combine at uniform ground speed.

iv) Adjust clearance and cylinder speed so that complete threshing is achieved — but not higher.

v) When hand threshing is the practice, avoid strong forces, such as driving a tractor over unthreshed plants.

vi) Check threshed seed periodically to determine extent of seed damage.

vii) Weathering reduces resistance of seed to cracking and splitting; therefore, thresh weathered seed at higher moisture content 14 to 15 percent and avoid strong mechanical forces.

13.3 Cleaning.

No matter what method the farmer uses for harvesting and threshing, he should aim for clean, whole seed. Where soybean is harvested by a combine, it is able to harvest, shell and clean at the same time. They usually blow air through the grain, this removes very light materials such as chaff, pods and dust. The grain is then sieved. The pieces smaller than the soybean seeds are removed by passing them over a fine mesh screen. The larger pieces of waste are passed over a screen that has a mesh size larger than the seeds. The screening technique can be used even when a machine is available.

However, it requires screens of proper size. When screens are not available, or when a substitute cannot be found for them, there are other less effective cleaning methods.

One of the simplest method of grain cleaning uses the wind. This method is called winnowing. The grain is thrown upward in the wind. As it falls, the lighter pieces, dust, broken seeds and powder are blown aside by the wind. But the heavier stones and pieces of earth fall with the seed. For good cleaning, winnowing must be done over and over. Some seed is always lost.

13.4 Drying.

Wet seed has a high respiration rate and is easily attacked by mold, and thus deteriorates rapidly (Milner and Geddes, 1946). Therefore it is essential to properly dry the seeds before storage. The drier the seeds, the longer they can be stored (Holman and Carter, 1952). However, the drying method can influence the viability and storability of soybean seed. When an artificial drier is used, drying temperature has to be adjusted to not more than 50°C. In studies conducted at IITA, seed dried at 40 and 50°C maintained adequate germination whereas drying at 60°C lowered percent germination particularly in the cultivars with high initial seed moisture content (Table 13.1).

Table 13.1: The effect of drying temperature on percent germination of three soybean cultivars (After IITA, 1978)

Cultivars	Initial moisture (%)	Drying temperature, °C		
		40	50	60
		Germination %		
Bossier	29	84.4	85.5	1.4
TGm	19	76.4	85.2	26.4
Improved Pelican	16	86.5	84.7	81.9

Small farmers generally dry soybean under the sun since artificial dryers are generally not available. Sun drying is satisfactory if it is done in the dry season having low relative humidity. If relative humidity is more than 80 percent and/or rain continues after harvest, the drying process is not satisfactory and the seed dried under these conditions can not be stored for more than three months. In Ghana where soybean were harvested in December and dried in the sun for a few days, most of the seed had emergence of between 20 and 60 percent when they were planted in April the following year (Mercer - Quarshie and Nsowah, 1975).

13.5 Large scale processing.

Soybean seed moves from the bulk storage bins through the cleaning plant and into the packaged seed storage warehouse as the processing progresses. Basic cleaning is accomplished with an air and screen machine. The air and screen machine removes fragments of pods, stems and seed, weed seed, immature

seed, and other contaminants that are lighter, smaller, and larger than mature, intact soybean seed. Basic cleaning can increase germination percentage by a few points through removal of badly damaged, immature, and rotten (light weight) seed. In most cases, basic cleaning is all that is necessary to prepare the seed for packaging and marketing. Most cleaning problems can be traced to attempts to "squeeze" too much capacity from the air and screen cleaner and other cleaners. It should also be pointed out that the cleaning machine, surge bins, and conveyors in the processing plant are potential sources of cultivar contamination. Therefore, the entire processing plant should be thoroughly cleaned at the beginning of the processing season and between any change in cultivar or seed kind during the processing season. Treatment of soybean seed with a fungicide is beneficial, particularly when germination is less than 80 percent and the seed is infested with a disease such as pod and stem blight. Only a relatively small proportion of soybean seed marketed, however, is treated because the risk of financial loss to the seedsman is too great. Once seed is treated with fungicide it can only be used for planting purposes. Thus, seed that is not marketed for any reason, e.g. drop in germination below market standard, slow market, and so on, cannot be sold as grain; it must be dumped. For this reason, when soybean seed is treated with a seed protectant, the chemical is most frequently applied in the planter box. The final step in processing is packaging. Soybean seed can be packaged in multiwall paper bags, woven plastic bags, or cotton cloth bags.

13.6 Storage.

The storage period for soybean seed at harvest (actually at the time seed reaches physiological maturity prior to harvest) and usually ends at

planting time the following season. This period can be divided into two phase: the bulk seed storage phase, and the packaged seed storage phase.

13.7 Attributes of seed quality.

Seed quality in soybeans encompasses several important attributes (Delouche, 1975)

i) Genetic purity: Cultivar purity is important from the standpoint of both total performance and uniformity, especially uniformity of maturity.

ii) Physical purity: Soybean seed should contain a minimum amount of inert material and should not be contaminated with seed of objectionable weeds and other crops.

iii) Germination: High quality seed should germinate 85 percent or better.

iv) Vigor: The germinable seed in a lot should be vigorous enough to emerge rapidly and uniformly under a broad spectrum of seed bed conditions and to develop into rapidly growing, productive plants.

Although the most chronic and difficult seed quality problems in soybeans relate to germinability and vigor, serious problems can also arise in connection with cultivar and physical purity.

13.8 Maintenance of cultivar purity.

Cultivar purity in soybeans is maintained through systematic seed multiplication and a rigorous in-company or in-department quality control program, or participation in the multiplication and quality control system of a seed certifying agency. Certification procedures designed to maintain cultivar

purity and other quality standards during multiplication/production and processing of soybean seed include:

(a) Limitation on generations - multiplication of soybean cultivars is limited to two generations beyond the foundation seed generation, viz., registered class seed, which is the progeny of foundation seed, and certified class seed, which is the progeny of registered or foundation seed.

(b) Control of seed source - the seed used to plant each seed crop for certification must be of the proper class, eg. registered class seed must be produced from registered or foundation seed.

(c) Land history - soybean seed cannot be produced on land on which the previous crop was another cultivar of soybeans, or the same cultivar but not certified, unless the cultivar planted can be easily distinguished from the one grown the previous season. This is to prevent cultivar contamination from volunteer plants.

(d) Isolation - soybeans are self-pollinated; nevertheless, field of different cultivars of soybeans must be adequately separated (minimum of 3 to 4m) to prevent mechanical mixtures.

(e) Field standards - soybeans subject to certification are field inspected at least once --usually at maturity--to ensure that the ratio of plants of other cultivars to those of the cultivar certified does not exceed established standards.

(f) Cleanliness of equipment and facilities - threshing equipment and floors, drying facilities, bulk storage units, conveyors and cleaning machines must be thoroughly cleaned before use and between any change in cultivar. Selection of equipment for ease of cleaning, therefore, is an important consideration in design of seed processing facilities.

(g) Seed standards - after processing and packaging, certified class seed must not contain inert matter in excess of 2 percent, seed of other varieties in excess of 0.5 percent, and seed of objectionable weeds in excess of established limits. Minimum germination is usually 80 percent.

13.9 Factors affecting germination, vigour and storability:

The sources of germination and vigor problems that cause difficulties in soybean seed production and supply are diverse: inexperience of "new" producers; compromises of production beyond harvesting, bulk storage, and processing capacity; umfavourable weather during harvest period, and so on. The basic and most important source of seed quality problems in soybeans, however and the one which directly or indirectly influences the occurence and severity of nearly all other problems, resides within the soybean seed.

