

# MAIZE PRODUCTION MANUAL

VOLUME II CHAPTERS 10-15

Manual Series No. 8

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Foreward

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

Our sincere thanks go to the following scientists who contributed chapters to 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 hope that this manual will be of assistance to the many research workers and extension supervisors who come to IITA for further training in maize production in tropical Africa.

Wade H. Reeves  
Assistant Director  
Head of Training.

## CHAPTER 10

### SEED PRODUCTION, TESTING AND HANDLING

#### 10.1 SEED PRODUCTION TECHNIQUES:

The primary aim of an effective seed production programme is to supply adequate quantities of high quality seeds to farmers at the right time and place.

High-quality means that the seeds are: varietally pure, of high germination capability, are free from seed-borne diseases, physical impurities and noxious weeds and are packaged to protect their viability and purity. The advantages of such seeds is not only in terms of higher yields but also in terms of reduced production costs. If a farmer uses high quality seeds with good germination he can reliably utilize recommended seed rate with greater precision without the need for thinning. Consequently, he would require less planting materials and less man-days per hectare for reliable crop establishment than he would have required using seeds with poor germination.

##### 10.1.1 Goals of seed technology:

The major goal of seed technology is to increase agricultural production through the use of good quality seed of high yielding varieties. It aims at the following:

- (i) Development and determination of most suitable varieties
- (ii) Rapid multiplication
- (iii) Timely supply
- (iv) Assured high quality of seeds, and
- (v) Reasonable price

##### 10.1.2 The Seed industry:

The seed industry comprises of interlocking operations necessary to ensure

a regular dependable supply of high quality seeds to the farmers.

The functions performed by a seed industry can be set out as follows:

- (i) Plant breeding
- (ii) Variety testing evaluation
- (iii) Seed multiplication i.e. growing seed crops, processing, drying, cleaning dressing, storage, distribution and marketing.
- (iv) Quality control including: legislation, certification and testing
- (v) Quarantine
- (vi) Extension services.

Plant breeding, variety testing, quarantine and extension activities are special subjects and may not divert the attention of seed technologists in the strict sense. Nevertheless, they are essential parts of a seed industry, and practising seed technologists should have a general understanding of them.

#### 10.1.2 Variety development:

There is need for a continuous development of superior high-yielding varieties of high consumer acceptability.

#### 10.1.4 Variety evaluation:

Field trials are necessary in every ecological area and consumer evaluation have to be objectively carried out so as to take decisions as to which of the several promising varieties are worth further multiplication. A nation wide system of performance trials in which new, promising varieties are tested along side with established varieties and compared is necessary. This national system ~~needs~~ to be organised and controlled by an independent agency set up for the purpose by the government. Its judgements must be absolutely unbiased and transparently recognised as such. Before approving a new variety, the agency has to satisfy itself that it is indeed Distinct and not an old variety under a new name, and that it is Uniform and Stable.

#### 10.1.5 Multiplication:

Every year the breeder of a variety issues a small quantity of authentic seed, and this has to be multiplied over a number of generations to produce the quantity required for sale to farmers.

Seed multiplication chain: Seed is multiplied in stages until the desired quantity is obtained. Each stage is usually assigned a class for identification such as Breeder Seed, Foundation Seed and Certified Seed. In self-pollinated crops like Cowpea and Rice or in crops having a low multiplication ratio e.g. Tomatoes, it may be expedient to have two classes of Foundation Seed instead of one i.e. Foundation and Registered classes of seed.

Breeder Seed refers to the small, pure seed quantity directly produced by the originating plant breeder or institution.

The Foundation Seed is the progeny of breeder seed or registered seed. The genetic identity and purity of the variety is carefully maintained in foundation seed.

Certified seed is the progeny of foundation seed or registered seed. Its production is guaranteed by inspection and certification by an agency independent of the seed producing agencies.

Not all countries use exactly the same name to describe these stages (ISTA 1967 - 1971). The number of seed multiplication stages necessary is determined by the quantities of seed required.

Thus seed multiplication ratio refers to the extent of increase in seed quantity in one seed multiplication generation, e.g. if 20kg of planted seed results in a yield of 1000kg of processed seed the multiplication ratio is 1 : 50.

In the multiplication of seed of a particular variety it is necessary to know its:

- (i) reproduction behaviour
- (ii) types of variety i.e. composites, pure line, hybrid sets
- (iii) distinguishing characteristic, and
- (iv) agronomic characteristics.

#### 10.1.6 Maintenance of varieties:

In self-pollinating crops like cowpea, the maintenance of varietal purity is not a serious problem provided the right class of seed is used and mechanical admixtures do not occur. In cross-pollinating crops like maize, maintenance of varietal purity is more difficult. However, by adequate isolation, roguing, avoidance of volunteers and by using approved source of seed for planting, the danger of varietal contamination is reduced.

Seed multiplication is an operation which may involve a combination of official, commercial, cooperative and private agencies. Approved private farms under a certification scheme can produce certified seed for government at a premium price of say 15-25% above the current grain price. Supervision of these private farmers is the function of the seed quality agency independent of the seed production agencies.

Self-pollinating crop varieties: The following are the major requirements for the seed multiplication of a self-pollinated crop:

- (i) Procuring breeder seed of recommended variety
- (ii) Building up pure foundation seed
- (iii) Avoiding mechanical mixtures
- (iv) Roguing i.e. removal of off-type plants
- (v) Proper seed processing, handling and storage, and
- (vi) Back-up with a seed quality control programme.

Cross-pollinating crop varieties:

In handling seed crops like maize, the following additional precautions are required:

- (i) assuring adequate isolation from other fields (400 metres isolation required), and
- (ii) adapting a limited generation plan i.e. renewing breeder seed and foundation seed frequently.

10.1.7 Hybrid seed production:

The difference between hybrid seed production and that of open-pollinated varieties (synthetics or composites) is that fresh seeds must be used for subsequent production while seeds for open-pollinated varieties could be used without loss of vigour. Thus for hybrid maize production there must be a regular supply of hybrid seed; such seed could be in form of

Open-pollinated varieties:

Maize is a cross-pollinated crop, therefore the commercial varieties are populations of selected heterozygous plants distinct in the sense that the variety can be differentiated by one or more identifiable morphological, physiological or other characteristics from other varieties; uniform in distinctive characteristics to the extent that is observable and acceptable by farmers. The variety is stable in the sense that the distinctive varietal characteristics will remain unchanged to a reasonable degree when reproduced and/or seed is increased from one cycle to cycle in a limited generation plan. (Breeder Seed - Foundation Seed - Certified Seed).

Thus superior genetic factors can be extracted, as for example from a maize population, and put together as an Open-pollinated variety meeting the requirements mentioned above e.g. Composites and Synthetics.

Both synthetics and composites are maintained by open-pollination under proper isolation. These may not be as high yielding as hybrids which are always first generation crosses.

#### 10.1.8 Maintenance and seed increase of an open-pollinated variety:

After an open-pollinated variety has been developed, tested, recommended and accepted by farmers, a system has to be set up to provide a regular flow of the good quality seeds.

#### Breeder seed production of open-pollinated varieties:

The responsibility of maintaining breeder seed should be with the organization that developed the variety. Breeder seed can be maintained in several ways e.g. (1) mass increase of breeder seed on grid system, (2) mass increase of breeder seed through adopted male and female rows. Breeder seed increases through half-sib progeny recombination planting.

#### Basic or foundation seed production:

Basic seed increase is intended for the production of certified seed. About 5 - 7kg of the "Breeder Seed" are planted in 400-500m<sup>2</sup> field in isolation. Throughout the growing cycle of the plants, technical experts remove plants showing characteristics not typical of the variety. At harvest the ears are carefully examined and off-types are discarded. The selected ears are bulked, dried and shelled.

Requisite quantity of basic seed should be made available in order to finally cover the targeted average with certified seeds of the variety.

#### Certified and registered seed production:

The seed production of requisite quantity of certified seeds may have to be made through one or more stages of certified seed increase.

Isolation requirements, roguing of off-type plants and ears must be implemented. Progressive farmers can be contacted for certified seed production and/or National State farms can provide the necessary facilities. A National Seed Certification Unit should have the responsibility for quality control.

Time sequence and dimension for the seed multiplication programme :

Figure 10.1 summarizes the time sequence and the dimensions which are needed for seed multiplication of up to 5,000 tons of certified seed of open-pollinated varieties to be distributed to maize growers. If the final seed quantity is 500 tons or less, there may be only 3 stages necessary to achieve the seed quantity for the farmers.

Seasons	Stage	Seed	Area Needed
1st season	stage-1	100 - 200kg bulk <u>Breeder seed.</u>	1,000m <sup>2</sup> needed for each variety
2nd season	stage-2	1-6 tons <u>Basic seed.</u>	1-4 ha needed for each variety
3rd season	stage-3	Large scale <u>Registered seed Production (1)</u> of 40-500 tons.	Multiplication 16-200 ha needed for each variety.
4th season	stage-4	2nd Large scale <u>Cert. Seed Production</u> up to 500 tons of certified seed (2) for distribution to farmers.	Multiplication up to 1,500 ha needed for variety

Figure 10.1: Schematic presentation of a large seed multiplication program.

## 10.2 Hybrids

Phenomenon of heterosis has been fully exploited by maize breeders and several types of hybrid combinations depending upon the number and arrangements of the parental inbred lines are commercially cultivated. They include single, modified single, three way, modified three way and double cross hybrid.

### 10.2.1 Types of hybrids:

Single cross hybrid - A single cross between two (2) unrelated inbred lines (A x B).

Single cross is the most common type of commercial hybrids:

- single cross provides greatest opportunity for expression of hybrid vigor.
- usually have higher yields than other types of hybrids.
- also provide maximum uniformity for important seed characteristics - e.g. height, maturity date of harvesting.

The main disadvantage of a single cross for maize is that the inbred line used as the female parent usually produces lower seed yields than the types of females used for producing other hybrids.

### Other types of hybrids:

The primary purpose of three-way cross, hybrids, modified single cross, three-way cross, modified three-way cross and double-cross hybrids is to reduce seed cost by use of more productive non-inbred female parent in the seed field.

### Modified single cross hybrid $(A^1 \times A) \times B$

- Produced by crossing two closely related inbred lines ( $A^1 \times A$ ) and using the related single cross as female parent for hybridisation with an unrelated inbred line B.

Three-way cross hybrid (A x B) x C

- Produced by crossing two (2) unrelated inbred lines (A x B) and
- Using the single cross as female parent for hybridisation with an unrelated inbred C.

Double-cross hybrid (A x B) x (C x D)

- Involves crossing two (2) single cross hybrids in the seed field.
- All four inbreds of a double cross are considered unrelated.

Modified three-way cross hybrid (A x B) x (C<sup>1</sup> x C)

- Involves crossing two (2) single cross hybrids in the seed field.
- One of the single cross hybrid utilised is a single cross between two related inbred lines (C<sup>1</sup> x C); whereas all the four inbreds of a double-cross are unrelated.

10.2.2 Hybrid seed classes - their maintenance and increase:

Seed stocks: Seed stock increase involves the maintenance and increase of inbred lines and the parent seed stocks needed to produce several thousand hectares of commercial hybrid seed corn produced by seedsmen.

Inbred maintenance:

Inbreds must be maintained and increased under rigid control to ensure satisfactory final produce performance. Procedures employed vary but generally involve at least two (2) important steps. They are:

1. Maintaining breeder seed stock,
2. Increasing inbred maintenance seed (Inbred seed increase).

The inbred lines are maintained by continued selling of representative plants or by sib-mating between plants within the row after the plot has been carefully rogued for plant type.

Some breeders alternate selfing and sibbing in their seed increase programmes. Selfing aids in maintaining the inbred lines in a pure condition and sib-mating to prevent excessive loss of vigour.

For convenience, maintenance and inbred increase is done by planting in an isolated plot (at least 400 metres from other maize) and hand pollination of selected plants within the plot. The hand pollinated seed is saved for further inbred increase and the inbred seed crop is used for producing single crosses.

Parent stock increase:

Parent stocks are used to plant and produce commercial hybrids. Basic seed is increased at the farms of seed companies or with designated agencies under the supervision of trained seed specialists. Parent stock may consist of any of three or more basic pedigrees such as:-

- (i) inbred
- (ii) related line cross, and
- (iii) single cross

In the case of inbred parents, increases are made using inbred maintenance stocks and are produced in isolated increase blocks using random sib-mating.

Single cross multiplication involves crossing the inbred lines. The parental inbreds are planted in an isolated plot, in alternate blocks. All plants of the rows on which seed is produced are detasselled before they have shed any pollen. The parent that supplies the pollen is called the Male or Pollen parent, and the one that is detasselled is called the Female or seed parent.

The ratio of male to female rows will depend on the pollen producing capacity of the male inbred line. The advanced generation inbred lines usually lack vigour and also produce less pollen, therefore two rows of male parent to every four rows of female parent are planted. Many of the new hybrids use early generation inbred lines which produce profuse pollen. The ratio of 1:3 or 1:4 in the single cross multiplication is used.

In case of three-way or top crosses, the female parent which is a single cross and an inbred or variety which is the male parent, constitute the basic seed.

In case of double cross hybrids, the two parent single crosses are classified as Basic Seed.

#### 10.2.3 Commercial hybrid seed production:

In production of hybrid seeds, the female and male parents are planted in alternate blocks. The ratio of female to male rows is maintained at 6:2 or 8:2 depending on the pollen shedding nature of the male parent. Usually four border rows of male are planted on all sides to ensure full seed set on plants near the field borders. Before dibbling, the male rows are marked with distinctly painted wooden pegs. In many countries, the seed growers use male labour crossing over the specified rows during planting. Some seed farmers prefer to plant the female rows first and then plant the male rows.

#### Isolation requirements:

For inbred and foundation single cross multiplication, most countries have recommended 400 metres from any maize with same kernel colour and texture as that of seed parent and 600 metres from maize with kernel colour or texture different from that of seed parent. For hybrid or variety seed multiplication, an isolation distance of 200 metres is recommended.

Detasselling:

It is necessary that the rows designated as female in single or double cross hybrid seed production fields are detasselled to effect a cross mating of kernels grown on the female parent.

Methods of detasselling:

(i) Tassels may be removed by hand

(ii) Machines are also used for mechanical cutting of the tassel.

The detasselling crew should be trained in proper techniques and state of putting the tassel - i.e. to hold the plant with his left hand at the last inter-node, take a firm hold of the tassel with his right hand and remove the tassel at or near the anthesis with a steady upward pull and throw it on the ground.

(iii) Use of cytoplasmic - male sterility

In advanced countries, it is getting increasingly difficult and expensive to get temporary labour for detasselling work. Therefore, use of cytoplasmic male sterility is becoming popular with seed organisations.

The types of parents that must be increased as foundation seed depend on the system used to eliminate fertile pollen in the female parents. The cytoplasmic - genetic system of male or male sterility requires three lines to produce a single cross hybrid; the A-line (male sterile), R-line (male-fertile maintainer); and R-line (male fertile with restorer genes). Foundation seed production of the A-line resembles that of a hybrid, with the A-line being the female and the R-line the male. Low ratios of A line (female) to B line (male) often are used - e.g. 1 :1. Foundation seeds of the B and R lines are produced by open-pollination in isolated fields.

Three-way crosses produced with cytoplasmic-genetic male sterility involve maintenance and production of four lines, and A and R line of one inbred and male-fertile inbreds of the other two.

Double-crosses involve six lines, A and B lines of two inbred and male fertile inbreds of the other two.

(iv) Chemical induction of male sterility:

Chemical sprays applied to maize foliage of the seed parent 1-2 weeks before anthesis of a new biologically active chemical (DPX - 3378) have been reported to successfully prevent the release of pollen. There have been no adverse effects on the leaves or on grain development. Economic use of such chemical is a distinct future possibility.

In any method of detasselling, it is important that trained technicians should supervise the quality of detasselling..

Miscellaneous:

Other important steps that must be practiced to ensure maximum genetic purity and seed quality include:

- (i) procurement of pure source of the parent from the plant breeder.
- (ii) proper isolation and cropping land history.
- (iii) roguing off-types throughout growing cycle to eliminate individual plants and ears which exhibit phenotypes varying from established phenotypes.
- (iv) adequate agronomic and crop protection practices. Grow-out tests of sample seed lots are often planted during off-season to estimate genetic purity prior to use.

#### 10.2.4 Harvesting seed maize;

Timely harvesting of seed maize at full maturity gives better seed appearance, more vigorous seed maize, have greater resistance to mechanical injury during drying - processing and gives increased yield. Maize seed is harvested:

- (i) by hand
- (ii) use of mechanical corn pickers
- (iii) use of combine harvesters.

Use of combine harvesters although economically efficient has the disadvantage that it does not permit sorting for off-types, off-colour and diseased ears.

Harvesting is generally started when the seed moisture and the husk is dry enough for easy tear and mechanical injury would be minimal. Harvesting of improved varieties, composites, or synthetic seed fields is started from one corner. One or two peripheral rows may be discarded as border rows. In hybrid seed production plots, the seed parent rows and male rows are harvested separately. Generally, the male rows are harvested first, dried, shelled, stored or sold. The seed farmer and the field inspector of the seed certification agency examine the field for broken or lodged male parents and then give permission for the harvesting of seed parent rows.

#### 10.2.5 Seed processing;

The main objectives of seed processing is to improve the planting value, to preserve seed viability and to produce seeds of good appearance. It involves the removal of undesirable materials such as thrashes, inert matter, weed; seeds other than crop seeds, broken seeds, shrivelled and under-sized seeds to conform to prescribed seed quality standards.

The separation may be based on seed size shape, length, weight, surface texture and colour.

When all undesirable materials have been removed, treatment with fungicide and insecticide is often practised to prevent seed-borne diseases, minimise insect infestation and to protect the germinating seed in the soil from disease infection. Finally, the cleaned, graded, treated seed is packaged to facilitate carrying, storage, maintaining varietal and seed lot identity and of relevant size for the expected farmers hectarage. Thus, seed processing comprises of safe seed drying, seed cleaning, grading, seed dressing and packaging.

The following factors should be considered in planning and designing a seed processing plant.

- (i) Nearness to the producing farms and seed users.
- (ii) Size commensurate with size of operation
- (iii) Drying is required, seeds must reach the drier as quickly as possible.
- (iv) Kind of crops to be handled
- (v) Selection of suitable equipment
- (vi) Source of power and type of power for running machinery.
- (vii) Ready availability of labour - skilled and semi-skilled.
- (viii) Opportunities for future expansion, and
- (ix) Reasonable provisions for spare parts.

#### 10.2.6 Safe seed storage:

Good seed storage is essential to maintain and ensure maintenance of high viability until planting time. Preservation of seed viability in the humid tropics presents a challenging problem because of the combination of high temperature and high relative humidity

In addition, most storage problems are due to:

- (i) placing inadequately dried seeds in storage
- (ii) low quality seeds stored
- (iii) seeds carried for too long
- (iv) placing immatured seeds in storage
- (v) insect infested seeds allowed entry in the seed store
- (vi) damage to seed in field before harvest (post maturity field damages)
- (vii) poor handling of seeds during distribution
- (viii) keeping too long on farmers premises before planting, and
- (ix) poor management of seed stores.

Good seed storage implies keeping the seeds in:

- (i) well designed seed warehouse
- (ii) rodent proofing
- (iii) arrangement for adequate fumigation and pest control
- (iv) seed store equipped with wooden pallets and
- (v) keeping seed store dry, cool and clean.

How cool and how dry depends on the type of crop, for how long storage is intended and type of packaging materials envisaged. Various workers and agencies have proposed and expounded on the rule of thumb for safe storage of all seeds. The rule states that good seed storage is achieved when the percentage relative humidity in the storage environment and the storage temperatures in degrees fahrenheit add up to 100 e.g. 50% R.H. and 50 F; 60% R.H. and 40 F. Actually conditions too favourable may not be indispensable for most kinds of field seeds unless the storage period will be longer than one year. Seedmen should however, understand their total storage problems and be resourceful in applying basic principles under given socio-agro economic circumstances.

### 10.3 Seed testing:

The primary aim of seed testing is to obtain information with respect to the planting value of the seeds meant for planting. Seed testing involves the examination of a representative seed sample to estimate the percentage germination purity, physical purity, varietal purity, moisture content and presence of weed seed contents. Other tests such as seed health, examination cold test, tetrazolium tests, examination for the presence of insect and other vigour test may also be carried out.

The sample submitted must be representative of the entire seed lot. The critical essence to this representativeness cannot be over-emphasized. Basic methods and practices of seed testing are well defined in ISTA rules for seed testing developed and approved by the International Seed Testing Association. These guidelines include:

- (i) The sampling procedures to ensure maximum representation
- (ii) Number of seeds required for each type of test
- (iii) Standard for physical purity, and
- (iv) Standards for germination tests. It may be mentioned that pure live seed (PLS) is an index indicative of the real value of a seed lot if both purity and germination percentage are considered. It is computed by use of the formula

$$\frac{\% \text{ Germination} \times \% \text{ Purity}}{100}$$

For example when two seed lot 'A' has a 90% germination and 97% purity it has a (PLS) value of 87, whereas a seed lot with 90% germination and 90% purity has a (PLS) value of only 81. Thus, the PLS is one single value which considers both qualities and shows the striking differences.

Introduction to seed certification:

The purpose of seed certification is to maintain and make available to the public high quality seeds of superior crop varieties in such a way that they maintain their varietal identity and high planting values.

Seed certification involves an officially recognised body not directly involved in the production or sale of seeds, vouching for the qualities of the seed lots. Therefore, those using certified seeds have assurance that the seeds have met certain prescribed standards. The reputation of certified seed promotes the sale and demand for certified seeds.

10.4 Seed marketing:

A dependable seed production programme requires an effective seed marketing organisation that ensures adequate quantities of improved seeds are available to the farmers at the right time and place. Seed marketing is different from the marketing of other agricultural inputs because of the following:

- (i) Seed is a living input and may soon prove to be useless due to loss of viability.
- (ii) Seed cannot be produced at short notice nor can it be freely imported.
- (iii) Seed demand is highly specific by variety, time and quantity.
- (iv) Unsold stocks pose storage problems and may become obsolete.
- (v) Seed, especially cereal seeds and vegetatively propagated materials are heavy.
- (vi) Most users of seeds in developing countries are in rural, difficult to reach areas, and
- (vii) Seed requirements per consumer is usually low due to small hectarages cultivated.

The following should be included in a seed marketing programme:

- (i) Demand assessment
- (ii) Market intelligence
- (iii) Logistics of seed movement
- (iv) Inventory control
- (v) Proper pricing policy
- (vi) Sales and collection of sale proceeds
- (vii) Dealers developments, and
- (viii) Seed promotion and publicity.

Seed quality control;

In order to ensure that the seed sold to farmers is indeed of high quality, it is necessary to exercise some control over the seed industry. Control involves the monitoring of seed quality throughout the various stages of production, processing and marketing. The control must be objective, fair and free from influence by any commercial, personal or political interest. It is usually the function of a government agency or of some authority officially designated for the purpose.

Quarantine:

A minor (but essential) requirement is a quarantine service to watch over the imports of seed from other countries and guard against the introduction of exotic seed-borne diseases.

A judicious policy would aim at home production of all seed required for the major crops, but sometimes it may be vitally necessary to import some. Seed of minor crops might have to be imported, because suitable conditions do not exist at home. In general, plant quarantine services look after seeds coming from abroad. National seed certification services take care of seed quality grown within the country.

Extension work:

The extension services have important parts to play in obtaining the best possible utilisation of high-quality seeds. Especially in the early stages of development, the farmer needs to be persuaded of the advantages of improved seeds; assured of the high purity and germination standards of certified seed; be made to understand that seed deteriorates on his farm through contamination or otherwise and that it is necessary to buy new seeds from time to time. The campaign should be planned in consultation with seed technologists and agronomists.

General practices for multiplication of high quality seeds:

Multiplication of high quality seeds requires a number of agronomic and procedural practices in many ways distinct from that followed in grain production. These are as follows:

- (i) Use of varietally pure basic seed, from dependable source.
- (ii) Seed should be multiplied on clean land that did not grow another variety of that crop the proceeding year (to prevent volunteer plants).
- (iii) The field should be free of serious weed seeds common to the seed crop and free from seed which may get mixed up with crop seeds to pose problems of separation.
- (iv) The variety should have proper isolation of specified distance from other varieties of the same species.
- (v) Proper cultural practices, fertilizer application, insecticide and weed control have a great influence on both seed quality and seed quantity and economics of seed production (seed multiplication ratio).
- (vi) Thorough roguing at appropriate stages of crop growth.
- (vii) Harvesting must be done at the right maturity and moisture content.

- (viii) Drying, threshing and cleaning should be done timely and carefully to prevent damages and mechanical admixtures.
- (ix) Proven treatment of seeds with fungicides and insecticides should be practised.
- (x) Timely and proper testing of seeds.
- (xi) Proper bagging, sealing in containers relevant to expected crop hectarages, and
- (xii) Cool dry storage needs to be provided so that the viability does not deteriorate before the seed is planted.

Fulfilling projected seed requirements:

The basic requirement for making improved seeds available to most farmers requires:

- (i) Estimation of total quantity of seeds required.
- (ii) Establishment of specific goals (i.e. 20%, 40%, or 100% production of total seeds required.
- (iii) Determination of the capacity of a modest seed production unit.
- (iv) How many of such seed units are required to produce the required quantities of seeds.
- (v) Estimation of reasonable financial and personnel requirements for implementation of the decided programme.
- (vi) Establishment of the type of management agency to successfully implement the programme.
- (vii) Provision of required resources.
- (viii) Undertaking periodic review of the progress of decided course of action coupled with necessary amendments of the programme as required.
- (ix) Creating an effective network for seed distribution to farmers, and
- (x) Staff motivation for retentivity and increased productivity.

Training needs:

Training is an important part of every seed programme. Planners, senior executive staff, supervisors, technicians and artisans working at any level in a seed programme should be well trained to efficiently perform their job responsibilities and to keep them abreast with new innovations in their fields.

10.5. Seed certification:

10.5.1 What is seed certification:

Seed certification involves an officially recognised body not directly involved in the production or sales of seeds, vouching for the qualities of the seed lots being offered for sale. Seed certification does this by means of:

- (i) Development of a certifying agency
- (ii) Establishment of seed certification regulations and standards.
- (iii) Regulating on the source of planting materials.
- (iv) Carrying out field inspection:-
  - a) Source of breeder/foundation seed
  - b) Cropping history of land
  - c) Isolation distances
  - d) Quality of seed produced
  - e) Proper roguing of off-types
  - f) Determination of weed seeds, other cultivar content, diseased plant etc.
- (v) Providing timely testing of all certified seed samples
- (vi) Providing tags, labels and seals to be fixed to approved seed packages.
- (vii) Registration of dependable seed growers, and
- (viii) Grow-out tests.

Those using certified seed as such have assurance that the seeds have met certain prescribed standards. The reputation of certified seed promotes the sale and demand for certified seeds.

Important role of certified seed: In totality, certified seed assures:

- (i) High yield
- (ii) Genetic purity
- (iii) Physical purity
- (iv) Disease/insect resistance
- (v) Freedom from noxious weed seed.
- (vi) Freedom from seed borne diseases
- (vii) High germination
- (viii) Good crop quality
- (ix) Other attributes bred into the variety, and
- (x) Assurance to growers concerning above.

Phases in seed certification: The process of seed certification can be divided into the following four phases:

- (i) verification of seed source
- (ii) field inspections
- (iii) sampling and testing of processed seed
- (iv) tagging and sealing of seed containers.

Preparing to inspect: For efficient field inspection, the inspector should be equipped with the following::

- reliable transportation for mobility
- knowledge of seed field's location
- certification standards
- proforma for inspection reports and field maps
- measuring tape

- clip board for writing
- pencil, pen and stationery
- note book
- tally counter
- identifying characteristics of the variety
- description of common crop diseases
- weed identification sheet
- certification manual
- a letter of introduction
- polyethylene bags to hold plant/head specimens picked during inspection for diagnosis, consultations etc.
- an umbrella, rain boots and a water bottle
- a box to hold the supplies.

#### 10.2.2 Stages of field inspections:

##### Pre-flowering inspections serve to:

- know the seed field and to confirm if land requirement has been observed.
- verify if the planted seed was from an approved source
- verify if planting done as per instructions (in hybrid seed production verify planting ratio and marking of male rows).
- verify isolation distance and if inadequate, suggest remedy if possible.
- guide and assist seed grower on off-type plants, pollen shedders, shedding tassels, diseased plants, weed plants suggest their timely removal and establish frequency of roguing.
- review with seed grower the prescribed standards and their application pointing out timely action on the part of seed grower

Flowering inspection (i.e. when more than 5% plants flowering) serve to -

- review actions of pre-flowering stage
- check the effectiveness of roguing
- verify isolation distance for acceptance or rejection
- verify recommended agronomic practices have been followed
- caution the seed grower if crop is liable for rejection.

Post-flowering inspection serves to:

- verify effectiveness of roguing, isolation and general condition of the crop.
- confirm if roguing frequency was maintained.
- in a self pollinated crop facing rejection, explain to seed grower the permissibility of re-inspection and his special attention to save the seed field from rejection.

Pre-harvest inspection serves to:

- determine the possible occurrence of factors that were not apparent earlier.
- verify varietal purity
- instruct seed grower on roguing based on ear, seed or chaff characters such as colour, shape, size and maturity.
- guide seed grower on the correct method of harvesting, storing, drying and threshing.
- discuss arrangements for drying and processing
- estimate yield from the seed field.

Harvesting inspection serves to:

- verify if crop from any rejected area has been adequately separated

- verify if in hybrid seed production, the male rows have been removed from the field.

Note: 1. In vegetatively propagated crops the appropriate stages for inspections would be classified differently.

- 2. In vegetable crops, fruit or root inspection is specially important to determine varietal purity.

General requirements for effectiveness:

Certification requirements should be realistic, attainable and encourage use of certified seeds. Too high, a standard will either lead to no seeds or to cheating. Having laid down the requirements, they have to be adhered to equitably and with firmness. The first pre-requisite for appropriate certification agency is that it should be independent from the agency producing or selling the seed.

10.5.3 How to inspect:

Since examining all plants in a seed field is impracticable, a system of random sampling and counting is to be followed on a representative sample of the crop.

Some useful hints to inspectors:

- (i) Make necessary arrangements for your tour well in advance.
- (ii) Inspection of the seed fields means going through the fields and not on bounds round the fields.
- (iii) Put in the inspection report, what you see, but be sure you see what you report
- (iv) Certification records are confidential, inspectors are not to spread unfavourable information about one producer to another.
- (v) Be polite, be fair but firm.

In the inspection of Maize, Rice, Sorghum, Millet, Cowpeas etc. seed crops, the inspector will be concerned with the following items:

- (i) Varietal mixture
- (ii) Presence of seed-borne diseases
- (iii) Weed at the seed bearing stage
- (iv) Isolation, and
- (v) Plants of other crops in the fields being inspected.

The amount tolerated of the items listed above will vary from crop to crop. The inspector should always have a copy of the seed certification standards for the crop being inspected. The number of inspections needed and the time of inspection will be specified in the standards for the crop.

#### 10.5.4 Procedure for making detailed counts:

- (i) Upon entering the field take a normal step in a row or line, then count the number of stalks of grain in the step. Do this 3 to 4 times in order to get an average of the number of heads in one step. If the field population is uneven, count the number of stalks per step whenever moving into an area of lower or higher population
- (ii) Divide the number of stalks per step into 1000 in order to determine how many steps will need to be taken in order to count 1000 heads.
- (iii) Move over the field taking counts at random .
- (iv) As you take your counts, pull loose smut or other seed-borne disease heads with one hand and heads of varietal mixture with the other hand.
- (v) Number of counts to take:
  - a) If the percentage of mixture is easily under the limits allowed in the standard, take five counts for the first two hectares

and one additional count for each additional hectares or fraction thereof.

- b) If the percentage of mixture is above the limits fixed in the standard or very close to the limit, double or tripple the number of counts.

Miscellaneous points:

- (i) A small notebook may be carried during field inspection in which notes are made. This information can be transferred to the inspection report form at the conclusion of the inspection.
- (ii) The details of actual counts of mixture and disease should be recorded and averaged in the table provided on the form.
- (iii) Information about the preceeding crop can be obtained by asking the seed producer.
- (iv) Isolation may be recorded as satisfactory or not satisfactory other kinds of crops in the field should be recorded as an estimate of the number per acre or as the actual number found in the counts.
- (v) Weeds listed should only be those that will bear seed at the time of harvesting the crop.
- (vi) An estimated yield is important as a guide for checking on the amount of seed that should ultimately be tagged and sold as certified seed.
- (vii) The date of inspection and the inspectors' name are both important and must be added
- (viii) Hand over the field inspection report form at the completion.

10.6 Evaluation inspection reports:

To confirm whether the seed crop is certifiable, the results of the observations recorded during field inspections must be compared with the prescribed standards.

A seed crop with a contaminant within the isolation distance is not rejected if its growth stage is so different that contamination will not occur (time isolation). The seed crop is rejected in part or in full as may be necessary if the contaminant is in a stage capable of causing contamination, i.e. the flowering stage in cross pollinated crops or the pre-harvesting stage in self-pollinated crops when mechanical mixture is likely. If, however, isolation is found to be unsatisfactory at a stage when contamination cannot be caused, the producer should be advised to rectify the fault and the action subsequently verified.

When a seed crop is liable for rejection, a rejection note should be issued on the prescribed form and copies marked to:

- First copy - to producer
- Second copy - to headquarters of national Seed Service.
- Third copy - retained by the inspection unit.

A seed crop conforms to the prescribed standards when the average percentage of field counts for each factor is equal to or less than the maximum prescribed. When this percentage in the first set of counts happens to be more than the prescribed standard (but not more than twice the limit) then a second set of counts is taken for that factor and the results compared on the basis of example given below:

Crop - Sorghum hybrid seed production

Parent inspected: Female

Field Area - 2 ha.

Number of counts 5 (1000 heads per count) - factor: pollen shedders.

Second set of counts -

(5000 heads)

B (number of heads)

Total of two sets

A + B

(10,000 heads)

Percentage pollen shedders -

$$\frac{(A + B) \times 100}{10,000}$$

If this percentage exceeds the maximum prescribed in the standards, the crop should be rejected

#### 10.7 Seed certification inspector and his duties:

Seed certification inspectors constitute the technical base of the seed certification system. The implementation of minimum seed certification standards depends upon the attitude of the inspector towards his work and the manner in which he carries out his duties. The inspector is the person who can disseminate information and cause seed producers to recognize the benefits of complying with the standards.

The inspector is an important person helping in the production of good quality seed. He is the person who can educate seed growers in efficient methods of quality seed production and thus build up viable seed programmes. For this reason, the role of an inspector is not of mere "inspector" but the role of:

- a) True seed extension specialist
- b) Seed production technician
- c) Seed crop inspector, and
- d) Seed processing and seed storage specialist.

The main duties and obligations of the seed certification inspector are:

- (i) The seed certification inspector should have reasonably satisfactory knowledge of field and laboratory standards of all the crop for which his organisation has taken the responsibility of certification. This will help him to do his job correctly and more efficiently.
- (ii) The inspector should have pleasing manners, a high level of integrity, initiative and above all good judgement.
- (iii) Be a man or woman of vision and ambition, the vision of leading the seed growers of his or her area to handle the best seed and the ambition to carry out that vision.
- (iv) Be tactful, polite and discrete in dealing with people and firm when firmness is needed.
- (v) Be service-oriented and totally dedicated to the growth and development of seed programmes.
- (vi) Be able to at times make do with minimum facilities.
- (vii) Be willing to work for usually long hours in rain or sun especially during peak inspection season.
- (viii) Be a good diplomat at all times and should not spread unfavourable information about one grower to another.
- (ix) Be able to educate, persuade and convince seed growers of their responsibilities and on the use of recommended techniques.
- (x) Be able to command the respect of the seed grower. Reject his seed field if necessary, and sympathise with him while doing it.
- (xi) Organize periodic farm meetings, field days etc.