13.10 Seed development and morphology.

The structural and physiolocal delicacy of the soybean seed contributes in a major way to many germination and vigor problems. Some knowledge of seed development and morphology is essential, therefore, for understanding

the complexity of factors involved in loss of germinability and vigor, and possible means of minimizing these losses. Development of the soybean seed begins with fertilization. The two cotyledons and growing points are fully differentiated within the first 2 weeks. Dry weight of the developing seed increases slowly until about 20 to 30 days after flowering, depending on date of flowering, while moisture content slowly decreases from about 90 to 80 percent. (Date of flowering — fertilization -- has a pronounced effect on rate of seed development in a determinate variety). Seeds from late season flowers develop much more rapidly than those from early season blooms. Seeds set late in the season, therefore, "catches up" to that set earlier as the season progresses. Beginning about 25 to 35 days after flowering, dry matter begins to accumulate rapidly in the seed reaching a maximum at 65 to75 days. Thereafter, dry weight tends to remain constant or to decrease slightly (sometimes substantially when the seed is severely weathered prior to harvest). During the period of rapid dry matter accumulation, seed moisture content decreases rather slowly to 40 to 50 percent at the time maximum dry weight is attained. Under good field drying conditions seed moisture content then decreases from 40 to 50 percent to 15 to 18 percent in about one week.

Soybean seeds are physiologically mature at the time maximum dry weight is reached (40 to 50 percent moisture content). At this stage germinability and vigor of the seed are highest even though the seed first becomes capable of germination when only about one-third of the dry weight has been accumulated.

The mature soybean seed is generally spherical in shape and has a relatively thin seed coat (Fig.13.1). The hilum, point of attachment of the seed in the pod, is linear to elliptic in shape and located on the ventral face of the seed coat. It may be variously pigmented. The endosperm is represented only by a thin layer of cells immediately beneath the seed coat. The remainder of the interior of the seed is occupied by the embryo, which consists of a short radicle-hypocotyl axis, two fleshy cotyledons (lateral organs), and a well-developed plumule - growing point with two leaves, which is terminal on the radicle-hypocotyl axis and between the cotyledons.

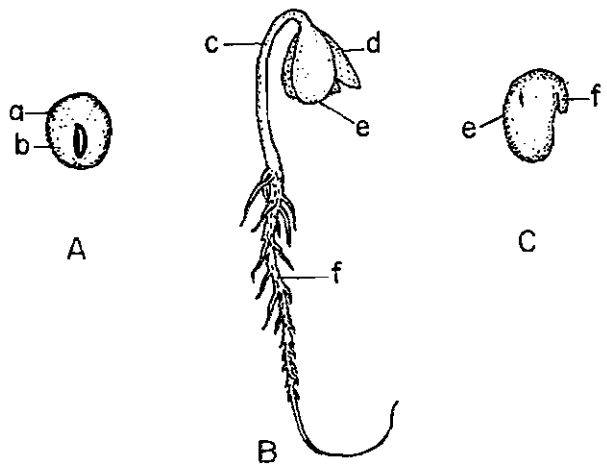


Fig. 13.1: Seed and seedling structure in soybeans: A, mature seed; B, seedling; C, embryo; a, seed coat; b, hilum; c, hypocotyl; d, plumule; e, cotyledon; f, primary root (radicle). Drawing from Delouche (1975).

The short radicle-hypocotyl axis is curved so that it lies against the basal margins of the cotyledons with its tip pointed in the same direction as the apices of the cotyledons.

The position of the radicle-hypocotyl axis and the delicacy of the seed covering which is its only protection makes the seed especially vulnerable to injury by mechanical abuse from any source-harvesting, conveying, processing, and so on. Since the radicle-hypocotyl axis is essential for normal germination, any substantial damage to it can be disastrous form the standpoint of seed quality.

13.11 Storage.

The longevity of seed in storage is influenced by four major factors: (a) inheritance of the species, (b) quality of the seed at the time it enters storage, (c) temperature of the storage environment and(d) the moisture content of the seed or ambient relative humidity (Grabe, 1965; Harrington, 1972). Soybean seed is inherently short-lived as compared to other major crop species. In subtropical and tropical areas, the poor storability of soybean seed is a major constraint on production. The seed often drops in germination to the extent that it is worthless for planting within a few months after harvest. The storability of seed is very much influenced by the degree to which the seed had deteriorated prior to storage. Soybean seed subjected to weathering before harvest, severely damaged during combing, and/or inadequately aerated during bulk storage does not store well even though it germinates moderately well at time of packaging. Relative humidity, temperature and cultivar interact closely in their effects on seed longevity during storage. In studies conducted at IITA (Nangju *et al.*, 1978), the U.S. cultivar Bossier could not maintain its high viability up to 100 days even when the temperature was kept

at 20°C and relative humidity was reduced to 20 percent. At 35°C and 40 percent relative humidity (equivalent to 7.2% moisture content) the germination of Bossier declined to 42 percent.

When the relative humidity was increased to 80 percent (equivalent to 14.7 percent moisture content) Bossier seed was completely killed after 100 days. In contrast, the Indonesian cultivar TGm 686 maintained its high germination up to 100 days at all relative humidities and temperature levels except at 35°C and 80 percent relative humidity. It was also found that in addition to its small seed, TGm 686 had lower rate of bacterial infection than Bossier. Bacterial infection in both cultivars increased markedly with an increase in temperature, relative humidity and length of storage. Ellis *et al* (1977) also found that bacterial infection increased with increase in temperature from 25 to 35°C. The most common bacteria in soybean seed are *Bacillus subtilis* and *Xanthomonas phaseoli* var. Sojensis (Anon, 1977). Fungal growth in the experiment did not show any trend with temperature and relative humidity. Results from Puerto Rico confirmed this observation (Anon, 1977). They found that percent germination during storage was negatively correlated with total bacterial infection ($r = -0.90$) but poorly correlated with total fungi infection ($r = 0.09$). These results suggest that bacteria had a more adverse effect on storability than fungi. Seeds treated with penicillin-G at 500µg/ml could maintain high germination (90%) even when they were stored for eight weeks at 40°C (Ellis, *et al.*, 1977).

Fat acidity, is a good index for measuring the storability of soybean. The higher the fat acidity, the shorter the period at which soybean can be stored

(Holman and Carter, 1952). Toole and Toole (1946) found that soybean seed can be stored up to 10 years at moisture content of 8.1 - 9.4 percent and temperature of 10°C, and less than a year at moisture content of 13-18 percent and temperature of 20-30°C. The question is how can the farmers in the tropics solve their problem if they do not have adequate storage facilities in which temperature and relative humidity can be maintained at low levels throughout the storage period. Tropical conditions of high temperature and relative humidity are not condusive to the maintenance of soybean viability.

Harrington (1963) gave practical instructions and advice on seed storage which are applicable to tropical conditions. Since the seed moisture content is a function of the relative humidity of the atmosphere, two things can be done to maintain low moisture content during storage.

(i) to grow soybean for seed in an area where relative humidity is low during the most part of storage period, and

(ii) to use moisture proof barriers such as steel bins with steel lids for bulk storage, or steel drums with aluminium foil layer and a gasket seal, sealed tin cans, hermetically sealed glass jars, sealed aluminized polyster pouches, properly sealed high density polyethelene bags for smaller quantities.

On the basis of the above principle IITA conducted storage studies with sealed plastic container and polythelene bags. Soybean seed kept in both methods were able to maintain high germination for six months whereas seed kept in an open bag showed a shard drop in germination after 3 months (IITA, 1976).