- (xii) Keep records up to date and confidential when necessary.
- (xiii) Conduct thorough field inspections so that the prescribed minimum standards for isolations, planting ratio, roguing and other requirements specified in the seed certification standards are met.
- (xiv) Assist the seed producer at the time of harvesting, drying and processing to ensure that these are done correctly. This is particularly true for new producers who are just gaining experience; it should not be necessary to supervise every step of the operation after the seedmen have had adequate experience in the programme.
- (xv) To operate in such a way as to ensure close working relationships between certified seed growers, research personnel, government officials and others with an interest in certified seed.
- (xvi) To investigate vigorously any violation of prescribed standards or complaint from users of certified seed and subsequently to take appropriate corrective action.
- (xvii) To issue appropriate seed certification tags for seed lots which pass inspection.
- (xviii) Maintain a season-wise, crop-wise and variety-wise list of seed fields under one's jurisdiction.
- (xix) Have good public relations and should, by this honesty and devotion to duty earn the good will and cooperation of the public in general and seed growers in particular.

10.8 Important terms in seed production:

- Backcross - (1) in breeding, a cross of a hybrid with one of its parents or with a genetically equivalent genotype;
- (2) in genetics, a cross of a hybrid with a homozygous recessive (see also testcross)
- B-Line - the fertile counterpart of the A-line. The B-line does not have fertility-restoring genes and is used as the male parent to maintain the A-line.
- Bulk-generation advance - harvesting of all the plants from a segregating generation and bulking the seed to constitute seed material for the next generation.
- Certified seed - the progeny of foundation, registered or certified seed, produced and handled so as to maintain satisfactory genetic identity and purity and approved and certified by an official certifying agency.
- Combining ability, general - the average or overall performance of a genetic strain in a series of crosses.
- Combining ability, specific - the performance of specific combinations of genetic strains in crosses in relation to the average performance of all combinations.
- Composite - a population at equilibrium developed from crossing two parents or inter-crossing more than two parents. Often open-pollinated cultivars are the parents.
- Detassel - removal of the immature tassel as practiced in the production of hybrid seed corn.
- Diallel crosses - all possible crosses, including reciprocals among a set of parents.
- F<sub>1</sub>, F<sub>2</sub>, etc. - symbols used to designate the first generation, the second generation, etc after a cross.
- foundation seed - seed stocks increased from breeder seed and so handled as to closely maintain the genetic identity and purity of a variety.

- Half-sib mating - mating between half brother and half sister. Such individuals have one parent in common.
- Heterosis (hybrid vigor) - (1) the increased vigor, growth, size, yield, or function of a hybrid progeny over the parents that results from crossing genetically unlike organisms;  
(2) the increase in vigor or growth of a hybrid progeny in relation to the average of the parents.
- Hybrid -  $F_1$  generation of a cross. Fresh crossed (hybrid) seed needs to be obtained for planting the crop each time when a hybrid is used for commercial planting.
- Male sterility - a condition in which pollen is absent or non-functional in flowering plants.
- Non-Current parent - that parent of a hybrid that is not again used as a parent in backcrossing.
- Pedigree - a record of ancestry of an individual, family, or strain.
- Pollination - transfer of pollen from the anther to a stigma of the same flower or another flower on the same plant, or within a clone.
- Pure line - a strain in which all members have descended by self-fertilization from a single homozygous individual. A pure line is genetically pure (homozygous).
- Reciprocal recurrent selection - a recurrent selection breeding system in which genetically different groups are maintained and in each selection cycle, individuals are mated from the different groups to test for combining ability
- Recurrent selection - a breeding system designed to increase the frequency of favourable genes for yield or other characteristics by repeated cycles of selection and crossing.
- Seed - a mature ovule with its normal coverings. A seed consists of the seed coat, embryo and in certain plants, an endosperm.

- Self-sterility - failure to complete fertilization and obtain seed after self-pollination.
- Sibs - progeny of the same parents derived from different gametes. Individuals that share common parents.
- Sibbing - intermating of the individuals of the same family.
- Synthetic - a population at equilibrium developed from inter-crossing a number of inbred lines of clones.
- Three-way cross - cross resulting from crossing a single cross with a third parent (inbred line, strain, or a cultivar).
- Topcross - a cross of selections, clones, lines, or inbreds to a common pollen parent. In maize, commonly an inbred-variety cross.
- Vegetative reproduction: - the formation of a new individual from a group of cells without the production of an embryo or seed.
- Xenia - the immediate effect of pollen on the character of the endosperm.

## CHAPTER 11

### INTRODUCTION TO PLANT DISEASES

#### 11.1 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.

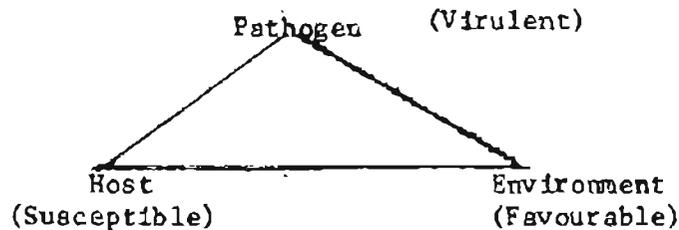
A disease is recognized by the external signs of the altered state of the affected plant or plant organ. This detectable response presented by the plant or its organ is called symptom. Symptoms are usually characteristic of the disease and the casual agent involved. Examples of plant disease symptoms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

##### 11.1.1 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 the 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:

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 plant by direct penetration of the cuticle, through natural openings or wounds. Resting bodies (chlamydo spores, sclerotis, co spores) 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 intracellularly, migrating through the plant. Bacteria survive in plant refuse, seeds, 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 more 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. Mycoplasmas differ from viruses in that they have 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 (f) witchweed (*Striga spp*) - root-invading parasites of maize, sorghum and other graminaceous crops. Its seeds live over 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 seed 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 or deficiency of air temperature, soil moisture, soil nutrients often cause symptoms that may be confused with those caused by fungi, bacteria, and viruses.

Host: Plants which harbour or support the activities of pathogens are called hosts or host-plants. The biotic pathogens for at least 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 specialised in their ability to attack these cultivars. The monoculture of these cultivars then causes a uniform population of hosts within which these strains can develop

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.

#### 11.1.2 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, penetration, infection (establishment), incubation, invasion, reproduction, 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 e.g. spores (fungi), seeds (parasitic higher plants) 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 a 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 pathogens 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 over-season in the systems of some insects and in seeds.

### 11.1.3 Classification of plant Diseases.

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-whip 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, lightning etc.
- (iv) Air pollutants (a result of say 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 (stalk) diseases e.g. stalk rots
- (iii) Leaf (foliage) diseases e.g. rusts, blight, streak etc.
- (iv) Floral diseases e.g. smuts of tassel and shoot.
- (v) Fruit (ear, cob) diseases e.g. cob rot
- (vi) Seed (kernel) diseases e.g. kernel rots.

III. Classification based on stage of plant growth affected:

- (i) Seedling diseases e.g. seedling blights, *Pyricularia* grey leaf spot of maize.
- (ii) Mature plant diseases e.g. many stalk rot diseases of maize
- (iii) Storage diseases e.g. kernel rots.

IV. Classification based on plant functions affected: Diseases affecting:

- (i) Absorption and accumulation of nutrients e.g. root rots
- (ii) Water conduction e.g. wilts
- (iii) Meristematic activity e.g. smuts
- (iv) Photosynthesis e.g. rusts, leaf spots and leaf blights, downy mildew, streak etc.
- (v) Translocation e.g. viral and mycoplasmal diseases
- (vi) Storage of food materials e.g. soft rots
- (vii) Break down and utilization of stored food materials e.g. seedling blights.

11.1.4 Role of plant diseases:

As enumerated above any function of the plant is subject to impairment by diseases. Thus, we have diseases that affect the absorption of water and nutrients, the interception of solar radiation for carbohydrate fixation and also those that deprive plants of the already fixed and stored-up food.

It is therefore obvious that the unaided farmer is at the mercy of losing his 'bread' to those pathogenic microorganisms which are blessed with high rate of prolificacy and great potentials to damage his crops.

The effect of a disease on the plant depends on the disease type, its causal agent most especially its degree of virulence, the host plant particularly its degree of susceptibility and the maturity stage at infection

and meteorological conditions. For many diseases, there is a negative correlation between the extent of economic disease loss and the maturity of the host plant. Thus, the amount of disease is less if the plant is about to mature when the disease sets in whereas total crop failure can occur if the crop should be affected early in the plant's life. For example, a maize crop affected by streak virus disease within the first four weeks of planting is likely to produce no grains - while infection by this same disease after tasseling will not reduce maize yield much.

The effect and therefore role of diseases on man is not usually just limited to the farmer concerned. By directly dwindling the total volume of crop yield, diseases tilt the balance of the interaction between supply and demand to that of high food prices. If a disease should reach an epiphytotic (epidemic) proportion, that is, severely affecting a large farm area in a geographical zone and season, losses may be in the magnitude of millions of Naira as was observed for *Helminthosporium* leaf blight (*H. maydis* race T) of maize in the United States of America in 1970. In fact, disease effects can be epoch-making as was the case for potato leaf blight (caused by *Phytophthora infestans*) disease outbreak which resulted in great famine and mass emigration of people from Ireland in the 1840's. And the outbreak of maize rust (*Puccinia polysora*) in West Africa in the early fifties led to the establishment of the West African Maize Rust Research Unit -- a Unit that laid the foundation for intensive maize improvement programme work not only in Nigeria but also in many West African countries.

#### 11.1.5 Identification of Plant diseases:

It is highly important that persons engaged in farming should be able to recognize the presence of diseases in plants. Crop producers should not only know how plants live and grow but should be familiar with those outward signs

or symptoms which exist when plants are sick.

Symptoms are the manifestations of physiological reactions of plants to the harmful activities of the causal agents (pathogens). For any disease in a given plant, there is a characteristic expression of symptoms usually occurring in a sequential series during the course of the disease. This series of symptoms is called the syndrome. The study of symptoms is the first step in making a diagnosis or the determination of the nature or identity of a disease.

Externally detectable symptoms may be exhibited by whole plants or by any organ of a plant. Such symptoms are termed morphological symptoms and are usually detected visually although some may be detected through the senses of smell, taste or touch. Symptoms that can be detected only by microscopic examination of diseased tissue are histological symptoms. Here, we shall be concerned only with morphological symptoms.

#### 11.1.6 Main types of morphological symptoms:

The various types of disease symptoms on maize (*Zea mays* L.) can be put into 5 classes namely:

- (i) Leaf spots, rusts and chlorosis
- (ii) Rots
- (iii) Wilts
- (iv) Hypoplasia
- (v) Abnormal growth forms

#### (i) Leaf spots, rusts and chlorosis:

Any change in the colouration of the leaf is easily noticed by most observers. Leaf spots or lesions can be distinguished by their size, shape and the pattern of their colouration. The colour of the lesions may be pale

yellow, grey, brown, tan or any other type. The exact size and pattern of colouration depends on the variety of the crop and the pathogen or even the strain or race of the pathogen. In fact, it is this specificity in the reaction between the strain of a pathogen and a strain or variety of a crop that forms the basis of our search for and the development of disease-resistant crop varieties.

While the spots incited by the *Helminthosporium* spp. are either rectangular, elliptical or boat-shaped, those incited by *Curvularia* spp. are more or less circular. Furthermore within a genus, the symptoms induced differ. For example, *H. maydis* incites somewhat rectangular and smaller lesions whereas *H. turcicum* induces large boat-shaped lesions; and of course there are some differences in the syndrome.

Rusts can be distinguished from other diseases spots by the presence of raised structures called pustules on the leaf, sheath or husks. These pustules are golden yellow to brown in colour. Pustules of rust incited by the fungus *Puccinia polysora* (the warmth-loving rust) are more numerous on the upper than on the lower leaf surface and are more roundish and lighter in colour than those incited by *P. sorghi* (cool climate rust) which have pustules present in equal quantity on both leaf surfaces. The 'powder' produced by rusts distinguishes them from the tiny yellow spots incited on the leaf by *Phyoderma maydis*.

Some pathogens do not incite definite spots; rather they induce a change from the normal green colour of the leaf. It may be that of a uniform chlorosis as caused by some downy mildew pathogens or some nutrient deficiency or excess like nitrogen deficiency or there can be a pattern of mottling such as the chlorotic stripes incited by some viruses like maize streak virus.

(ii) Rots:

Most of the organs of the maize plant are susceptible to rot caused by some pathogens. Thus, there are root rots, stem (stalk) rots, fruit (cob/ear) rots and seed (kernel/grain) rots. The different types of rots can be distinguished by their colour, their consistency and the type of agents causing the rot as revealed by the agent's frutification (fruiting). For example, there are wet stalk rots induced by some bacterial species or by some fungi of the genus *Pythium* and there are dry rots as caused by such fungi as *Diplodia*, *Fusarium*, *Macrophomina*, etc. The wet rots can also be detected by their bad odour. Dry rots can be distinguished by their colour which is usually that of the mass of the fruiting bodies of the causal agent. Such colour may be brown (*Diplodia* rot), pink to red (*Fusarium* or *Gibberella* rot), black (*Macrophomina* or charcoal rot) etc. These symptoms are more clearly observed by splitting the stalk into longitudinal halves. Furthermore, stalks suffering from rots succumb easily to gentle hand pressure.

Cob and kernel rots can be distinguished by their colour. Lack of seedling emergence or seedling wilt may be due to seed rot or root rot. The lower portion of such wilted seedling may be water-soaked and may eventually collapse, this is called damping-off.

(iii) Wilts:

The wilting of a plant is caused by the blocking of the flow of water and nutrients from the roots through the stem into the leaves. Thus, both root rot and stalk rot can cause wilting. The rate of wilting may help in the determination of the type of causal agent. For example, *Cephalosporium maydis* which also cause the stalk disease called black bundle induces the leaves of the maize plant to wilt at a moderately rapid rate beginning at tasseling.

Leaves turn dull-green and then dry, and vascular bundles in the stalk are discoloured.

Insect feeding such as the activities of the maize stem borers can also cause wilting. This insect-induced wilt can be distinguished from that caused by pathogens in that the upper portion of the plant may wilt leaving the lower portion apparently healthy. Such wilted upper portion can be pulled out with considerable ease. The tunnelling of the insect through the stem could also be observed.

(iv) Hypoplasia:

Hypoplasia is the failure of the plant or its organ to develop fully. Dwarfing of the plant may be caused by such viruses as the maize dwarf mosaic virus and the maize streak virus. Also, seedlings that manage to recover from diseases may produce under-sized mature plants; so also can nutritional deficiencies or excesses bring about under-sized plants. Diseases like downy mildews can produce spindly plants with narrow upright leaves. Dwarfing of the plants usually results in the production of below-average cobs. Diseases such as streak or downy mildews can produce barren plants; in fact, downy mildew may produce plants without shoot or even tassel. Also, unfavourable weather conditions like drought or high temperature may lead to the plant not producing any shoot or to the tassel shedding little or no pollen.

(v) Abnormal growth forms:

Smuts caused by the fungi *Ustilago* spp. convert plant parts into huge masses of the fungal body. Downy mildew can turn the shoot or tassel into leaf-like structures - a condition termed phylloidy. The phylloidy of the tassel is described as the 'crazy top symptom'. Herbicide or other

chemical (pesticide or fertilizer) can induce unusual plant forms. For example, the herbicide 2, 4-D induces 'buggy whip' which is the slight or complete fusion of the upper plant portion into a tube enclosing the upper leaves and tassel., but 'buggy whip' may be induced by other factors such as insect damage; it may even be a genetic trait of that plant.

#### 11.1.7 Towards diagnosis:

The most rewarding phase of ones training in diagnosis is the development of ones ability to observe accurately all symptoms and the growing conditions which might contribute to the problem in question and the ability to draw valid conclusions. This should, with practice, become automatic. Of course, skill will improve with years of experience and one is never too old to improve further.

In case of doubt, it may be necessary to send disease specimens to the specialist, that is, the pathologist who may even have to carry out intensive investigation into isolating the suspect - pathogen and going through the process of incriminating the suspect in disease causality. This process is known as the proof of pathogenicity. There are four rules for the experimental proof of pathogenicity of a micro-organism. Briefly these are:

- (i) the suspect causal organism must be constantly associated with the disease.
- (ii) it must be isolated and grown in pure culture.
- (iii) when a healthy host is inoculated with the suspect-pathogen from a pure culture, symptoms of the original disease must develop, and
- (iv) the same suspect-microorganism must be re-isolated from plants infected under experimental conditions and be identified as the first isolated from the diseased host.

In order to help the pathologist in reaching a quick and accurate diagnosis, your sample should:

- (i) contain as many stages of the disease as possible
- (ii) be protected from deterioration due to exposure to heat and drying
- (iii) be submitted as quickly as possible taking adequate care of possible communication handicaps, and
- (iv) be stored in the refrigerator or cold room if the sample arrives in the absence of the pathologist.

Also, the following information usually goes a long way in assisting the pathologist in rapid and accurate diagnosis: the description of the symptoms in your own words, cultural conditions like the fertilizer and pesticide used (name, rate, time and method of application), cropping history of the site of disease, nature of the soil (topography and soil type etc), unusual weather conditions, and other details that you consider helpful. You will, of course, request the pathologist to supply you with control measures.

#### 11.2 Basic concepts in plant disease control:

Plant disease control refers to the prevention of disease or the reduction in the incidence and/or severity of disease. In controlling plant diseases, plants are generally treated as populations rather than as individuals; sometimes, virus-infected plants are treated individually. With the exception of trees, however, damage or loss of one or a few plants is usually considered insignificant and control measures are generally aimed at saving the population rather than a few individual plants. Plant disease control involves the manipulation of the inter-action of the host and parasite in air and soil environments to the disadvantage of the parasite.

Precise diagnosis is essential to effective plant disease control so also is a thorough knowledge of the course of development of the disease. Basically, it is the disruption of the balance required by the disease triangle that can result in controlling of the particular disease. Plant disease control therefore involves the application of one or more of the following principles:

- (i) Exclusion of inoculum, that is, preventing the introduction of inoculum or the establishment of a pathogen within an uninvaded area.
- (ii) Avoidance - avoiding disease by planting at times when, or in areas where, inoculum is ineffective, rare, or absent.
- (iii) Eradication - reducing, inactivating, eliminating, or destroying inoculum at the source, either from a region or from an individual plant in which it is already established.
- (iv) Protection - preventing infection by interposing a toxic agent or other effective barrier between the host and the pathogen.
- (v) Altering the genetic constitution of the host that is, disease resistance - including all the techniques that contribute to altering the physiological process, structural nature, or habits of individual plants or plant population in order to make them resist or tolerate the infection.
- (vi) Therapy - reducing severity of disease in an already infected plant.

For practical disease control, the above-cited principles will be treated under four broad headings:

- (i) Cultural control;
- (ii) Chemical control;
- (iii) Host resistance; and
- (iv) Exclusion

### 11.2.1 Cultural measures:

Any adjustment in crop management that would minimise disease development represents a cultural disease control measure. This class of control methods includes measures directed at avoiding disease or suppressing the causal agent.

Most cultural practices aimed at disease control are preventive. They may reduce (a) the amount or activity of the inoculum as in crop rotation, green-manuring, deep ploughing, sanitation and roguing, or (b) they may be employed to avoid disease by choice of location, time of planting, seed preparation, plant-spacing, and nutrition. The various methods are presented schematically below:

#### A. Using Pathogen-free propagating material:

- (i) Produce seed crops in areas isolated from sources of infection and under situation not congenial to disease development e.g. raising seed in arid areas with the aid of irrigation.
- (ii) Use of isolation culture in maintaining uninfected planting stock e.g. virus-free meristems, cuttings free from fungus or bacterial pathogens, and vegetative rhizome buds of banana free nematodes, virus, fungus and bacterium.
- (iii) Disinfection by heat therapy. Hot-water treatments and especially stem-air mixtures, are particularly effective in attaining clean seed. Seed or vegetative propagating materials may be treated prior to planting to eliminate bacterial blight organisms in bean seed, *Fusarium* infections in corn, viruses in tree fruits, etc.
- (iv) Avoiding seed infection by early harvest. Delay in the harvest of a seed crop extends the periods of exposure of the seed to pathogens

that may build up locally or come in from outside the field e.g. invasion of pepper fruit by *Rhizoctonia solani* and that of mixture heads of grains by *Fusarium (Gibberella)*.

B. Adjusting crop culture to minimize disease:

- (i) Choice of planting site: The principal factors in selecting a geographic area in which to raise a crop are temperature and humidity. Many crops that are highly susceptible to certain fungal or bacterial diseases when grown in humid areas can be grown relatively free from disease under surface irrigation in more arid regions. In a local area, the choice of a suitable site for planting a crop can be important in avoiding fields infested with root-infecting organisms such as *Verticillium*, *Fusarium* and *Pratylenchus* spp. or containing crop residues that can serve as a source of local spread of air-borne foliar organisms.
- (ii) Choice of Planting date: Planting date may be selected to provide environmental conditions, principally temperature and moisture conditions, that are more favourable for growth and development of the host than that of the pathogen.
- (iii) Crop rotation: This is a time-tested practice that serves to maintain or improve soil fertility as well as reduce the chance of disease build-up. The object of an effective crop rotation as a disease-control measure is to reduce the incidence of a certain pathogen in the soil by growing crops immune from or resistant to its attack. Crop rotation may be effective against transient soil invaders, since they normally do not persist long in the soil, but may be much less effective against soil-inhabiting organisms that are capable of surviving in the soil for a period of several years

without access to a host.

- (iv) Balanced nutrient supply: Successful agricultural production implies optimum yields per unit area under existing conditions. Optimal nutrient supply depends on the specific crop and environment. Diseases vary in the way they are influenced by nutrient supply and soil reaction. Diseases that result from deficiencies of essential nutrients may be avoided by proper soil or foliage application whilst diseases induced by excesses may be avoided by soil leaching and/or balanced fertilization.
- (v) Effective water management: In some instances, water management can be utilized for plant disease control. Thus, Panama disease (*Fusarium oxysporum f. cubense*) of banana is controlled by flooding the plantation for several months. Conversely, adequate drainage will enhance the control of downy mildew of maize (*Sclerospora spp.*) as well as reducing the severity of root-rot diseases of maize, soybean, and tobacco.
- (vi) Manipulation of tillage practices: Tillage practices not only improve soil texture, but they may also be applied successfully as means of reducing losses due to diseases. For instance, deep ploughing is an effective way of controlling potato late blight (*Phytophthora infestans*). Frequent cultivation may also markedly reduce the quantity of inoculum present through the destruction of alternate weed-hosts.
- (vii) Avoidance of crop injury at or before harvest: Crops such as root and tubers and grains subjected to unfavourable harvesting procedures are bruised or cracked thus making them vulnerable to diseases in transit or storage.

C. Sanitation:

(i) Roguing infected plants: Systematic roguing of systemically infected plants may be used to control some diseases. To be effective, the roguing must be done as soon as diseased plants are spotted.

(ii) Destruction of crop residues: Infected crop residues not only provide for over-seasoning of inoculum but in some cases greatly increase the amount of inoculum each succeeding season. Burning may be employed to destroy the residues. Also, deep ploughing buries inoculum concentrated in the soil surface and replaces the top-soil with soil relatively free of pathogens.

11.2.2 Chemical control:

One of the most effective means of plant-disease control is by use of natural or synthetic chemicals. Chemical control is often the only feasible means of attacking a disease problem.

Chemicals may act either to reduce, remove or eliminate inoculum at the source (eradication); to prevent plant diseases (protection); or to cure them (therapy). The great majority of chemical control measures involve the principle of protection; this requires preventing inoculum from entering the host and starting an infection. To accomplish this, chemicals may be used to prevent growth or sporulation of micro-organisms, or to kill or inactivate the inoculum of the source, in transit, or at the court of infection.

Properties of a good toxicant:

- (i) Differentially toxic or inhibitory to organisms, that is, less toxic to the crop plant than it is to the organism it is designed to control.
- (ii) Lethal to pathogens at low concentration

(iii) Easy to prepare and apply

(iv) Inexpensive

(v) Adhesive and retain its lethal action for considerable period of time or preferably throughout the growing season.

Surface protection:

The greatest volume of chemicals for plant disease control is used as surface protectants. Surface protectants must be applied in advance of infection by a pathogen to be effective; and must be maintained by renewed applications during critical periods when infections by phytopathogens can occur or are likely to occur. Chemical protection is therefore an insurance against possibility of disease establishment.

(a) Leaf Protectants are fungicides such as sulphur, bordeaux mixture, ferbam, zineb, maneb, etc. which are applied as sprays or dusts to susceptible leaf surfaces to prevent common diseases such as leaf spots, rusts, powdery mildew and other foliar diseases.

(b) Flower and fruit protectants are generally the same chemicals as leaf protectants but greater care must be exercised in selecting chemicals for this purpose. This restraint is from the standpoint of possible effect of the toxicant on the consumer as well as for fruit appearance. Chemicals that give a heavy residual deposit are highly undesirable.

(c) Seed protectants are chemicals which have been specially formulated for specific use on seeds for the purpose of inactivating or inhibiting spores of surface-borne pathogens. They are also employed for protection of the seed after emergence against invasion by soil-borne pathogens. Seed treatment can be applied as wet treatment, dust or slurry.

Chemical soil treatment:

Soil-borne plant diseases have always been the most persistent and most difficult to control. Modern agricultural practices such as mono-crop system (monoculture) are vulnerable to high incidence of soil-borne pathogens. Chemicals have been used for the suppression of soil-borne disease of several major crops. They could be volatile chemicals applied as soil fumigants or as granular and wettable powder soil additives.

Chemotherapy:

Chemotherapy is the control of disease through the use of chemicals that exert their action within the plant. The principle may be used in attempts to protect plants from invasion by pathogens, or to treat established infections. Chemicals may act internally in plants in several ways by (i) inactivating toxins produced by the pathogen; (ii) a direct fungitoxic or fungistatic effect on the pathogen, (iii) combination of (i) and (ii).

Chemotherapeutic activity requires entry into the plant and subsequent distribution locally or systemically to the site of infection. Many types of chemicals can enter plants through leaves or roots. However, few chemicals have shown the required properties of translocation in effective concentration to the site of infection or to the area to be protected, persistence as a fungitoxic entity, low phytotoxicity and low mammalian toxicity.

Key points towards effective chemical control:

- (i) Choose the right type of chemicals
- (ii) Choose your rate based on the manufacturer's recommendation or better still on the recommendation of locally based scientists.
- (iii) Choose the appropriate method of application and equipment
- (iv) Calibrate your equipment correctly and spray in accordance with your

- (v) Do not spray or dust in windy weather.
- (vi) Follow all precautionary measures such as:
  - (a) wearing of protective utilities;
  - (b) keeping off smoking or taking refreshments while applying chemicals;
  - (c) exercising care in storage or disposal of chemicals to guarantee safety of human, livestock and wildlives (Do not empty remnant chemical into streams). Label the chemicals appropriately;
  - (d) thorough wash after application; and
  - (e) in case of harm, run water over affected parts then approach a doctor immediately, in case of internal poisoning ask for instant medical attention.

### 11.2.3 Host resistance:

The development of plant varieties that resist, tolerate, or escape the attack of pathogens has been one of the most significant and profitable approaches to the problem of reducing losses caused by plant diseases.

Use of disease resistant crop varieties is usually the most effective, simple and economic means of controlling plant diseases. This is because even the most economical of the other control methods adds to the cost of production and requires operations that millions of individual plant growers in many countries have difficulty in performing. The more man can develop crop plants to ward off diseases, the less work and worry he will have in controlling the diseases. The successful development and release to growers of disease-resistant crop varieties, although by no means inexpensive, has been one of

the major factors in increasing and maintaining high levels of crop productivity in the United States of America.

Without resistant varieties, it would no longer be profitable to grow some crops in certain areas. Many examples of success in developing varieties for resistance to specific diseases may be cited. These include rust- and smut-resistant varieties of cereals; *fusarium* wilt-resistant varieties of tomato, cabbage, cotton and watermelon; mosaic-resistant sugarcane; curly top-resistant sugar beets; yellow dwarf virus-resistant barley; bacterial wilt and black shank-resistant tobacco; bacterial wilt-resistant alfalfa; anthracnose-resistant sweet sorghum; mosaic resistant bean; and cyst nematode-resistant soybeans.

Basis of resistance:

Breeding for disease resistance seeks to exploit the genetic variability that exists within a crop species for reaction to infection by pathogens. The basis of resistance can be (a) mechanical, that is structural or morphological, which includes such characteristics as unusual thick cuticle, or cork layer, or other physical characteristics that makes it difficult for organisms to come into direct contact with or penetrate protective layers of the host, (b) Physiological - based on the presence of an inhibitory substance in the protoplasm of the host plant or on some form of metabolic incompatibility of host and pathogen, (c) functional, such as the closure of stomata when conditions are favourable for infection.

Stability of resistance:

There have been many cases of apparent loss of resistance to some diseases. This so-called breakdown of resistance has however been attributed to the appearance of new races of the pathogen in question. It is therefore

important that a resistant variety must be exposed to a broad spectrum of the pathogen strains/races before it is released to the growers. This is especially so for pathogens that are very prolific particularly those that have mechanisms for sexual reproduction.

#### 11.2.4 Quarantine and regulatory measures (Exclusion):

Plant quarantines have as their objective the local, state or international restriction of all commodities suspected of being carriers of plant pests. Its purpose is to prevent the dissemination of plant pathogens from areas where they are prevalent to areas where they do not occur. Such measures seek to exclude photopathogens, as well as insect pests and weeds that could potentially initiate or add to the threat of destructive epidemics.

Quarantine regulations vary widely in response to the nature of the disease in question and its economic host. They may be very broad and general, or quite specific, and can be generally classified as being either **exclusive** or regulatory.

##### Exclusive quarantines:

Are those which prohibit importation of plant materials into a stated area. They may be extremely broad in the sense that they prohibit the entry of all plant materials from a specified area; or they may specify the plant or plant parts and the areas from which importation is restricted.

##### Regulatory quarantines:

Regulatory quarantines establish conditions under which plant materials can be imported into protected areas. In some instances importation is permitted after inspection to make certain that the shipment is disease-free; other regulations require that specified plant materials be routinely fumigated before importation. In special cases, provision is made to ship propagative

stock to a control-quarantine station where it is grown under observation for a stated period of time before being released to growers. A general regulatory measure may provide that all plant materials not covered by special quarantine regulations may be admitted only upon presentation of an official phytosanitary certificate from the country of origin.

Controversy over quarantines:

There are strong arguments on both sides of the quarantine controversy. The three principal points which the antagonists of quarantine make are that they are not effective on a long range basis, they are not economical and they are frequently abused. The protagonists counter by stating that they are clearly of economic value; they are frequently completely effective and are usually effective to the extent of reducing crop losses; and that their abuse is not a criterion of their value.

It would be as unwise to eliminate all quarantines as it would be to apply them indiscriminately and without a proper basis. Ideally, they should be the product of mutual understanding among the agencies concerned; should be based on scientific evidence; and should offer higher probabilities for success in attaining the desired objective. Finally, quarantines should be dynamic rather than static and flexible enough to meet changing conditions.

11.3 Fungal leaf diseases of maize:

Most of the important diseases of maize are foliar. These diseases are prevalent on maize growing in the humid coastal and rain-forest areas of the tropics and are less troublesome in the drier areas of the interior. Coincidentally, the bulk of the maize produced in West Africa comes from this humid zone with high pathogen activities.

Frequently encountered fungal leaf diseases of maize are the rusts, *Helminthosporium* leaf blights, *Curvularia* leaf spots, *Physoderma* brown spot and downy mildews.

Maize rusts:

These are diseases characterized by the presence of roughly circular golden-yellow to brown raised structures called 'pustules' on the leaf or other green tissue. The presence of these pustules in a large number robs the plant of the much-needed green leaf tissue for photosynthesis and overall crop productivity. Severely infected leaves dry off. Two major types of maize rust are found on maize. The more prevalent form is that caused by the warmth-loving fungus *Puccinia polysora* Underw. It is favoured by high temperatures (about 27°C) and high relative humidity. It is the more important rust in Africa and in several countries in the Eastern Hemisphere. The *polysora* rust is also frequently encountered in the warm humid areas of Central and South America. Elevations above 1220 metres are unfavourable for disease development. The other type of maize rust is caused by *P. sorghi* Schw. It is found on maize growing in the cool climate like that found in the highland areas of East Africa and the Cameroons. Also, a low incidence of this rust can be found during the sparingly-occurring cool periods in some lowland maize-growing areas of coastal West Africa. The pustules incited by *P. sorghi* are more elongated and darker than those caused by *P. polysora*. The *sorghi* rust is found in the cool humid climate of the maize-growing regions of the world's subtropics, temperate zones and on highlands of the tropics. Cool temperatures (16 to 23°C) and high relative humidity favour disease development and spread.

Economic importance:

When rust infection is severe, chlorosis and death of the leaf blade and leaf sheath may occur; this leads to appreciable grain yield reduction. Yield reduction of 50 percent or more have been reported in many west African countries. Complete crop failure may result when disease sets in early in the development of the crop. In the late forties and early fifties, the *polysora* rust occurred in epiphytotic proportions in West Africa, and the Madagascar. This epiphytotic led to the establishment in 1952 of the West African Maize Rust Research Unit (WAMRRU) at Moor Plantation, Ibadan, Nigeria. This Unit constituted the springboard for the establishment of Maize Research Centres in many West African countries. Thus, the disease was the major stimulus for maize improvement in West Africa.

Disease cycle:

*P. sorghi* is a macrocyclic rust which usually goes through the complete life cycle of aeciospores - urediospores - teliospores - basidiospores and it makes use of a shrub *Oxalis* sp. as its alternate host. On the other hand, *P. polysora* is a microcyclic rust. It does not produce aeciospores. Teliospores of *P. polysora* are rare and are not known to germinate. They therefore appear to be unimportant in the disease cycle. Urediospores constitute both primary and secondary inoculum and are carried by wind, rain or on infected husk leaves of the harvested green cob. No alternate host for *P. polysora* has been found but alternative hosts include the following grass weeds: *Erianthus divaricatus*, *E. alopecuroides*, *Euchlaena mexicana* and *Tripsacum* spp.

Control:

Although fungicidal control is possible (e.g. Dithane S-31 protects against *P. polysora* infection), the most feasible control measure is by growing resistant varieties. But the occurrence of a particular rust species as different strains or physiological races makes the exercise of the development of rust-resistant maize variety a continuous one since a resistant variety effective against some races of the pathogen may 'breakdown' i.e. be ineffective against certain other races of the same pathogen. This is most especially true for the qualitative type of resistance characterized by chlorotic flecks. This is called hypersensitive or vertical or race-specific resistance. But resistance characterized by low pustule density i.e. quantitative resistance is more stable across all the different races of the pathogen than hypersensitive resistance. Quantitative resistance is also called horizontal or non race-specific or general or field resistance.