In a more detailed study conducted in Puerto Rico, sealed metal containers of plastic bags placed in metal containers with covers offered adequate storage protection for seed with a low initial moisture content up to 9 months. The most significant single factor was initial moisture content. Since the sealed tin containers serve to hold moisture content, emergence remained high for the first 6 months of storage at 7% and dropped off slightly after 9 months of storage. Seed at 10% moisture began losing viability after 3 months, and gradually fell to about 55% after 9 months. Seed at 13% moisture fell rapidly in 3 months and did not emerge after 6 months even if they were kept in sealed tin containers. These results clearly show the importance of proper drying prior to storage. In addition, the temperature during storage should be kept as low as possible since exposure of seed containers to high temperature can also reduce germination even when the initial moisture content is less than 10 percent.

Keeping seeds in sealed plastic bags or containers is recommended even if they are kept in air-conditioned rooms. In the tropics power supply may be intermittent. When the power is cut off, seed moisture content will increase due to high humidity in the room unless they are kept in moisture proof containers or bags. Proper design for intermediate and long term storage in the tropics has been described by Delouche *et al.*, (1973).

Delouche (1975) further suggested that in tropical regions seed production should be concentrated in the minor rainy season or in the dry season under irrigation so that the storage period will be reduced from 9 months to less than 3 months. The yields may be less but seed quality and germination

in the minor or dry season is generally high. This suggestion, however, is only applicable to biomodal rainfall regions and in places where irrigation facilities are available.

The other approach to storage problem in the tropics is to develop improved cultivars having high storability under tropical conditions. The work in this direction has begun at IITA since it was found that the Asiatic cultivars had much better storability than the American cultivars (IITA, 1978). The American cultivars, however, have better agronomic characteristics than the Asiatic cultivars. Thus, the logical approach is to cross these two types of soybean and select cultivars with both good agronomic characteristics and storability.

13.12 Evaluation of seed quality.

The quality of soybean seed is routinely evaluated by standard test procedures (ADSA, 1970). These procedures include a purity analysis, germination test, and usually a moisture test.

Purity Analysis. In the purity analysis the percentage by weight of pure seed, other crop seed (including seed of other varieties as can be identified), weed seed, and inert matter is determined. Modern soybean varieties can seldom be positively identified by seed characters alone. Although various seed and seedling characters are useful in determing truness-to-cultivar in soybeans, field grow-out tests generally are necessary to accurately assess cultivar purity.

Germination test: The percentage by number of seeds capable of producing "normal" seedlings is determined. The germination test has serious limitations as a measure of the stand and crop producing potential of soybean seed.

Moisture test: The moisture content of the seed, wet weight basis, is determined, usually with an electric moisture meter. Moisture content data are very important from harvest through marketing.

13.13 Germination, deterioration, and vigour:

The stand and plant producing potential of soybean seed, and other kinds of seed as well, are most commonly evaluated by a germination test. Exacting procedures for determining the germination percentage of seed lots have been developed and perfected over the past 100 years and are codified in the Rules for Testing Seed. In many ways, the standard germination test appears to admirably serve the needs and interests of seed analysts, seed control officials, and seed producers. The germination test, however, has several deficiencies which should be recognized. The deficiencies of the germination test as a measure of the plant producing potential of seed stem from two main sources : the overall philosophy of germination testing, and the nature of seed deterioration. Procedures for germination testing of seed have been established on the basis of the "optimization" principle, i.e. test conditions are optimized so that maximum germination percentages are obtained. Thus, germination tests are made largely on "artificial", standardized, essentially sterile media, in humidified, temperature controlled germinators for periods sufficiently long to permit even the weakest seed to make its debut as a normal seedling.

It has not been well established that the performance potential of a seed is progressively impaired through deteriorative processes that inevitably occur over time—a few minutes or many years. The identity and sequence of the deteriorative changes—or the manifestations of change—that occur in a seed as it dries are known only in a general way. The available evidence, however, suggests that during deterioration essential biological systems and mechanisms are progressively impaired so that the consequences, in terms of germination and subsequent growth and development, become progressively more serious.

Membrane degradation and loss of permeability control occur at an early stage during seed deterioration. Energy yielding and biosynthetic processes are then impaired with resulting decrease in rates of respiration, transfer of dry matter from supporting tissues to the embryonic axis, germination and early seedling growth. At about this stage in the progress of deterioration, the seed appears to lose much of its natural resistance to environmental stresses and seed rotting microorganisms.

Reduced rate of germination and early seedling growth are subsequently reflected in a decreased rate of plant growth delayed flowering and maturity, and reduced yield. As deterioration progresses further, the seed fails to emerge from the seed bed even under rather favourable conditions. Finally, it loses its capacity to "germinate" even in the optimum environment of the germinator. Because the seeds within a lot are not uniform in physiological quality and they become progressively more so as deterioration advances, irregular and non-uniform emergence, plant growth, development, and

maturation are other important consequences of deterioration that precede the "0' percent germination stage.

The germination test is an insensitive and misleading measure of seed quality because it focuses primarily on the final, albeit most disastrous, consequences of deterioration, and does not adequately take into account the very substantial loss in performance potential that can and does occur before the germination capacity is lost. Yet, the lesser consequences of seed deterioration, such as reduced resistance to environmental stresses decreased seedling and plant growth rate, and so on, have become of greatest importance. Few seedsmen knowingly sell, and few farmers will knowingly plant, dead or low germination seed. Both seedsmen and farmers, however, are damaged all too frequently because seed of "good" germination fails to perform satisfactorily when planted in the field. Seed that germinates moderately well but has low stand establishment potential is said to be low in vigor.

Many attempts have been made to rigorously define the term vigor as applied to seed. The result is a multitude of concepts and definitions all of which have some degree of validity and applicability, and which collectively cover the subject rather thoroughly. While space does not permit examination of the various definitions and concepts of seed vigor, it should be pointed out that vigor, as an attribute of quality, is meaningful only in reference to germinable seed. A non-germinable seed has zero performance potential, hence, no vigor. Vigor tests, therefore, supplement the standard germination test. The germination test establishes the percentage of germinable seed in a population or lot, while a vigor test evaluates the performance

potential of the germinable seed. Vigor, tests, of course, also assay the extent of deterioration of seeds within a population which really determines their performance potential. Thus, vigor and degree of deterioration are essentially the positive and negative aspects, respectively, of performance potential.

A variety of vigor tests have been developed but only a few have found application in a more or less routine manner in seed quality evaluation and control programs (Delouche and Caldwell, 1960). The more successful vigor tests evaluate response-reactions of individual seed which permits expression of test results as a percentage by number of seeds tested, much as in the germination test.

Byrd and Delouche (1971) compared the efficiency of several of the more widely used vigor tests with the germination test for evaluating the progress of deterioration during storage and the field emergence potential of soybean seed. They found that germination percentage was the least sensitive index of the progress of deterioration and reduction in emergence potential during storage. Soybean seed stored in an environmentally controlled room at 30°C and 50 percent relative humidity did not significantly decrease in germination percentage until after 7 months. Accelerated aging and cold test responses, however, significantly decreased after 1 to 4 months' storage, as also did field emergence percentage.

Results from extensive studies conducted with the objective of establishing a vigor rating system for soybean seed lots indicate that the modified accelerated aging test is especially promising for soybeans.

13.14 Accelerated aging test.

The accelerated aging test was developed for evaluating the storability of seed lots (Delouche and Basking, 1973) The accelerated aging test also has proven useful as a vigour test for evaluating the stand producing potential of seed. In regard to soybean seed lots, accelerated aging under conditions of 40°C and 100 percent relative humidity for 48 hours or for 72 hours followed by regular germination test have produced results that correlate closely with field emergence. However, fungal cross contamination of seed often occurs at 100% R.H. Wien and Fueneman (1981) found reducing the RH to 75% and increasing the aging period to 6 weeks permited good vigor assessment without complication of fungal cross-contamination.