Comparison between <i>Polysora</i> and <i>Sorghum</i> rusts	
POLYSORA RUST	SORGHI RUST
<u>Occurrence:</u> Warm humid climate	Cool humid climate
<u>Causal agent:</u> <i>Puccinia polysora</i> Underw.	<i>P. sorghi</i> Schw
<u>Life cycle:</u> (1) Incomplete life cycle i.e. microcyclic. Only urediospores (in uredia or uredinia) and teliospores (in telis) are produced. (2) No alternate host (3) Uredinia (i.e. uredial pustules) are smaller, circular (4) Uredinia are more on the upper leaf surface and the leaf epidermis remains intact over the pustules for a longer period	(1) Complete life cycle i.e. macrocyclic. Aeciospores → Urediospores → Teliospores → Basidiospores  (2) Alternate host is barberry ( <i>Oxalis</i> sp) (3) Uredinia are oval to elongate and brownish yellow. (4) Uredinia are equally many on both leaf surfaces and the pustules break through the epidermis early
<u>Disease cycle:</u> (1) Urediospores constitute the primary and secondary inoculum; they are carried to maize principally by wind.	Although the urediospore is the chief means of secondary infection on maize fields, the other spore forms are important.
Teliospores are rare and they are not known to germinate and so apparently unimportant in disease cycle	Teliospores form basidia → basidiospores infect <i>Oxalis</i> leaves → Spermagonia (pycnial and aecial stages). <i>Spermatia</i> + receptive hyphae → aeciospores which infect maize leaves → unurediospores → teliospores.

### 11.3.1 Maize leaf blights:

Maize leaf blight is a disease characterized by the appearance of spots on the leaves. Sometimes these spots (technically called lesions) could be many and could coalesce enough to make the leaves appear 'burnt' hence the name "blight". There are two common kinds of leaf blights namely:

1. Southern leaf blight.
2. Northern leaf blight

Both are caused by the *Helminthosporium* group of fungi.

Southern leaf blight:

This occurs in warm humid areas and is the more common maize leaf blight in Nigeria (20-32C). It is caused by the fungus *Helminthosporium maydis* Nisik and Miyake (*Cochliobolus heterostrophus* Drechs). This pathogen has also been called *Drechslera maydis* and lately *Bipolaris maydis*. The lesions are tan and roughly rectangular with the longer side being parallel to the leaf axis and of a size range of 1.9 - 2.7cm long and 0.6 - 1.2cm wide. The spots appear first on the lower leaves and the disease progresses upward until in severe cases nearly all the leaves of the plant are heavily infected.

There are two races of this fungus distinguishable on the basis of the incited symptoms and other characters particularly cytoplasmic specificity. Race 0 is the old common race and it is not specific on any type of cytoplasm and is principally a foliage pathogen. On the other hand, Race T occurs on plants having the Texas (T) type of cytoplasm (T-cms) that conditions male sterility on the plant. On such maize varieties, it infects not only the leaf blades but also the sheath, husks, shank and cob. The lesions incited by Race T are also larger and less rectangular but more spindle-shaped or elliptical than those incited by Race 0. The tan lesions incited by Race T usually have dark, reddish brown borders and may occur not only on the leaf blade (lamina) but also on leaf sheaths, ear husks, shanks, ear and cobs. Race 0 usually attacks only leaves. Race T is not virulent on maize with normal cytoplasm, that is, carrying no sterility factors.

Northern leaf blight: - occurs in the humid cool climate as found in the subtropics or on the highland areas of the tropics such as occur in the Camerouns and East Africa and the Plateau State of Nigeria. The disease is characterized by large (generally 5 - 10 cm long and 1.3cm wide) boat-shaped, greyish-green

lesions on the leaves of susceptible plants. They later become tan. Temperatures of 18 to 27°C favour disease development. This disease is caused by the fungus *H. turcicum* (*Trichometasphaeria turcica* Luttcell).

As with Southern leaf blight, the spots appear first on the lower leaves and the disease progresses upwards.

Economic importance: (1) The lesions may become so numerous as to involve nearly all the leaf blade leading to premature plant death and sometimes total crop failure. The yield reduction is not severe if the disease appears late in the season. (2) Seedlings from infected kernels (Race T) may wilt and die within 3-4 days after planting. (3) Ear rot can occur. (4) Early shank invasion can cause premature death of ear and possibly ear drop. (5) Plants infected with leaf blight are usually predisposed to more stalk rot infection.

Disease cycle:

The fungus overseasons as mycelium and spores (conidia) on infected leaves of previous season crop and on kernels in storage houses. Disease spread is by means of conidia and under ideal weather conditions disease cycle is completed in about 60-72 hours (Race T). Conidia of both *H. maydis* and *H. turcicum* play the principal role in disease development and can also be transformed into chlamydo-spores (resting spores).

Control:

The disease has been successfully controlled by fungicidal sprays like Zineb, Maneb, and Cuman. But effective control requires repeated spraying from silking to maturity and therefore it is not economically feasible. Seed treatment and rotations are not effective as control measures. The disease is most effectively controlled by planting resistant varieties. This is achieved through

either an absolute inability of the pathogen to enter or survive in such varieties or through a major reduction in the reproductive rate of that pathogen. The result is an overall cut in the amount of disease available. Expression of resistance to *Helminthosporium* leaf blights may be qualitative or quantitative. In qualitative resistance, lesions are different in form from those incited on susceptible variety e.g. the chlorotic lesion resistance to *H. maydis* identified by the National Cereals Research Institute, Ibadan, Nigeria. On such maize, the lesions are small, chlorotic and having instead of lesions that are large, brown and dead found in susceptible varieties. While the plant is living, the fungus produces almost no spores on such lesions. Leaves of such varieties are green beyond the grain-filling stage of the crop. In the case of quantitative resistance, although the lesions are similar to those found on susceptible varieties they are fewer in number compared to those formed on an equal area of the leaf of a susceptible variety e.g. many of the newly developed varieties.

#### 11.3.2 Curvularia leaf spot.

*Curvularia* leaf spot is another disease of maize affecting primarily the leaf. The disease is found throughout the tropics and like rusts and blights, *Curvularia* leaf spot thrives best under hot humid environment.

The disease is caused by the fungus *Curvularia pallescens* Boed or *C. lunata*. The spots are usually small and circular (1-6mm in diameter) with grey centre and a brown border beyond which there is often a chlorotic background. On very susceptible varieties the disease is found also on the sheath and husks.

Economic importance: The disease has been found to be capable of reducing

grain yield by as much as 33 percent.

Disease cycle:

*Cornularia* leaf spot is perenated by conidia that survive on maize debris. The conidia are also very effective in the secondary spread of the disease during the growing season.

Control: Can be effected by spraying such fungicides as Miltox and Coprantol but the frequency of application is too high to produce economic returns. The most feasible means of control is by planting resistant varieties.

11.3.3. Brown spot:

Brown spot is common in humid hot climate especially when maize is repeatedly planted after maize on a particular plot. It is caused by the fungus *Physotherma maydis* Miyake.

The first signs of the disease are tiny yellowish spots (0.1 - 1.5mm in diameter) on the leaves; these spots eventually turn brown (the early stage of the disease can be confused for rust but the brownish yellow powder produced in rust is typical). On the leaf sheath, mid-rib and stalk, the spots are chocolate brown. High disease severity may lead to leaf and stalk breakage particularly in a windy environment.

Control: A well-planned crop rotation should reduce the incidence of the disease. Plant disease resistant materials where available.

11.3.4 Downy mildew:

Downy mildews constitute perhaps the most serious diseases of maize wherever they occur. These diseases caused by fungi of the genera *Peronosclerospora* and *Sclerophthora* are very important in several countries in Asia and have been found in two African countries namely Zaire and Nigeria. Downy mildew is

favoured by very humid environment thus it is severe where soils are water-logged.

Symptoms:

Infected plants show some form of chlorosis which could be uniform or striped depending on the particular pathogen involved. Systemically-infected plants are stunted, spindly and brittle with their leaves erect, narrow and chlorotic. Infected plants may display a leafy proliferation of the tassels; such leafy masses constitute the so-called "crazy top" symptom. On plants infected later in the season, that is aerial infection, the ear shoots tend to be numerous (false prolificacy), elongated, developing many leafy appendages and usually barren.

After a humid spell such as occurs early in the morning, a white fungal growth called 'down' is found on the leaves of infected plants particularly the lower leaf surface.

Types:

Some downy mildews known to infect maize are the sorghum downy mildew caused by *Peronosclerospora sorghi* Java downy mildew (*P. maydis*), Philippine downy mildew (*P. philippinensis*), sugarcane downy mildew (*P. Sacchari*), Graminicola downy mildew or green ear disease (*P. graminicola*), crazy top or yellow wilt of rice (*Sclerophthora macrospora*) and brown stripe downy mildew (*Sclerophthora rayssiae var zea*)

Control:

In areas where downy mildew is known to occur, avoid planting in poorly drained soils. Also, late planting should be avoided. Chemical control by foliar sprays is not advisable because it requires uneconomically frequent applications especially in areas with high and frequent rainfall. Recently,

a chemical called Ridomil or Apron SD has been developed by Ciba Geigy which gives very satisfactory control when used as a seed dressing at the rate of 2g/kg of seed. Roguing and burning of infected plants is another control measure.

The most feasible control measure is the development and cultivation of disease resistant maize varieties. Such varieties are now available at IITA. Strict plant quarantine regulations should be enforced to prevent introduction of downy mildews and other diseases into free areas.

#### 11.4 Maize viral , virus-like and bacterial disease.

##### 11.4.1 Maize streak virus diseases;

Maize streak virus disease was first recorded in South Africa in 1901. It is now widely distributed in Africa and Mauritius where it causes serious crop losses. Maize streak is most commonly observed on off-season crops such as maize planted late in the main seasons, on second season maize particularly if planting is delayed and on irrigated crop. The disease is spread by several species of leafhoppers that belong to the genus *Cicadulina*. No other method of spread is known.

##### Symptoms:

Leaves of infected plants show broken to almost continuous longitudinal chlorotic lines along the veins and distributed uniformly over the leaf surface. The primary veins are less affected than the secondary and tertiary veins, so that there tend to be pronounced groups of 5-7 parallel strokes on the leaves. The chlorotic streaks are caused through failure of the chloroplasts to develop in tissues surrounding the vascular bundles.

Only new growth develops these symptoms and there are normally green leaves at the base of the diseased plants. This feature allows the stage of the

plant at time of infection to be estimated. Plants infected at an early stage of growth become stunted and produce poor cobs. Photosynthesis is reduced, respiration is increased, and there is a reduction in leaf length and height of plants. Plants infected less than a week after germination produce no yield, at 3 weeks about half yield, and at 8 weeks nearly full yield of maize.

Maize streak disease virus:

(a) Nature of the virus: Maize streak virus contains single-stranded, predominantly circular DNA of  $0.71 \times 10^6$  daltons with a cryptogram of D1: 0.71/★; S/S:S/A. Four strains of the virus have been described taken namely from maize, sugar cane, guinea grass, and millet. Although these are morphologically identical, they are serologically distinguishable and show considerable host adaptation.

(b) Transmission of the virus: The leafhopper could become infective by feeding for as short a period as 15 seconds in the mesophyll of a chlorotic area of diseased plant. The transfer of the disease to a healthy plant is achieved by feeding for at least 5 minutes. In general, for field screening, feeding of viruliferous leafhoppers on healthy plants for 24 hours is recommended to achieve good infestation. The first sign of the disease is the appearance of pale, circular spots 0.5 - 2.0mm in diameter on the lowest exposed portions of the youngest leaves of the maize plants. As the leaves grow, the number of spots increase and some elongate.

(c) Hosts of the virus: Streak symptoms have been seen on wheat, oats, barley, rye, finger millet (*Eleusine coracana*), pearl millet (*Pennisetum typhoides*), sorghum, sugarcane, Napier fodder (*P. purpureum*); wild grasses such as *Sporobolus*, *Eleusine*, *Paspalum* and *Brachiaria*. But as there are

various strains of the virus with considerable host adaptation, it is not possible to distinguish the hosts of the forms virulent to maize by the symptoms apparent on the grass hosts.

Vector of maize streak virus:

(a) Description: *Cicadulina* species are generally easily recognised by their delicate appearances and by a pair of round black spots on the anterior margin of the crown of the head. The insects range in length from 2 to 4mm, and they are most readily seen as they sit head up in the shelter of the funnel of leaves of young maize plants.

(b) Distribution: The known distribution of *Cicadulina* species throughout the world is given below:

<u>Identity:</u>	<u>Distribution</u>
<i>C. arachidis</i> China	Gambia, India
<i>C. bipunctata bimaculata</i> (Evans)	Australia (NSW and E. Queensland)
<i>C. bipunctata bipunctata</i> (Melichar)	Kenya, Egypt, Yemen, India, Saudi Arabia.
<i>C. bipunctata bipunctella</i> (Matsumura)	Algeria, Egypt, Tripolitania, Israel, Iraq, Turkey, India.
<i>C. punctata</i> (Melichar) ssp	Pacific Islands, Philippines, Taiwan, W. Malaysia, N. Australia,
<i>C. chinai</i> Ghauri	Kenya, Egypt, India.
<i>C. fijiensis</i> Linnavuori	Fiji
<i>C. funeralis</i> (Distent)	Seychelles
<i>C. latens</i> Fennah	Kenya, Nigeria
<i>C. mbila</i> (Naude)	Kenya, Nigeria, S. Africa, Rhodesia, Tanzania, Zaire, Mauritius, Cape Verde Islands, Yemen, India, Tadzhik S.S.R., Togo, Benin.
<i>C. niger</i> Ghauri	Kenya, S. Africa, Tanzania
<i>C. parazeae</i> Ghauri	Rhodesia

<i>C. pastusae</i>	Ruppel & Delong	Columbia, Ecuador
<i>C. similis</i>	China	Gambia, Rhodesia
<i>C. storeyi</i>	China	Rhodesia, Tanzania
<i>C. tortilla</i>	Caldwell	Columbia, Peru
<i>C. triangula</i>	Ruppel	Nigeria, Rhodesia, Egypt.
<i>C. vesicula</i>	Ruppel	Sudan, Benin, Upper Volta, Rhodesia, Zaire.

Although only six species have been shown experimentally to be vectors namely *C. mbila*, *C. storeyi*, *C. bipunctata bipunctata* (*C. zaeae*), *C. latens*, *C. parazeae*, and *Cicadulina* species indeterminate, most *Cicadulina* species are probably capable of transmitting maize streak disease. Other diseases transmitted by *Cicadulina* spp. are maize mottle in East and West Africa, wallaby ear disease in Australia, enanismo disease in South America, and eastern wheat striate disease in India.

(c) Hosts of *Cicadulina* spp: *Cicadulina* spp may settle on crops on which they will not breed, and this may happen particularly during periods of peak dispersal flights. Consequently some caution has to be used in the interpretation of host records, particularly on hosts other than Graminae. Adults and nymphs of *Cicadulina* have been sampled on the following natural grassland species: *Hyparrhenia*, *filipendula*, *Sporobolus festivus*, *S. pyramidalis*, *Setaria anceps*, *Eragrostis patentipilosa*, *Brachiaria brizantha*, *Heteropogon contortus*, *Stereochlaena cameronii* and *Rhynchelytrum repens*. These grassland species are extensive in nature and are an important source of *Cicadulina* during the dry season in parts of Africa. Perennial grasses cultivated as pastures, especially if irrigated, often support breeding populations of *Cicadulina*. These include *Pennisetum clandestinum* (Kikuyu grass), *Chloris gayana* (Katamboura grass),

*Cynodon plectostachyus* (star grass), *Panicum coloratum* (Makarikari grass), *P. purpureum* (napier fodder), and *Paspalum urvillei* (vasey grass).

(d) Life cycle and dispersal: Life cycles of the various species of *Cicadulina* studied reveal that the insects go through 5-9 generations in a year with 5 being for the cool environment such as in highlands and 9 for the hot climate. During the cool seasons nymphal development is slow, and adults lay few eggs. The sizes of the populations are mainly determined by the numbers of host grasses suitable for oviposition and development of nymphs. The suitability of vast areas of natural grasslands depends on rainfall patterns, and consequently the populations are small at the end of the dry season and largest at the end of the seasonal rains.

Population cycles follow a distinct pattern. Young annual grasses and cereals are colonized by predominantly female populations, and eggs are deposited singly in slits made near the leaf veins. As the grass hosts mature, the numbers of gravid females present fall and fewer eggs are laid. Eventually only nymphs and equal number of newly developed male and female adults are present. These adults disperse from the grasses which by then are unsuitable for oviposition and are not attractive to migrant populations.

Adults of some *Cicadulina* spp such as *C. mbila*, *C. storeyi* and *C. parazeae* are capable of flying long distances. Their main flight period occurs at the end of the wet season when populations in natural grasses are at their highest. Females fly higher than males. *C. mbila* flies higher than *C. storeyi*, and most dispersing females contain immature ova. Natural grassland are by far the major source of *Cicadulina*, which disperse long distances during the flight season. Reports are available that reveal a positive correlation between the amount of rain at the end of each wet season and the number of *Cicadulina* caught in suction traps the following season.

Epidemiology:

Maize streak disease may increase linearly (simple interest form) or exponentially (compound interest form). During the flight season, particularly at its tail end, maize streak disease often increases in a simple interest way. There is a linear arithmetic progression of the disease that corresponds with the period or periods during which *Cicadulina* immigrants are settling on plants. The hoppers do not stay long and there is little if any spread of the disease from one plant to another. Exponential or compound interest increase in disease occurs when the rate of invasion by *Cicadulina* is high, and uninfected vectors stay long enough to become infected by streak plants. At this density roughly about one leafhopper immigrate to every three plants, trivial movement ensures that some leafhoppers pick up and spread infection even when few streak plants are present in the crop. It is doubtful however, whether the progeny of *Cicadulina* breeding in a maize crop are ever an important source of streak increase within the crop, although they are a most important source of spread of the disease to later planted maize.

Control:

Control strategies depend on whether the vectors of maize streak disease are flying from rain-dependent grasses or from previously planted cereals and grasses on irrigated lands. In the former case the *Cicadulina* are flying long distances from widespread grasses and are invading cereals throughout the region, few are infective. In the latter case, most are flying short distances from local sources and many are often infective before flight. In both cases most dispersal occurs as hosts mature or dry.

The most important cultural control measure is to avoid planting downwind from previously planted maize during the vulnerable season. A barrier of land about 10 meters wide between previously planted infected maize and new maize plot is found to reduce infection appreciably because *Cicadulina* are able to spread by trivial movement through the canopy of host and non-host plants and only by active dispersal flights over bare ground.

A well-thought out management program is essential for prevention of maize streak disease on irrigated areas where cereals are grown. These must provide for a sensible rotation of crops, both in time and place, so that invasion by infected *Cicadulina* is unlikely or limited, and for selective use of insecticides e.g. Furadan. Infection sources may be eradicated before planting maize by (i) destroying any remnants of previous season crop, (ii) treating previously planted crop with insecticide or by (iii) planting all the irrigated maize at one time so that infection does not increase in a succession of plantings. Infection risk is high when adjacent crops and grasses are drying, possibly because irrigation has been stopped or because there is drought during the wet season.

The most reliable method of control is by the use of streak-resistant crop varieties. Various types of streak resistant varieties are being developed at IITA, they include early and late maturing varieties, white and yellow grained and those for lowland and highland.

#### 11.r.2 Maize stunt:

The causal agent of this disease, previously believed to be a virus, is now known to be a spiroplasma - a mycoplasma-like organism. A most striking symptom is the proliferation of tillers and elongation of ear shanks at nearly every node. This gives the plant a bushy appearance. If infection

takes place early internodes are shortened, if infection is later only upper internodes will be reduced in length. Small, circular, chlorotic spots develop at the bases of the leaves on young plants. These often coalesce to form stripes that are discrete or diffuse. Reddish-purple stripes and general chlorosis appear as plants become older. Numerous ear shoots and poorly filled ears, or barrenness, are common symptoms in plants infected early. Two strains of the organism are recognised. The stunt agent is transmitted by the leafhoppers *Dalbulus maidis* Delong & Wolcott; *D. elimatus*, Bell; *Graminella nigrifrons*, Forbes; *Balduhus tripsaci* Kramer & Whitcomb and *Deltoccephalus sonorus*, Ball. The disease has been reported in the U.S.A., Mexico, Central and South America, Puerto Rico and Cuba. In Latin America, the disease is known as "achaparramiento". Control is by the planting of resistant varieties. The development of stunt resistant varieties is one of the major objectives of CIMMYT.

#### 11.4.3 Maize Dwarf mosaic:

Symptoms of maize dwarf mosaic first appear on the youngest leaves as an irregular, light and dark mottle or mosaic which may develop into narrow streaks along veins that appear as dark green "islands" on a chlorotic background. As plants mature, leaves become yellowish-green. Plants with these symptoms are sometimes stunted with excessive tillering, multiple ear shoots and poor seed set. As plants approach maturity, the leaves turn purple or purple-red. Thus symptoms are in part similar to those caused by maize stunt.

The disease is caused by a virus that can be transmitted mechanically and by at least 12 species of aphids including the maize leaf aphid (*Rhopalosiphum maidis* Fitch). The disease is widely distributed in the United States. Control is by planting resistant varieties.

#### 11.4.4 Bacterial leaf spots:

These spots are found on susceptible maize plants from seedling to post-pollination stages. Leaves develop very small, pale-green lesions. Under optimum conditions of warm moist weather, lesions expand along veins producing a conspicuous striping, mainly in the youngest leaves; stripes later turn brown. Severe damage of the top leaves results in tassel rotting because the tassel is enclosed by dead leaves. The causal agent is *Pseudomonas rubrilineans*. Control is by the cultivation of resistant varieties.

#### 11.4.5 Bacterial leaf stripe:

Typical primary symptoms are amber-to olive-coloured, oil-soaked, translucent lesions with parallel sides that tend to elongate and coalesce. Symptoms appear first on lower leaves and spread upward. Leaves above the ear are seldom infected. Lesions later become brown and necrotic. Very susceptible cultivars show chlorotic striping or bleaching of the upper leaves. The disease is caused by the bacterium *Pseudomonas andropogoni*. Control is by the use of resistant varieties.

#### 11.4.6 Stewart's wilt or bacterial leaf blight:

The causal agent of Stewart's wilt or bacterial leaf blight is *Xanthomonas stewartii* which is transmitted by certain beetles, primarily the flea beetle (*Chaetocaema pulicaria*) and through seed of infected plants. Infected plants wilt rapidly resembling plants suffering from drought. Leaves show linear, pale green to yellow streaks with irregular or wavy margins and may extend the length of the leaf. These streaks soon become dry and brown. Infected plants may produce premature, bleached and dead tassels. Cavities may form in the stalk part of severely infected plants near the soil line.

The disease occurs in USA, Mexico, Costa Rica, Puerto Rico, eastern Europe, Italy, USSR and China. The use of resistant varieties is the recommended control. This disease is of plant quarantine importance because it is still absent in many countries.

#### 11.5 Stalk and root diseases of maize:

##### 11.5.1 Stalk and root rots:

Stalk rots and root rots constitute another major group of widespread diseases of maize. Some stalk rot is present in almost every maize field at harvest.

When conditions favour rapid disease development, infected plants may die several weeks before ears are fully mature resulting in cobs that are poorly-filled and in chaffy kernels. Indirect yield losses occur through stalk breakage and root lodging which make harvesting difficult and also cause many fallen ears to rot.

#### Causes:-

Several different species of fungi may cause stalk and root rots, the most common being:

Diplodia rots (*D. maydis* or *D. zeae*) - Brown

Gibberella rots (*G. zeae* = *F. graminearum*) - Pink-red

Fusarium rots (*F. moniliforme*, *F. m. var Subglutinans* = *G. fujikoro*

*G.f. subglutinans* - Red

Charcoal rot *Macrophomina phaseoli* (*Sclerotium bataticola*) Black.

The above rots are distinguishable by (i) the colour and consistency of the rotten stalk (ii) the identity of the causal agents. But common to the four of them is that usually they appear in plants that are approaching maturity rather than in young actively growing plants.

Stalk rots may sometimes be caused by another fungus called *Pythium* (*P. aphanidermatum*, *P. debaryanum*) and by some bacteria. This latter group of rots differ from the more common rots both in symptom and in timing of infection. The rot is soft and usually stinky and often attacks plants before silking. The type and severity of the rots that predominate in a particular region depends on the weather conditions.

Control:

- (i) Plant resistant varieties if available.
- (ii) Ensure balanced soil fertility because high N and low K predispose plants to more stalk rot.
- (iii) Avoid blight susceptible plants since such susceptibility also predispose plants to more stalk rot.
- (iv) Avoid over population of plants.
- (v) Do not delay harvest beyond safe moisture level (because stalk rot is progressive until harvest).

Specific common stalk rots of maize, their symptoms, causal agents, epidemiology and their control are tabulated below.

COMMON STALK ROTS OF MAIZE

	DIPLODIA	GIBBERELLA	FUSARIUM	CHARCOAL
SYMPTOMS	1. Early infections (immature plants) show dull, greyish green leaves	1. In early infected plants lower stalks softens turning tan or brown		1. Greyish streaks of lower internodes
	2. Lower part of stalk turns from green to tan or brown	2. Internal pink to red- ish discolouration. More shredding, more severe than <i>Diplodia</i>		2. Plants breakover crown (soil line)
	3. Sub-epidermal dark brown	3. Superficial (i.e. scrapable) bluish black spherical perithecia on dead plants (less numerous than <i>Diplodia</i> )	As in <i>Gibberella</i> but affects roots, plants base and lower internodes	3. Pith absent in nodes; numerous sclerotia on the shredded vascular strands
	4. Stalks are easily crushed and broken in wind and rain	4. Cottony pink growth on leaf sheath and at nodes		4. Causes brown watery lesions on seedlings later turning black
	5. Split stalk has deteriorated pith with brown colour but the vascular bundles are still intact (spongy to shredded appearance)			
CAUSAL AGENTS	<i>Diplodia maydis</i> and <i>D. macrospora</i> produces pycnidia which gives rise to 2-celled spores. No sexual stage.	<i>Gibberella roseum</i> f. sp. <i>cerealis</i> ( <i>G. zeae</i> ) = asexual <i>Fusarium roseum</i> ( <i>F. graminearum</i> ): produces macroconidia (3-5 septate spores) No microconidia + chlamydospores in some isolates	<i>Fusarium moniliforme</i> or ( <i>G. fujikuroi</i> ) F.m var <i>subglutinans</i> . Macroconidia sparse; microconidia abundant Perithecia rarely observed.	<i>Microphomina phaseoli</i> ( <i>Rhizoctonia bataticola</i> ) Produces black globular irregular sclerotia strains; do not produce spores.

COMMON STALK ROTS OF MAIZE (Cont.)

	DIPLODIA	GIBBERELLA	FUSARIUM	CHARCOAL
	1. Overseasons as spores in pycnidia or as debris or spores on seed.		1. Fungi on crop residues in or on soil surface	1. Overseasons in plant debris
EPIDEMIOLOGY	2. Warm moist weather → spores in long cirri → infection through crown, mesocotyl, roots or lower nodes. Do not invade entire plant.	In warm and moist weather, perithecia ascospores → which infect stalks and ears.	2. In warm and moist weather there is infection through wounds (base of leaf sheath, roots, seedlings, ear or kernels).	2. Enters through roots, grows into stalks maturity cortex.
	3. Seed borne infection causes seedling blight.			

CONTROL:

1. Grow resistant varieties
2. Harvest crop as early as possible
3. Ensure proper storage to reduce seed transmission to subsequent crop.

COMMON STALK ROTS OF MAIZE (Contd.)

	PYTHIUM ROT	BACTERIAL ROT
SYMPTOMS	1. Usually confined to the first internode above soil level	1. Occurs just above ear placement
	2. Diseased part tan to dark brown, water soaked or slimy	2. Dark brown and pith shredding
	3. Falls over but not broken completely, remains green one week after falling because vascular bundles still intact	3. Top part of plant dies
CAUSAL AGENT	<i>Pythium aphanidermatum</i> (Syn. <i>P. butleri</i> )	4. Early infection leads to dwarfing and/or with multiple sterile or rotten ears.
	1. Develops during extended hot but very humid weather, poor drainage enhances development	5. Accompanied by elliptical narrow stripe lesions; olive green and oily or water-soaked becoming tan and dry with reddish margin; leaves may shed.
EPIDEMIOLOGY	2. Through seeds, seedlings, rootlets or roots. Many also attack stems directly or indirectly through wound.	<i>Pseudomonas alboprecipitans</i>
	3. Sporangia and oospores produced within or outside host tissue.	1. Favoured by hot showery weather
CONTROL	1. Plant injury-free seeds or resistant varieties.	2. Bacteria enter through wounds.
	2. Good cultural practices such as planting in warm fairly moist soil.	
	3. Use seed dressing chemicals.	

11.6 Ear and Kernel diseases of maize:

Maize ears are prone to attack by some fungi especially when rainfall is above normal from silking to harvest.

Most of the fungal species associated with stalk rots are also responsible for inducing ear and kernel rots. Thus we have *Diplodia* ear rot, *Fusarium* ear rot and *Gibberella* or red ear rot and charcoal rot. Others include *Nigrospora* ear rot and grey ear rot (*Phyfalospora zea* = *Macrophoma zea*), *Penicillium* ear rot (*P. oxalicum*) and *Aspergillus* ear rot (*A. niger*, *A. glaucus*).

EAR AND KERNEL ROTS

	<u>DIPLODIA</u>	<u>FUSARIUM</u>	<u>GIBBERELLA</u>	<u>NIGROSPORA</u>	<u>GREY EAR ROT</u>
SYMPTOMS	1. Husks on early infected ears are bleached or straw-coloured.	1. Pinkish discolouration of the caps of kernels ranges from faint pink turning to reddish brown depending on the water content of the ear	1. Reddish mold at the ear tip	1. Ears are light and kernels are bleached with whitish streaks	1. Early stage is in <i>Diplodia</i> rot with bleached stuck husks and greyish white mould
	2. With infection within 2 weeks after silking, entire ears turn greyish brown, shrunken and light with inner husks tightly stuck together and to the grains.	2. As disease progresses, infected kernels show a powdery pinkish mould growth	2. Early infected ears have tightly stuck husks with pinkish growth between the husks and ear.	2. Close examination would reveal large number of streak-sized black spore masses in the shredded pith of the cob and the tip of kernels.	2. At advanced stage the ear is dark grey compared to greyish brown for <i>Diplodia</i> .
CAUSAL AGENT	External signs are black pycnidia on husks and sides of kernels but no external signs on late infection except white mould between kernels. Kernel tips are discoloured.		3. Superficial blue black perithecia sometimes found on husks and ear shanks.		3. Severely infected kernel have grey to black streaks under pericarp
					4. Severely infected ears are shrivelled and mummified by harvest time.
	<i>Diplodia maydis</i> <i>D. macrospora</i>	<i>F. moniliforme</i> ( <i>Gibberella fujikuroi</i> )	<i>Gibberella zeae</i> ( <i>Fusarium roseum</i> ).	<i>Nigrospora oryzae</i> ( <i>Basisporium gallarum</i> )	<i>Phylospora zeae</i> ( <i>Macropnomina zeae</i> )

FAB AND KERNEL ROT

E P D F M I C O L O G Y	<i>DIPLODIA</i>	<i>FUSARIUM</i>	<i>GIBBERELLA</i>	<i>NIGROSPORA</i>	
	<ol style="list-style-type: none"> <li>1. Dry weather early in the season followed by wet condition just before and after silking.</li> <li>2. Ears most susceptible from silking to about 3 weeks after.</li> <li>3. Poor husk coverage and thin pericarp promotes infection</li> <li>4. Infection usually begins at ear-base.</li> </ol>	<ol style="list-style-type: none"> <li>1. Dry warm weather favours development and spread</li> <li>2. Infection follows some form of injury e.g. growth cracks or insect/bird damage.</li> <li>3. Certain high lysine maize are more susceptible.</li> </ol>	<ol style="list-style-type: none"> <li>1. Cool humid weather at silking.</li> <li>2. Ears with loose open husks.</li> </ol>	<ol style="list-style-type: none"> <li>1. Overseasons in plant debris especially under developed secondary ears.</li> <li>2. It is a weak parasite because attacks only after plants have been weakened e.g. by rpot damage, drought leaf blight etc.</li> <li>3. Occurs on infertile soils.</li> </ol>	<ol style="list-style-type: none"> <li>1. Development favoured by extended periods of warm wet weather for several weeks after planting.</li> <li>2. Fungus overseasons on infected leaves</li> <li>3. Perithecia and pycnidia occur in large lesions on leaves and occasionally on tassel wecks and under uppermost leaf sheath.</li> <li>4. Only sclerotia are formed in rotted ears and kernels</li> </ol>

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<p>ECONOMIC IMPORTANCE</p>	<ol style="list-style-type: none"><li>1. Reduce yield and feeding values of maize grains. Consumption of grains infested by <i>Gibberella</i> causes vomiting, dizziness, loss in weight, abortion or death in hogs.</li><li>2. Important especially when rainfall is above normal from silking to harvest.</li><li>3. Prevalence of ear rots is increased with physical damage to the plant.</li></ol>
<p>CONTROL:</p>	<ol style="list-style-type: none"><li>1. Plan your production in a way that maturity will not fall within the rains.</li><li>2. Good crop management (balanced soil fertility etc.) reduces incidence of ear and kernel rots.</li><li>3. Harvest your crop early.</li><li>4. Proper storage - below 18% moisture for ears and 15% for shelled grains.</li><li>5. Varieties with tight husk coverage unexposed tips and with ears maturing in downward (drooping) position are less prone to rot.</li></ol>

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### 11.7 Disease rating methods:

Diagnosis and assessment of plant disease are two most important functions of plant pathologists. Diagnosis of the more common diseases is based on identification of pathogen and/or symptoms using methods universally known and accepted. By comparison, disease assessment methods have received much less attention. Many different terms have been used to define disease measurement; we shall consider the two most widely used.

Disease incidence:- is defined as the number of plant units infected, often expressed as percentage of the total number of units assessed, e.g. percentage of maize plants infected by streak.

Disease severity or intensity:- is defined as the area of plant tissue affected by disease expressed as a proportion of the total area.

#### Need for Disease assessment:

If we are to understand disease, we must surely know how to measure it. Disease measurement is essential in the following basic fields of plant pathology:

(i) Epidemiology: Dispersal of a pathogen either by wind, water, insect vector etc. leads to the development of a disease within a crop to the point where many individuals are infected, that is an epidemic. In order to follow the progress of an epidemic, we must first have a means of measuring the disease. Successive measurements of the disease within the particular crop population gives the pattern of the disease. Disease development is initially slow because there is relatively little inoculum, then it accelerates and finally slows again because now there is little healthy host tissue left for the pathogen to colonize. Related to this is the measurement of diseases for the purpose of survey for the particular

(ii) Disease versus crop loss appraisal:- Plant pathology is primarily concerned with measuring crop losses attributable to plant diseases. The difficulty is that not all yield is governed by loss (from disease) and not all loss is governed by disease. We therefore need to have a reliable method of relating the amount of disease to some quantity or quality of crop loss. Disease - crop loss appraisal is needed so as to decide priorities for research and development.

(iii) Disease resistance:- Disease resistance is a relative measure of disease on a cultivar when compared to the amount of disease on the other cultivars subjected to the same environmental conditions particularly given the same quantity of initial inoculum. A very reliable method of disease assessment is therefore a prerequisite for effective screening of cultivars for resistance and is the overall goal for the development of disease resistant crop varieties.

Methods:

In disease assessment, three parameters can be measured: incidence, intensity/severity both of which are direct measures of disease effect, and yield which of course is the reverse of loss.