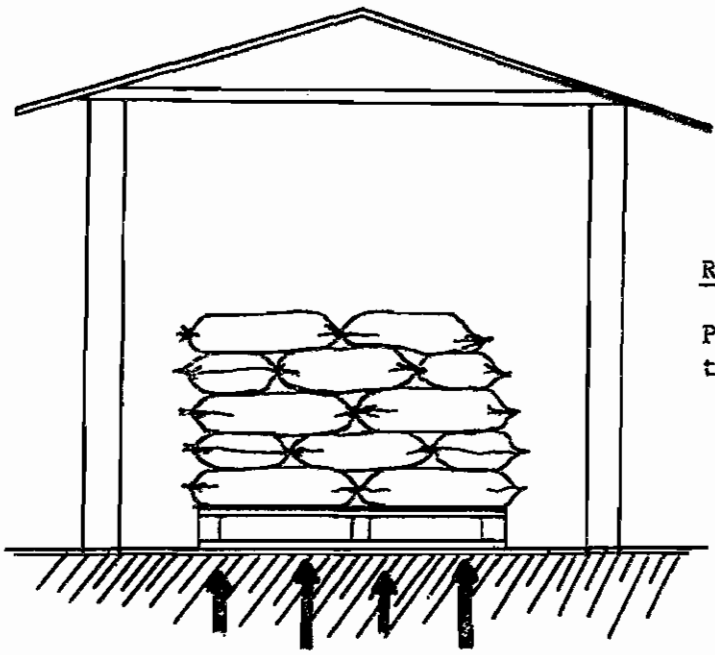
17.15 Tetrazolium test:

The tetrazolium test is most widely used to rapidly estimate the germination percentage of seed lots. Procedures for use of the tetrazolium test in this manner have been developed and published (Delouche *et al.*, 1962; Grabe, 1970). The tetrazolium test is equally applicable for evaluating vigor of seed as has long been advocated by Moore (1962, and 1966). The test is rather subjective and unless the experimenter has extensive experience the results are of little value.

Care of Produce in a Warehouse:

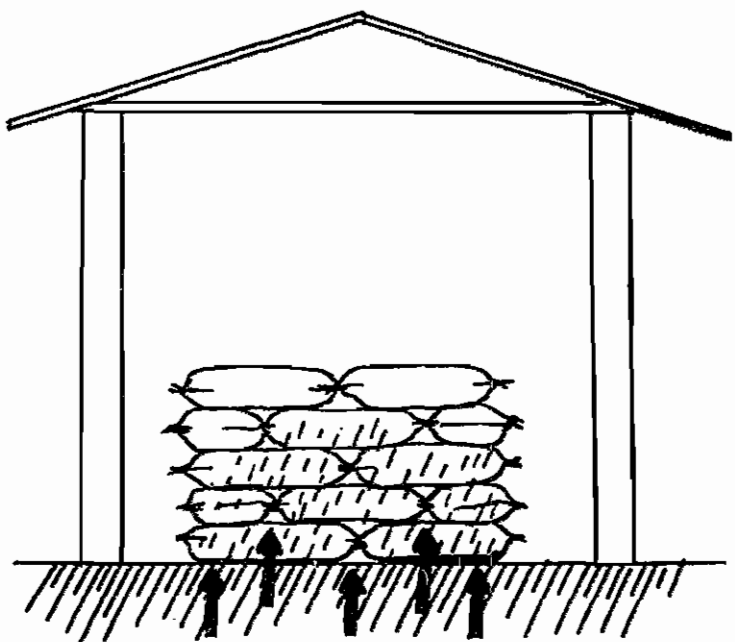
The four most important points to remember:

Prevent damp from the floor reaching the produce



RIGHT:

Pallets, dunnage etc. to form damp barrier.

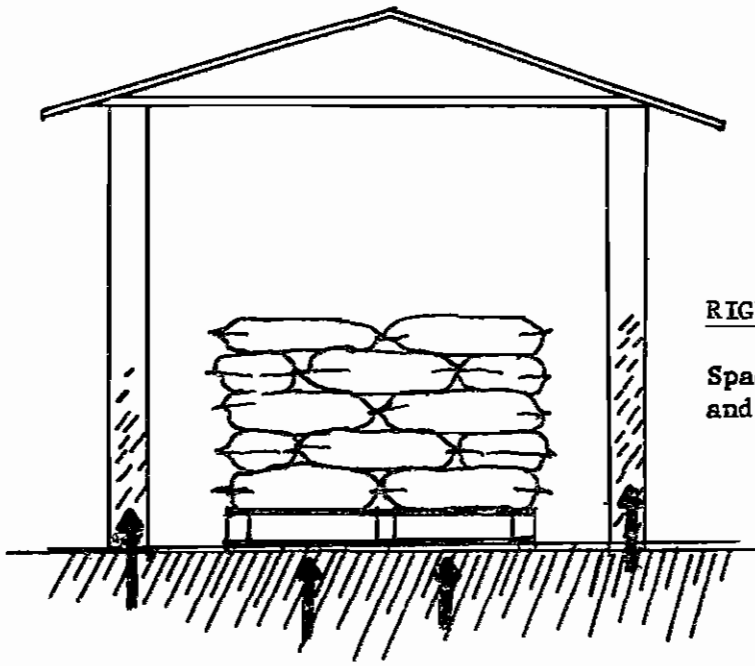


WRONG:

Bags straight on floor.

Figure 13.2: Illustration of correct method of storing grain in a warehouse.

Prevent damp from walls reaching the Produce



RIGHT:

Space between produce and walls.

WRONG:

Produce touch walls.

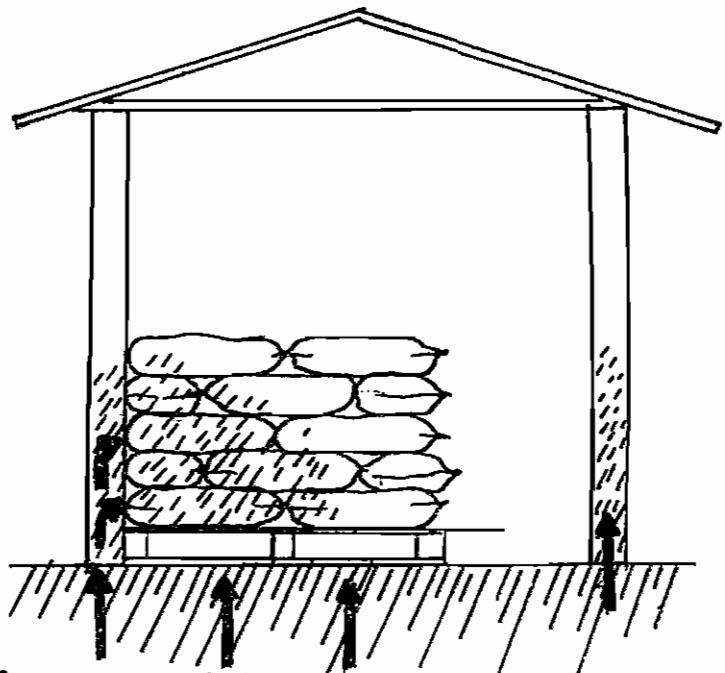


Figure 13.3: Illustration of correct method of storing grain in warehouse.