Recording incidence:

Incidence is the most popular parameter of disease to measure because it is the easiest and quickest. One can count accurately and reproducibly the number of wilted beans or virus-infected maize plants. One can express the number as percentages and transform them into logs, probits or logits. Incidence is often used to measure the spread of disease through a field, a county, or country.

The limitation of incidence in disease measurement is that it can only be correlated with loss in diseases where the presence of disease means the loss of the infected plants, that is fatal diseases such as wilts, downy mildews. In other diseases where the mere presence of the disease symptom does not mean premature death and hence loss of the plants, the time of infection and the degree of attack determine the effect of the disease on the productivity of the plant. For example, late infection of maize by streak e.g. after 8 weeks has little or no effect on yield. Incidence *per se* has no significance in this case. Hence the actual area of plant tissue damaged must be assessed.

Measuring disease severity:

Disease severity is specific to the plant whereas incidence relates to a plant population or an area. Disease severity or intensity is described by dividing the range between no disease and fully diseased i.e. 0 - 100% into a number of categories or classes. The plant tissue subdivided may be the whole plant such as total leaf area for rust and blight or the whole cob for ear rot or it may be a portion of the plant such as the ear-leaf or 2-4 lower internodes as for stalk rot. Careful grading is necessary for reliable, reproducible results. If the number of classes distinguished is too small, the key has no discriminative capacity, or resolution; if the number is too large, precious time is lost deciding what grade best matches the plant/plant part observed. Each class is characterized by a particular grade of disease, which has a numerical value and sometimes a ranking number or letter serving as a code indication. The term scoring is used for the activity of giving each item of the sample the appropriate class value or code number.

All methods of assessment of disease severity are subjective to some extent because they are the results of some visual judgements. A commonly used scale is the 0-5 scale, a form of which is presented below:

Code	<u>Disease class/interval</u> <u>% Infection</u>	<u>Description of</u> <u>Infection</u>	<u>Host</u> <u>Disease Reaction</u>
0	0	No disease	Immune or escape
1	0 - 10	Slight	Highly resistant
2	10 - 25	Mild	Resistant
3	25 - 50	Moderate	Moderately suscep- tible
4	50 - 75	Heavy	Susceptible
5	75 - 100	Very heavy	Very susceptible

Interpolation can be made such as 1.5, 2.5, 3.5 and 4.5. It is not feasible to advise a multi-purpose key for any host-pathogen combination; often the result is a compromise between conflicting interests. Two methods/tools are used:

(i) Disease scale: This is a verbal and numerical description of the classes to be distinguished.

(ii) Standard diagram or pictorial disease scale: It shows the percentage of the leaf, fruit, or tuber area infected.

In both cases, what the observer really has to do is to visualize what area the lesions (including the surrounding chlorosis) would cover if he could gather them all together, and then to estimate this area as a percentage of the total area of the plant tissues being assessed.

It has been observed that when making a percentage disease assessment, the eye actually assesses the diseased area up to 50% and the healthy area above 50%.

In disease assessment it is desirable that before the adoption for general usage say for germplasm screening and crop-loss appraisal, experiments must have been carried out to correlate the amount of disease as assessed by that method with actual crop loss. Also the method must be related to the phenology (growth stage or development) of the host. Also, it is absolutely irregular to delay scoring till a time when it would be impossible to record any differential response of the various cultivars being assessed. It should be realized that at that time the increase in disease no longer has any significant effect on crop productivity typical of that disease.

CHAPTER 12

INSECT PESTS

Insects are the dominant group of animals on earth today and they occur practically everywhere. Insects belong to the class *INSECTA*. The class insecta is one division of immense group, or phylum of the *ARTHROPODS*, to which belong all animals without backbones, but with jointed legs. The word "insect" has been derived from its class name *Insecta*. *Insecta* is the latin plural of the word "insectum" meaning the invertebrate animal having a segmented body and three pairs of legs. The insects are distinguished primarily by having the body with three distinct regions: head, thorax and abdomen and with three pairs of jointed legs. These legs may be extremely well developed as they are with the locusts, grasshoppers and stick insects, or they may be rudimentary and almost without function, as they are in some species of scale insects and mealybugs. This development or non-development of the legs becomes important when the movement of the insect from plant to plant is considered. The insects are also the only invertebrates with wings.

Any insect or animal or plant which becomes a source of trouble or loss to us is generally considered a pest. Therefore any insect population whose existence conflict with people's welfare, profit and/or convenience is called an insect pest. The degree of pest status varies with the nature of damage and degree of man's sensitiveness. When an insect causes considerable damage and the loss is very serious and substantial then the insect is marked as a major pest. On the other hand when the damage is slight, then the insect responsible for such damage is recognized as a minor or occasional pest.

12.1 The basic anatomy and physiology of insects:

(i) The skeleton.

Insects do not possess an internal skeleton; they have, instead, an exoskeleton, or covering of cuticle on their bodies. This covering is not continuous, but jointed to allow for movement. Although tough and fairly flexible it does not stretch and insects, in order to grow, must cast their skins. The outer layer of the cuticle is waxy and water-proof and this prevents the insect from losing too much water through the skin.

(ii) Respiration:

Insects breathe by means of branched tubes called tracheae which carry the air all over the body. The tracheae open to the surface of the insect through holes in the cuticle called spiracles. They are usually found one on each lateral side of certain segments of the insect and are easily seen in larvae such as caterpillars. The air is drawn into the tracheae through the spiracles by a pumping action of the abdomen. Some oils which are used as smothering insecticides act by blocking the spiracles so that the pest cannot breathe.

(iii) The blood circulation:

An insect has only one blood vessel, the "heart", a tube closed at the hind end and open at the end nearest to the head. It lies along the centre of the back and just below the skin. There are small openings on each side along the length of the tube and through these the blood, which is free in the body, enters until the "heart" is full of blood. Then these openings are closed by valves and the organ contracts, forcing the blood out through the open end. The blood is a colourless liquid which bathes all parts of the body, carrying

food substances and removing the waste products of metabolism. It does not carry oxygen and carbon dioxide as these circulate in the tracheal system.

(iv) The digestive system (see Fig. 12.1):

From the mouth of an insect, the food passes through the oesophagus to the crop, which is an enlargement of the gut tube without a digestive function. Here it is moistened and softened by saliva which has been mixed with the food in the mouth. After being moistened in the crop, the food passes into the gizzard which is lined with cuticle. By muscular movements the gizzard grinds the food into small particles, after which it passes through the valve to the stomach where digestion takes place. The products of this are absorbed into the blood. There are small, blind bubular growths called caecae at the place where gizzard and stomach join, and these serve to increase the surface for digestion. At the other end of the stomach or mid-gut, the food moves into a hind-gut, and at the point where mid and hind-gut join, is a collection of many fine tubular outgrowths called Malpighian tubules.

These act as kidneys, removing the waste products from the blood which is all round them, and passing them into the hind-gut for excretion.

Two points connected with digestion need further elaboration. The first is connected with the saliva. The saliva is mixed with the food in the mouth. It enters the mouth through a duct leading from the salivary glands. When an insect acts as a carrier, or vector of viruses or other disease organisms, these are being picked up by the insect, often enters the salivary glands.

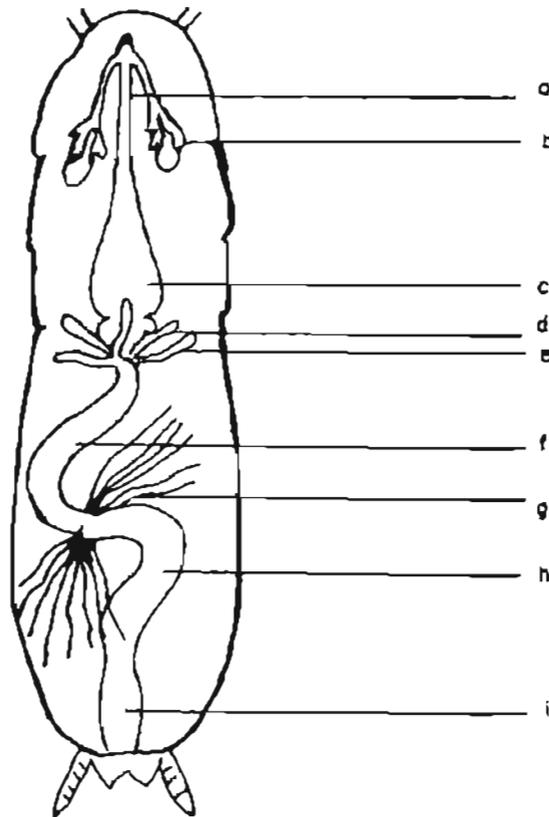


Figure 12.1: The digestive system of a Cockroach.

- |                   |            |                       |
|-------------------|------------|-----------------------|
| a) Oesophagus     | d) Gizzard | g) Malpighian tubules |
| b) Salivary gland | e) Caeca   | h) Hind-gut           |
| c) Crop           | f) Mid-gut | i) Rectum             |

(Adapted from de Purry 1968).

Many insects, particularly sucking insects, pass saliva down into the plant tissues in order to moisten their food before they suck it up. By doing this the insect introduces the disease organism into every plant on which it feeds. The insect itself is not affected by the disease, it only acts as a carrier from plant to plant.

The second point is concerned with the excreta. Many sucking insects do not utilize all the food they suck from the plant and their excreta still contain enough food value to be attractive to other insects. This is particularly found in aphids, scale insects and mealybugs, whose sugary excreta attracts certain species of ants. These ants tend these insects carefully, encouraging them to produce excreta on demand by stroking them. Any excreta not eaten by the ants, forms a good basis for the growth of fungi, and the leaves near colonies of the pest insects are often covered with patches of black fungus growing upon excreta.

(v) The reproductive system: With insects, males and females are normally separate individuals. The females of some species can reproduce parthenogenetically, that is without fertilization by the male.

(vi) The nervous system: In the head of an insect there is a small brain. From this, nerves go to the mouth-parts and there is also a double nerve cord which runs down through the thorax and abdomen. In the thorax there are three swellings in the cord - the thoracic ganglia, one in each thoracic segment and these give off nerves to the legs and wings. In the abdomen there are six ganglia whose nerves go to the abdominal organs.

Some insecticides, for example pyrethrum, are quick acting nerve poisons which, on contact with the insect, paralyse the nervous system and rapidly knock them down. Others, such as DDT, are also nerve poisons, but may not be so rapid in their effect.

(viii) The body divisions and their appendages:

The body of an insect is divided into three parts, head, thorax and abdomen. With some insects the divisions may be easy to see with the naked eye, but with others, for instance scale insects, they may be difficult to distinguish.

The head bears the antennae, eyes and mouthparts (Fig. 12.2). The antennae are the organs of smell and touch, and although their shape may differ very considerably in the members of one order, all members of a family within an order usually have similar antennae. The eyes can either be compound or simple and these are the organs of vision. The head of an insect consists of six fused segments, the antennae being appendages of the second segment. The three pairs of jaws are appendages of the fourth, fifth and sixth segments. These jaws are mandibles, which lie immediately below the labrum or upper lip, the first maxillae, which are to be found below the mandibles and which bear sensory palps, and the second maxillae, which are fused to form a single structure, the labium. This acts as the lower lip of the mouth in biting and chewing insects.

In a typical biting or chewing insect such as the locust (Fig. 12.2) all these parts are present, the mandibles are short, very strong, and toothed along one side for biting. The first maxillae are also short and strong, and the central part of each maxilla, the lacinia, bears some teeth for chewing.

In a typical piercing and sucking insect of the plant bug type, the mouthparts are modified (see Fig. 12.3). The maxillary and labial palps disappear and the labium itself is extended into a tube which is partly open on the anterior side. This is the labial gutter and it holds and protects the mandibles and maxillae, which are modified to piercing, needle-like stylets.

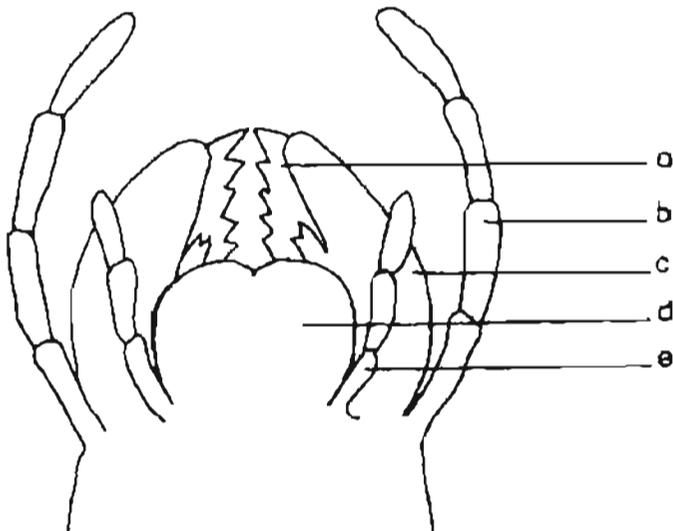


Figure 12.2: Biting and chewing mouth parts of a locust - Ventral view:

- |                   |                |
|-------------------|----------------|
| a) mandible       | d) labium      |
| b) maxillary palp | e) labial pulp |
| c) maxilla        |                |

(Adapted from de Purry, 1968)

The labium guides and protects the stylets but is not inserted into the plant tissue. When the four stylets, two mandibles and two maxillae, are thrust into the plant, the maxillae stylets are pressed closely together and form two canals, the anterior being the one up which the food is sucked, the posterior carrying the saliva down into the plant tissue.

These two types of mouth parts, biting and chewing or piercing and sucking, are found in most of the insects which cause damage to crops. Other mouth parts found are variations or reductions of these basic types.

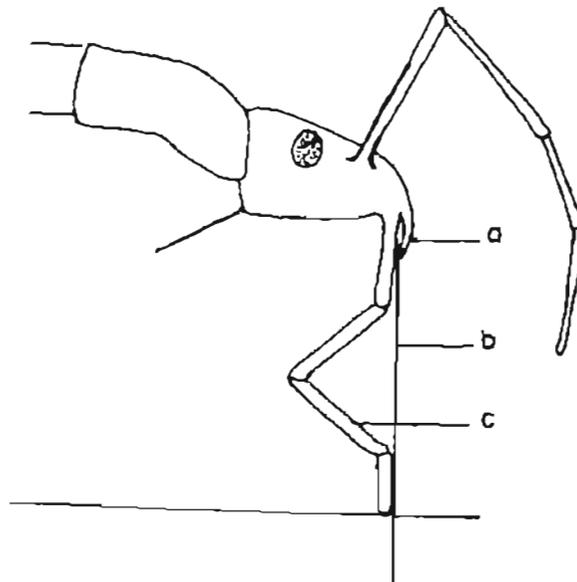


Figure 12.3: Feeding position of the piercing and sucking mouthparts of a plant feeding bug - *Heteroptera* species.

a) labrum

b) stylets

c) Labium

(Adapted from de Purry, 1968)

The thorax bears the true jointed legs and the wings. The leg of an insect is made up of five parts (Fig. 12.4), the coxa, the trochanter, the femur, the tibia, tarsal segments and a terminal claw.

The wings are attached to the second and third segments of the thorax. In their adult stage most insects have two pairs of wings, although there are exceptions, the most notable being the order Diptera, where adults have one pair of wings on the second segment, and the second pair is reduced to a pair of halteres, or knob-like structures, arising from the segment.

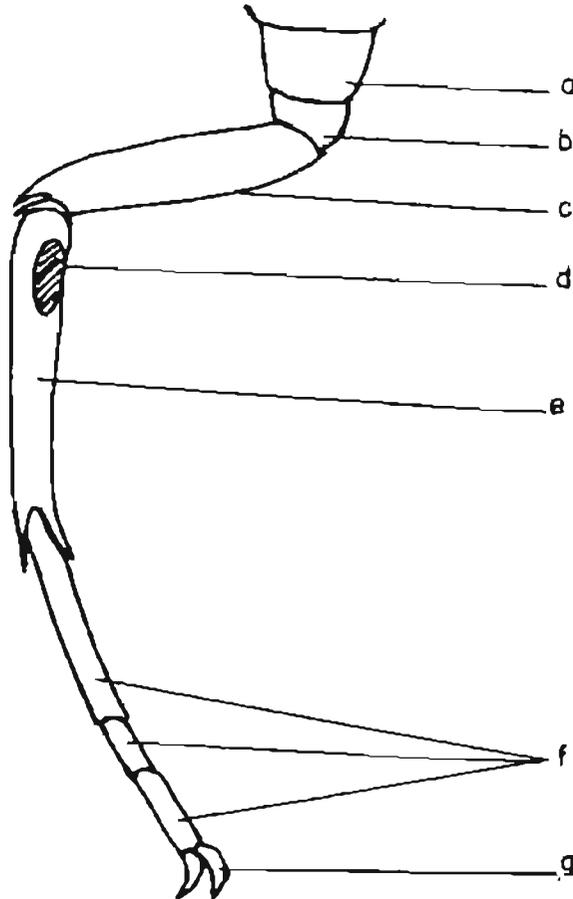


Figure 12.4: Left foreleg of a Cricket.

- |                  |                    |
|------------------|--------------------|
| a) coxa          | e) tibia           |
| b) trochanter    | f) tarsal segments |
| c) femur         | g) claw            |
| d) hearing organ |                    |

The abdomen has eleven segments although this number may be reduced in some insects. The eight and ninth are the genital segments in the female and they may sometimes bear an ovipositor, or egg-laying organ.

## 12.2 Life cycles:

The development from egg to adult and again to egg represents a life cycle. Most insect species complete one life cycle or one generation each year and are considered univoltine. Some insects complete more than one life cycle each year and are considered multivoltine.

From the time of hatching from the egg to adulthood, the individual passes through a period of growth and changes. This change in form in different stages during the post embryonic development is called metamorphosis. Generally there are two types of metamorphosis - simple metamorphosis and complete metamorphosis. In case of simple metamorphosis the insects have three life stages: egg, nymph and adult but in case of complete metamorphosis, the insects have four life stages: egg - larva - pupa - adult. Crop damage can be done either by larvae or adult. But there are some insects which damage the crop both by larvae and adult (e.g. leafhopper). Moreover, the mode and kind of damage done by insects vary from species to species.