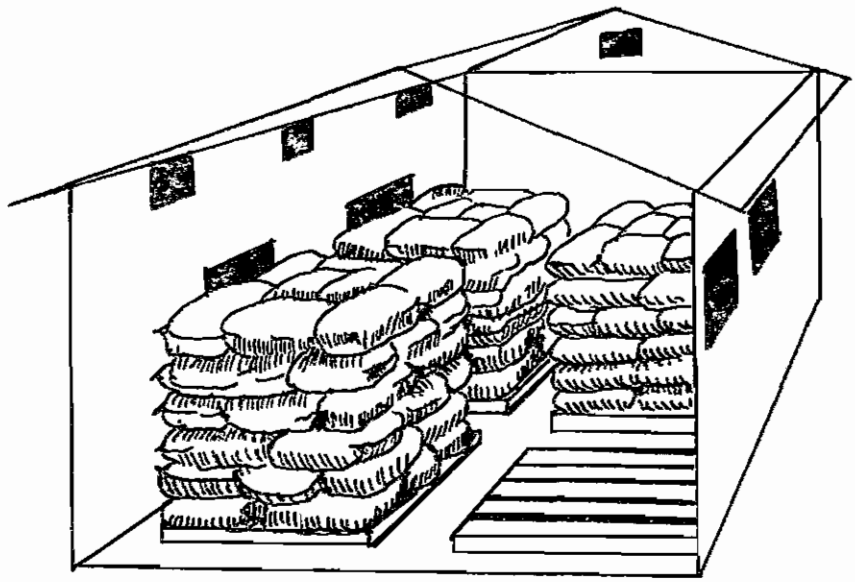
Stack the sacks properly to allow:

(a) optimal use of space

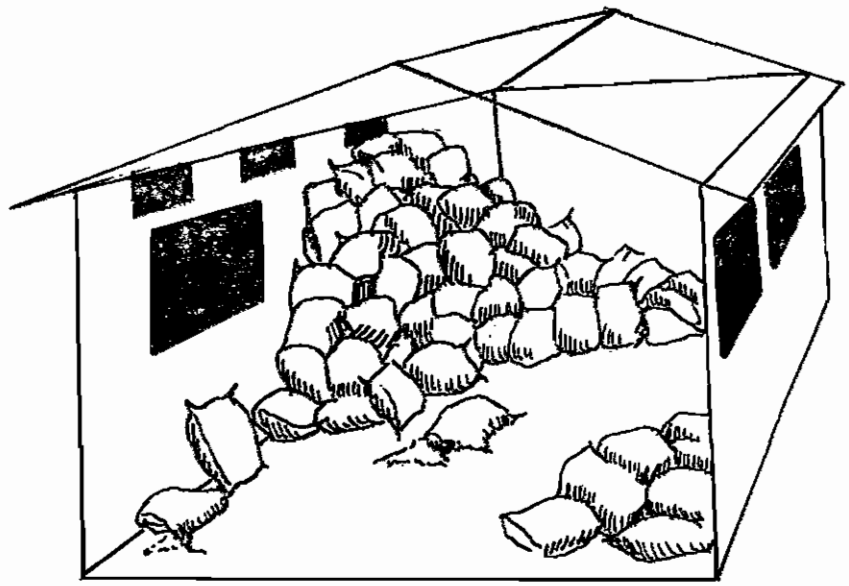
(b) ease of sweeping the floor

(c) ease of inspection of produce for rodents and insects

(d) ease of counting sacks



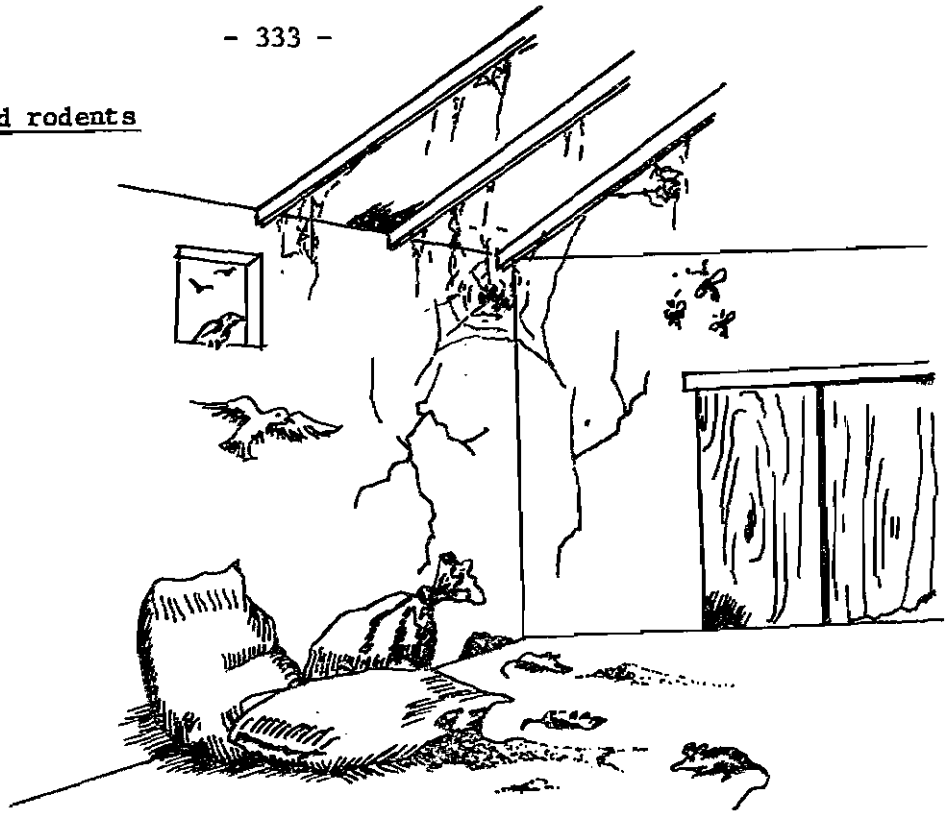
RIGHT



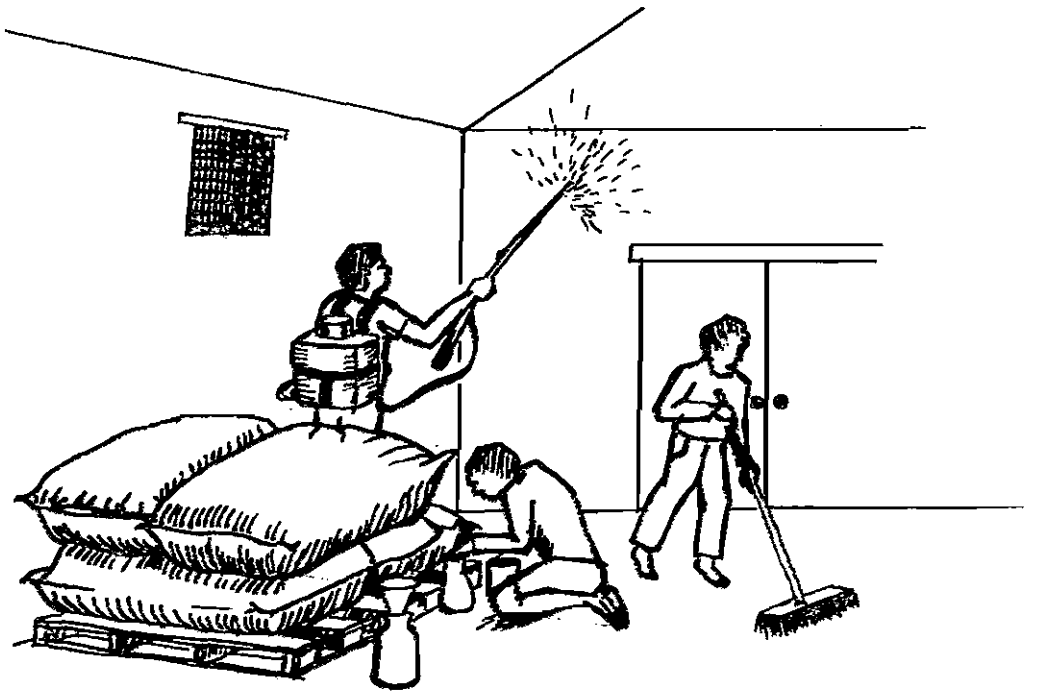
WRONG

Figure 13.4: Stacking grain in bag storage

Control insects and rodents



WRONG



RIGHT

Figure 13.5: Control of insects and rodents in storage

(a) Good building - proof against rodents and insects
(b) Inspection - to detect infestations
(c) Treatment - against rodents or insects
(d) Cleanliness - remove all infested residues and keep free of dust
(d) Maintenance - repair cracks where pests can hide and close holes at doors, roof etc.

Warehouse management practices:

Types of Dunnage: Dunnage is material that can be placed between the floor of a warehouse and the sacks of produce to prevent moisture moving from the floor into the produce, and thus causing moulding and rotting.

The cheapest dunnage is simply a thick mat or unpunctured plastic sheet, on which the sacks are placed, as shown below.

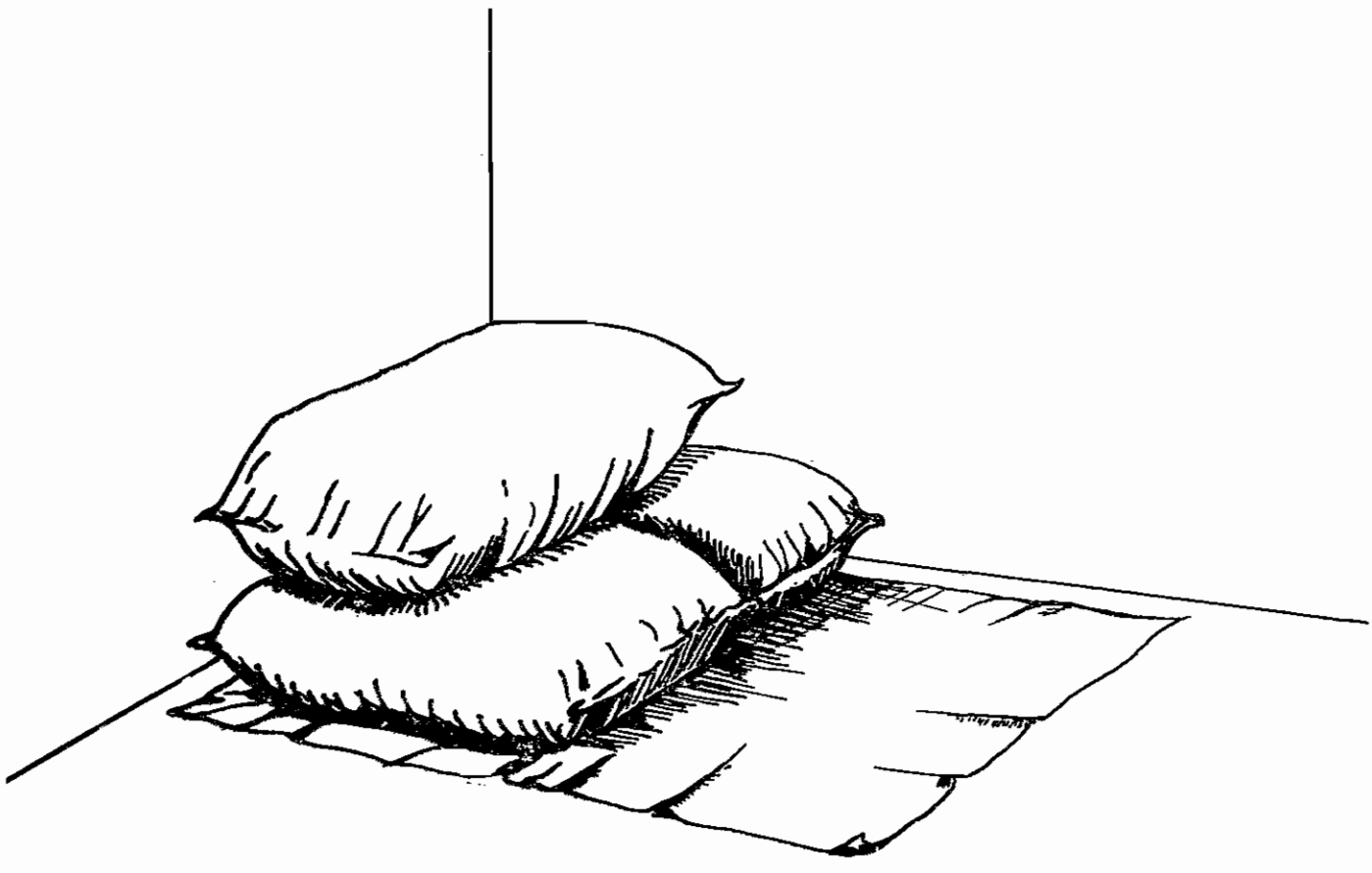


Figure 13.6: **Dunnage material** for warehouse floors

Alternately, one could simply lay down straight poles on the floor and place the sacks on them as is shown.

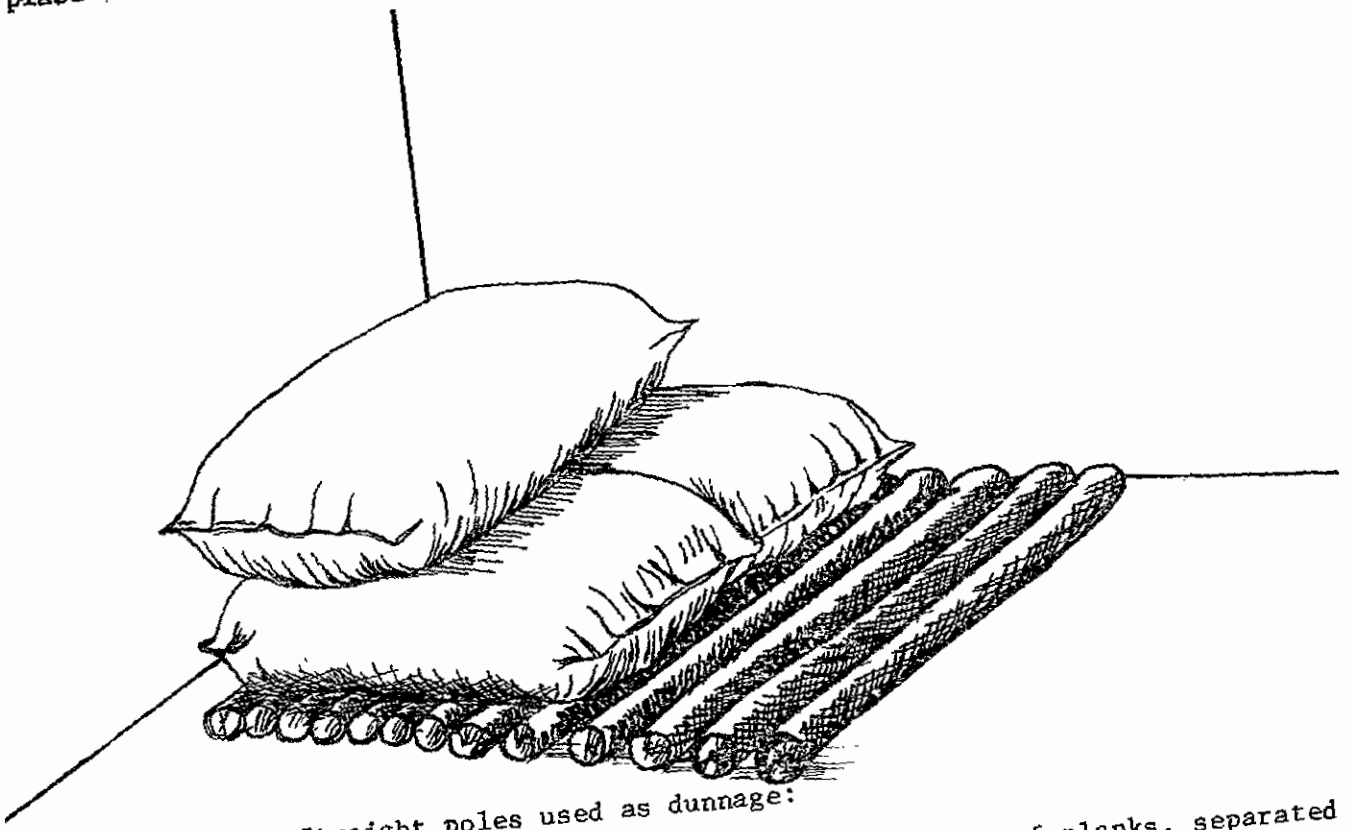


Figure 13.7: Straight poles used as dunnage:

The more expensive type of dunnage consists of two layers of planks, separated by a space. These are suitable for use with forklift trucks as is shown.

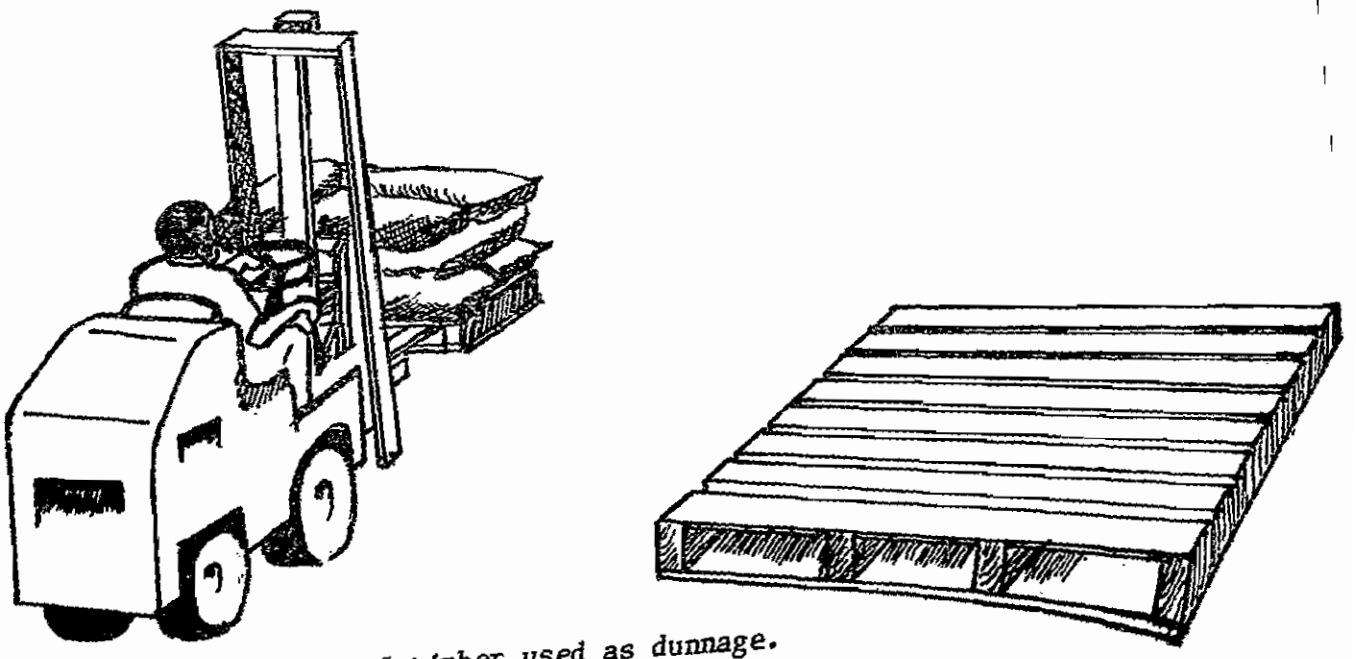
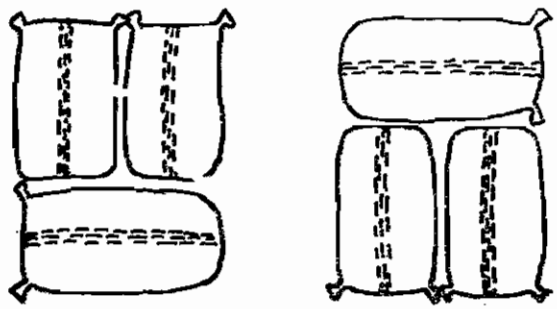


Figure 13.8: Planks of timber used as dunnage.

Stacking of sacks:

If one lays the sacks exactly on top of each other in successive piles, the sack will be extremely unstable. To overcome this, one always make sure that there is "overlap" in each successive pile.

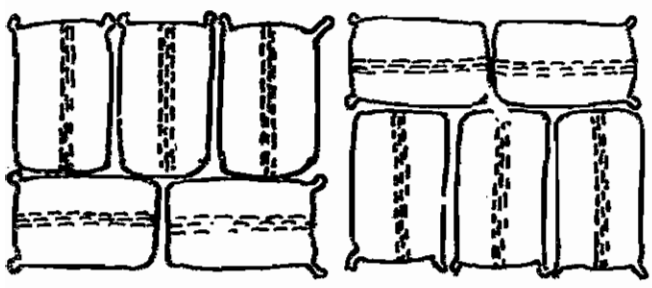
For instance, if you have three sacks per pile the first pile will be shown on the left and the one on top ot it will shown on the right. This ensures overlap and the interlooking of successive piles in the stack.



1st pile 2nd pile

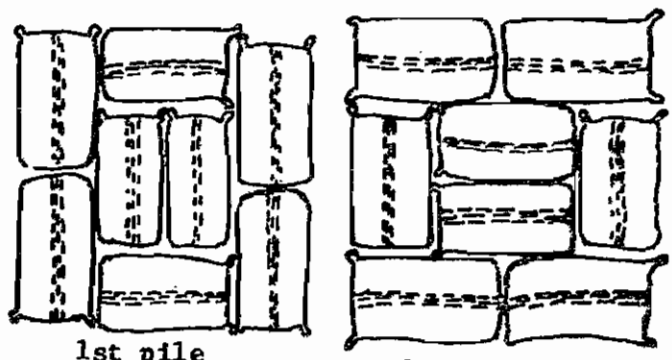
Figure 13.9t: Examples of a 5 sack pile and 8 sack pile is shown below:

5 sacks/pile



1st pile 2nd pile

8 sacks/pile



1st pile 2nd pile

Insect control in sacks stored in warehouse:

There are three common chemical methods for controlling insects in sacks stored in a warehouse, apart from the very important matters concerning hygiene, as mentioned before.

The three common chemical methods are, the admixture of insecticidal dusts with the produce before loading it into the sack, the spraying of successive layers of sacks with a liquid insecticides or dusts as the stack is built, and finally, fumigating the sacks by enclosing a fumigant with the sacks under a gasproof sheet.

The admixture of insecticidal dusts can be very effective if a suitable insecticide is used. In recent times, some synthetic pyrethroids and pirimiphos methyl dust, applied at the rate of 5ppm and 15ppm of active ingredient respectively has been found to completely eliminate insects in stored bags for at least 8 months.

The mixing of the dusts with the grain can be done in many ways such as shovel mixing on a tarpaulin or for large scale operations, a drum with an accentric axle as shown below.

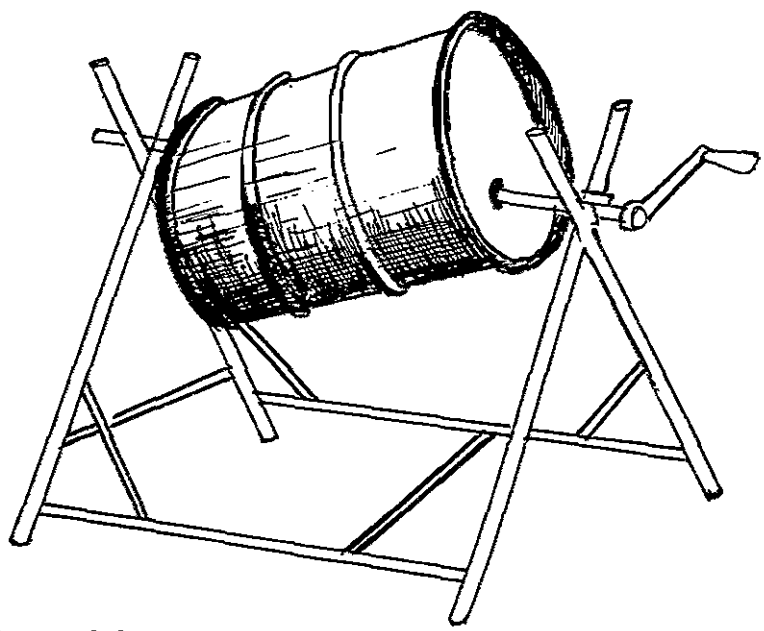


Figure 13.10 : Drum with an accentric axle for mixing dust with grain.

The admixture of dusts with stored grain imposes a potential health hazard and is generally not recommendable unless a very safe insecticide is used and consumption of the grain only takes place after a prolonged period in store.

The spraying or dusting of successive layers of sacks with insecticides as shown below is less hazardous to humans, but is not always very effective. However, in recent times the emulsifiable concentration of pirimiphos methyl (Actellic 50 EC) applied undiluted (50 EC) at the rate of 2-3 strokes by means of a simple domestic applicator per bag eliminated weevils from heavily infested sacks of maize and controlled the population to a very small level even after 8 months.

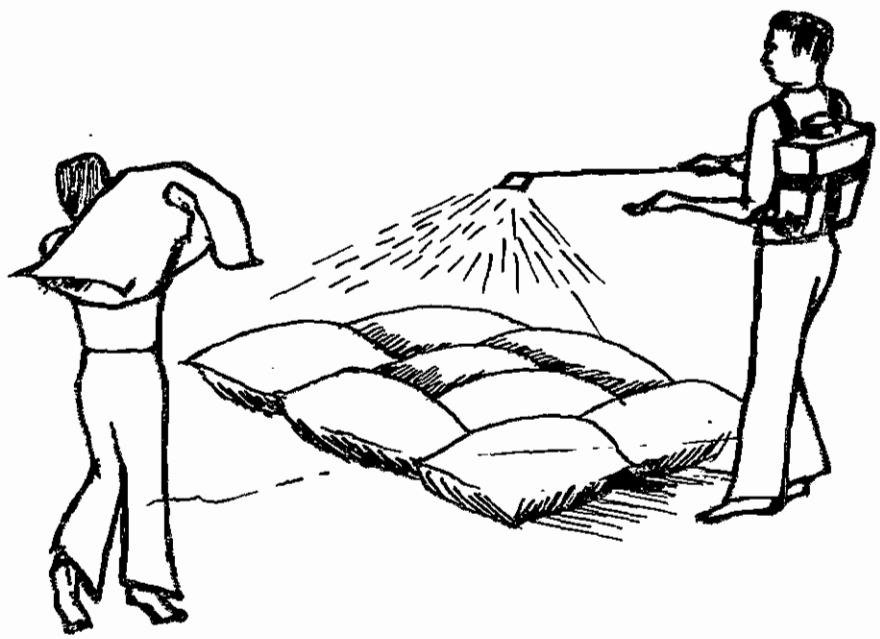


Figure 13.11 Spraying and dusting of sacks with insecticide.

Ultimately, the most satisfactory method of insect elimination and control in bagged grain is by fumigation involving the release of a fumigant (gas).

among the bags covered by a gas tight sheet as shown below held down by "sand snakes" or a heavy chain wrapped in hessian. The sheeted stack is left for at least three days.

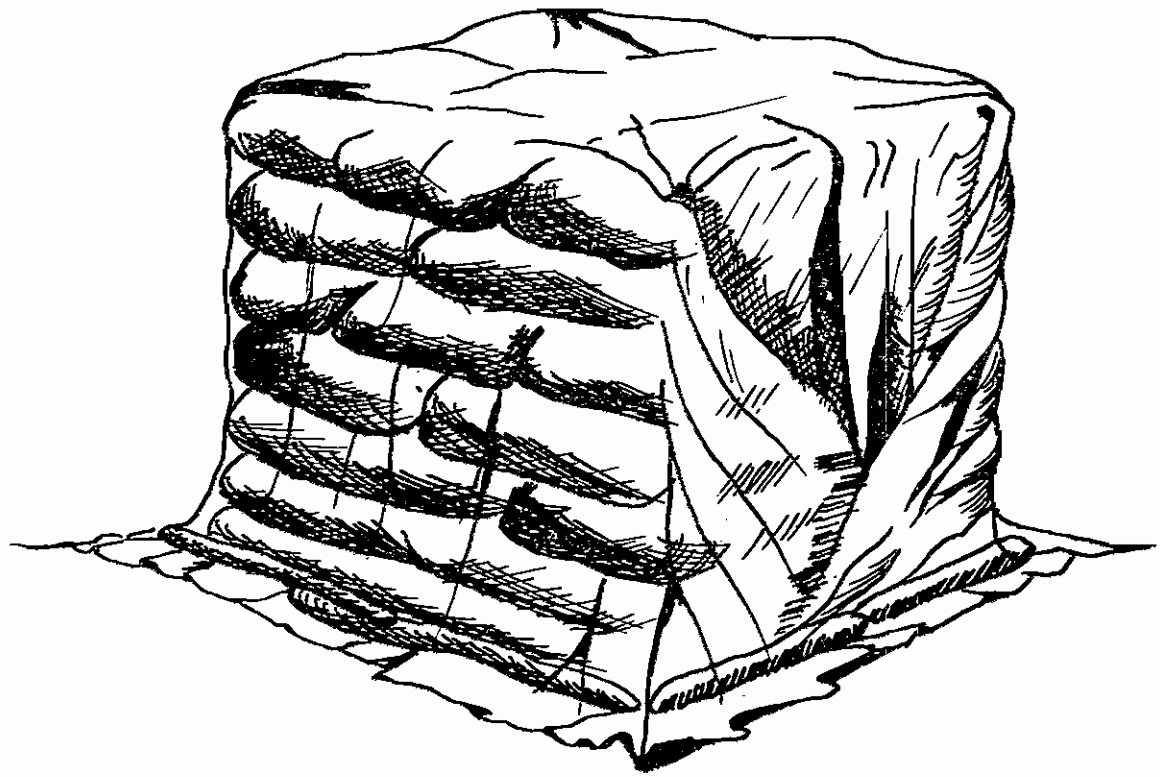


Figure 13.12: Fumigation of bags of grain.

For relatively small scale storage (100 - 300 tonnes) the most convenient fumigant to use is aluminum phosphide. It is recommended to use one tablet of the fumigant per 2 bags, provided the stack is of such a size that it will be completely covered within two hours.

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