### 12.2.1 Diapause:

In some insects, under certain conditions, any one of the developmental stages - egg, nymph, larva or pupa - can pass into a more or less prolonged state of arrested development or diapause; even the adult may enter what has been called "reproductive diapause", during which the reproductive organs remain non-functional.

Development can not be resumed, even under apparently favourable conditions, until the diapause has been "broken". Various environmental changes are now known to be responsible for inducing diapause, though they normally exert their effect some appreciable time before development is arrested. These include the ~~number~~ of hours of daylight per day, drought and high temperatures. From a biological point of view, diapause is an adaptation which often permits survival without feeding during adverse environmental conditions and which tends to synchronize development so that all members of an insect population resume activity together when conditions become favourable. The diapause often lasts for much longer than the normal time taken in that stage. An example can be found in the maize stalk borer moth in East Africa (de Purry, 196<sup>a</sup>).

This moth has two generations during the growing season of the maize plant. In the first generation, eggs are laid by moths which have emerged at the beginning of the rainy season. These hatch to larvae and, after about forty days, the larvae pupate in the maize stem. A pupal period of about two weeks follows and then the adults emerge to start the second generation, and by the larvae of this generation have fed, the rains are over and the dry season begun. Therefore, instead of the second generation adults emerging, finding no maize to feed on and probably dying, the insects go into diapause inside the maize stalks, and the adults will not emerge until the beginning of the next rainy season. Diapause may last for several months, in contrast to the normal pupal period of two weeks.

### 12.3 The control of maize pests:

Insect control broadly includes everything that makes life hard for insects and tends to kill them and to prevent their spread or increase over the area within a given area or from one area to another. This control can be

broadly classified as (i) Applied control measures, which depend upon man for application or success and can be influenced by him to a considerable degree and (ii) Natural control measures, which do not depend upon man for their continuance or success and can not be influenced greatly by him.

Knowledge of insect classification, growth, feeding habit and life cycle are requisite for a successful control programme. The accurate determination of insect species and related references are valuable tools in developing control measures. Life cycle data are of utmost importance in the timing of control measures. One of the most familiar principles of insect control is that of the "weakest link" either in the life cycle or seasonal pattern of abundance. Only through a thorough knowledge of insects' life cycle can control measures be effectively aimed at the most vulnerable stage. In practice, one finds the types of insect control listed in this way:

- (i) Biological control, both natural and manipulated forms
- (ii) Cultural control
- (iii) Use of resistant varieties
- (iv) Chemical control.

But, except perhaps for purposes of study, control should never be considered as divided in this way; in application, all methods should be considered and used so far as the circumstances of a given situation allow. These circumstances will be largely governed by the habits and life cycles of the pests concerned, and all the ways in which their numbers can be affected by their environment, either natural or man made. A programme of chemical control should never be attempted without first considering whether the pest could be as well controlled, or at least seriously reduced, by either or both of the

other methods. Depending on the level of resistance, resistant varieties can be used either as the principal method of control or can be integrated with other methods of control. Biological control and cultural control also can not be used as the principal methods for controlling maize pests but can be integrated with other control methods.

The methods of cultural control, altering of planting dates, techniques of cultivation, weeding or roguing, removal of possible alternate hosts for the pest, can be extremely effective on their own. If they are not entirely effective, then ways of increasing the available natural control of predators and parasites should be considered, and often the best method of doing this will spring from cultural practice; altering the condition of climate around a plant by mulching to encourage a parasite is an example.

The use of resistant varieties is one of the most effective methods of controlling insect pests. Insect populations are affected by the abundance and quality of the food. Plant resistance is related with the quality of the food. Resistant varieties provide an inexpensive method of pest control. It costs only for seeds of the improved varieties. Moreover, it is compatible with other pest control methods and devoid of environmental pollution. The effect of resistant variety on the pest population is specific, cumulative and persistent. Work is now in progress at IITA to develop maize varieties resistant to stem borers.

The assistance of chemical control should only be sought if the other methods are seen to be failing, as may happen in unusual conditions of climate, droughts or prolonged rains, or radical changes of environment, such as the destruction of natural vegetation or introduction of mono-crop culture.

These, to the farmer, uncontrollable factors, may favour the pest overwhelmingly, or discourage the predators and parasites. It is in this situation that chemical control comes into its own and can be used to check the rising population of the pests, but it should be restricted to times when this population is really increasing and likely to cause economic damage. When the pesticides have taken effect and numbers of pests are beginning to go down, natural and cultural controls should be allowed to take over again. As a rule, chemicals should only be used when populations are high or rapidly increasing. *Busseola fusca* Fuller is the most widespread noctuid in the African region south of the Sahara. This species does not live in dry tropical zones and although polyphagous, it is mostly observed on maize, and in wet zones sometimes on sorghum but because of sorghum's ability to tiller and make good the damage caused by the pest, it is only of minor importance in this crop. It has alternate hosts in two species of grass, *Setaria* and *Eleusine*, and can also live in oats, barley and wheat, but probably it is not able to grow large enough to pupate in these last three crops.

The moths emerge from pupation in maize stalks at the beginning of the rains, are night flying, and lay their eggs in a long line beneath the leaf sheaths of the young plants which have been sown at the onset of the rains. About 400 eggs are laid and the caterpillars which hatch out in about 10 days are a deep purple. Some of the brood may be carried by wind to other plants.

The young caterpillars feed on tender leaves in the funnel or central shoot of the plant, and produce the characteristic lines of "windows" which run across the leaves at right angles to the main vein, and are seen when the leaves unfold. The shoot may turn yellow and die off under this attack, but if the plant survives, the caterpillars will burrow down into stem and feed there.

The caterpillars mature while eating the central tissue of the stem, and when fully grown they are 3 to 4cm. long and a pinkish - white colour with small black spots along the sides of their bodies. The entire caterpillar stage can last about 40 days. Before it pupates, the caterpillar cuts a small round hole to the surface of the stem, and through this the moth will eventually emerge. The pupal stage for the first generation of the pest lasts for two weeks.

It can be seen that this first generation lasts for roughly seventy days, and by the time the new generation of adults commence egg-laying, those maize plants which have survived are tall and forming cobs. The new adults lay their eggs on the sheath leaves of the cobs and the caterpillars attack the cobs, causing great damage. Sometimes these second generation caterpillars pupate in the cobs, sometimes in the stem, but before pupation they go into a long diapause which lasts over the dry season into the next rains. They then finally pupate and the moths emerge with the rains.

Control will only be effective if this life cycle is understood. Damaged cobs and stems, which might harbour diapausing larvae, should not be left in the field, since they will increase infestation in the next crop. A watch should be kept on young plants for signs of 'windowing', and control must be applied early in the season for two reasons. First, if the first generation is allowed to go unchecked, there will be greater damage to the cobs by the second generation. Next, the caterpillars are most vulnerable to insecticides when they are in the funnel (whorl) of the plant, and before they begin boring in the stem. Once there, they are extremely difficult to reach with either DDT spray or dust, both of which are very effective against young caterpillars.

The pest can be controlled by putting a little DDT dust into funnels of the plants when they have six or seven leaves, if "windowing" damage has been seen. The treatments should be repeated when the plants are 30 to 45cm. high. A close season of maize would go far to reduce the pest, the object being to have as long a period as possible when there are few hosts for it to feed on.

#### 12.4.1 Spotted stalk-borer (*Chilo partellus*):

*Chilo* is the most important of the stalk-borers found at low altitudes, particularly the East African coast region. The adult is a dull coloured, night flying moth. The caterpillar can be distinguished from that of *Busseola* and *Sesamia* by the arrangement of the hooks of its prolegs. On *Chilo* these form a complete circle, whereas on others, they are arranged in a crescent. This can be seen with a hand lens. "Windowing" of the unfolding leaves is an early symptom of the pest and it can kill the central shoot of maize and sorghum. Sorghum may be able to survive by tillering, but maize will rarely do so. Pupation takes place inside the stem and the entire life cycle takes about five weeks. Sometimes the early stages mine into the leaves causing yellow streaks in addition to the "windowing".

#### 12.4.2 Pink stalk-borer (*Sesamia calamistis*):

This is a night flying, fawn-coloured moth. The habits of its life cycle and the damage it causes are similar to those of *Chilo*, but its larval and pupal stages take longer. It attacks maize and sorghum.

Early planting of cereals so that they get through their vulnerable early stage before the population of borers has time to build up is advised.

Young plants which have been killed should be rogued by hand. There is some doubt whether the method of dusting in the funnel, effective against maize stalk-borer, is any use against these other stalk borers.

This may be because the larvae spend less time in the funnel than those of *Busseola*, they quickly bore into the stem where they are protected from insecticide. The plants may be sprayed with DDT on the leaves, but the spray should not be allowed to run into the funnel where it sometimes causes scorching. Crop residues should be burnt, deeply buried or fed to livestock.

12.4.3 Maize leaf hopper (*Cicadulina mbila* ~~*triangula*~~):

This insect carries maize leaf streak virus (Fig. 12.5). The eggs are laid in slits in midrib of the leaves. Incubation period is about 10 days and the nymphs are fully grown in a month. There may be several generations in a year. The adults are hyaline coloured (brownish) and about 2mm long.

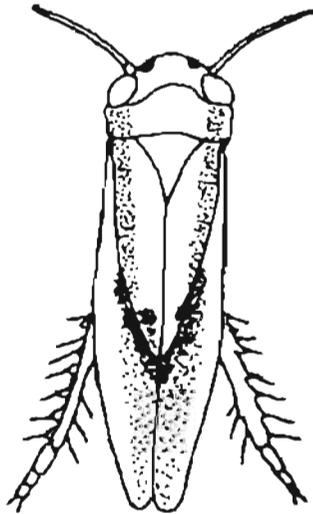


Figure 12.5: Maize leaf hopper - *Cicadulina mbila*

(Adapted from de Purry, 1968)

The streak disease is noticed as broken white line on the leaf, parallel to the veins, and is most harmful on young plants. The remedy is not to spray against the leaf hoppers, which would be far too expensive, but to use varieties of maize resistant to the virus. A good deal of work is being done to produce resistant varieties. Another remedy is early plant establishment before the jassids appear.

12.4.4 Maize aphid (*Rhopalosiphum maidis*):

A dark green aphid found on maize, barley and sugar-cane. Except in very dry weather it is usually of minor importance. It is preyed on by hover fly larvae and by several species of ladybird and the larvae of one of the ladybirds produces a mealy covering like a mealybug.

12.4.5 Army worm and lesser armyworm (*Spodoptera exempta* and *Spodoptera eriqua*)

These two moths are very similar in appearance and habits at all stages. The armyworm (*Spodoptera exempta*) is an occasional pest on maize; during outbreaks larvae extensively damage maize, stripping leaves to the midrib. The insect occurs in May and September and has been observed throughout Nigeria. In East Africa, *Spodoptera exempta*'s attacks are restricted to cereals and grasses, but will also feed on cotton. Both species do damage by defoliating and plants they attack and they are especially dangerous pests because, under certain climatic conditions, they have gregarious or swarming phases.

Control of armyworm 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 for armyworm outbreaks, a close watch should be kept on grasslands and young cereal crops, so that the caterpillars can be found and destroyed in their early stages. Persistent insecticides such as DDT are effective against armyworm. There are many birds which are natural enemies of the caterpillars, and these include stork and kites. Parasitic wasps and tachinid flies also attack them, and also there is known to be a virus disease which causes the contents of the caterpillar to liquefy, and the empty skins of these which have been attacked by the virus can be found hanging from vegetation.

#### 12.4.6 Other pests:

Other Lepidopterous pests are *Mythimna loreyi* and *Spodoptera littoralis* both common on late season crops. The former species in its larval stages lives in the whorl on which the larvae initially feed, and attack spread to other leaves subsequently. Damage to maize by some orthopterous pests, *Locusta migratoria migratorioides* and *Nomadacris septemfasciata* is most severe during outbreaks (Fig. 12.6). Although locusts have a number of natural enemies and a few diseases, control by insecticides is the only feasible technique and it is likely to remain so for many years.

Because locusts breed in localized areas and spread in swarms to various countries to do their damage, control operations need to be coordinated between national governments and organizations such as the United Nations which are well placed to achieve this.

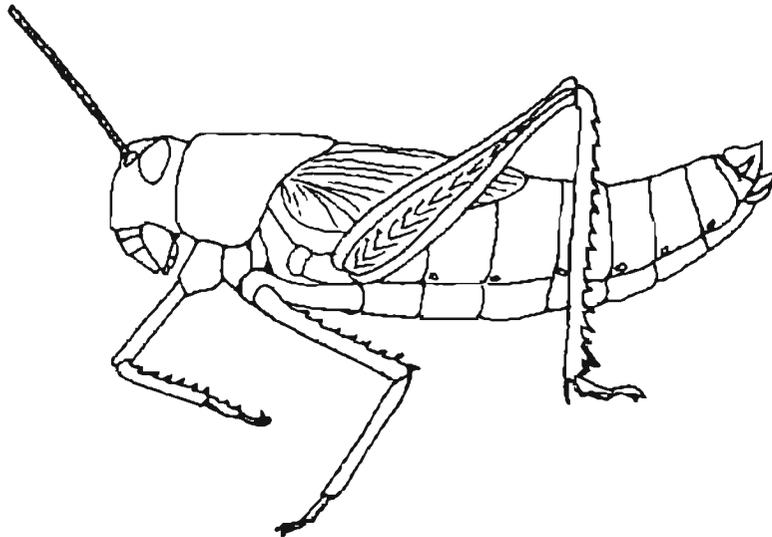


Figure 12.6: Migratory locust - *Locusta migratorioides* 5th instar nymph.

The gregarious phase nymph is patterned with yellow and black.

(Adapted from de Purry, 1968).

#### 12.4.7 Termites:

These social insects, often erroneously called "white ants" are found everywhere in the tropics. While they damage many crops, some build mounds which interfere with mechanized farming, termites nevertheless play a

generally beneficial role in the breakdown and incorporation of organic matter in the soil. Furthermore, their subterranean mining activities may improve the soil texture.

The termite genera that attack maize are *Macrotermes*, *Nasutitermes* and *Odontotermes*. The most destructive termite attacks occur at times when plants are least resistant, and in maize it is usually near the time of maturity and during dry periods. Some of the vascular tissues of a living plant may be cut by termites during periods of high moisture availability but associated wilting may not appear until a slight water stress occurs. While vigorously growing plants are less frequently attacked than drought-stressed or senescent plants, termite damage is often apparent on lush young maize plants as well as mature maize. Untreated maize plots average 29 per cent loss attributed to termites (IITA, 1971). In Southern Tanzania, over a five year period, (Bigger, 1966) found an average stand loss of 27 per cent in maize.

Control:

Although no successful method of biological control has yet been developed, termites have natural enemies. The predatory animals which eat termites include certain species of ants, dragonflies, lizards, frogs, toads, birds, bats, and man. These deprivations and the few known termite diseases exercise too little control over termite populations to prevent crop losses in tropical Africa. The use of insecticides is therefore necessary.

Aldrin and dieldrin are the insecticides still mostly used for termite control. Sands (1971) summarized the current method of chemical control of mound-building and subterranean termites and presented useful comments on the economics and limitations of several approaches to the use of pesticides against species which attack food crops. He dealt with the subject under the

(i) Mound poisoning

(ii) General application

(iii) Local application

(i) Mound-poisoning - crops are frequently attacked by several species of termites and only some of them are mound builders. Therefore, mound-poisoning often fails to control damage. It is essential to have an accurate identification of the pest species before control is attempted.

(ii) General application of insecticides to the soil- Ride, furrow and broadcast treatments were included in this category. These are the most widely used methods for termite control in all parts of the tropics. Effective control by this method depends upon uniform dispersion and shallow incorporation in the soil.

(iii) Local applications of insecticides - This category of treatments is economically and environmentally attractive. The category includes protection of seeds and seedlings by dipping them in dust or water suspensions of appropriate insecticides before planting.

REFERENCES.

- Bigger, H. (1966): The Biology and Control of Termites Damaging Field Crops in Tanzania. Bull. Ent. Res. 56, 417-44.
- de Purry, J.M.S. (1968): Crop pests of East Africa: Oxford University Press Nairobi.
- IITA (1971): Annual Report, 1971. International Institute of Tropical Agriculture, Ibadan, Nigeria.
- Sands, W.A. (1971): Termites as pests of tropical food crops. Ford Foundation/IRAT/IITA Seminar on Plant Protection of Tropical Food Crops, Ibadan, Nigeria.

## CHAPTER 13

### NEMATODES AS PESTS OF ECONOMIC PLANTS

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 a 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, thread-worm or roundworm.

#### 13.1 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 or 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.

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 water.

13.1.1 The anatomy of the various organs of a typical

Nematodes or the diseases they cause in man, animals 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 1743 when he dissected '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 green-house 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 tropic climates and an extensive host range that includes most 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 sugarbeet nematode (*Heterodera schachtii*) and the potato root nematode (*Heterodera rostochiensis*), respectively.

These early workers found that certain crop rotations reduced crop damage and the concept of limiting losses through chemicals (carbon disulfide) 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-dichloropropene 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 marked 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.

That plant parasitic nematodes could have causative role in a plant disease complex involving fungi, bacteria or viruses was eventually realized. Plant cultivars bred for resistance to certain plant diseases 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.

### 13.2 Nematode loss estimates in agricultural crops:

Accurate yield loss data are not available for most crops in many nations of Africa. Limited or no 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 reduction 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, cowpea, sorghum, sugarcane, citrus and certain vegetables. In certain root and tuber crops nematode damage and disfigurement may cause serious losses due to consumer rejection.

### 13.3 Gross plant symptoms of nematode infection:

Plant-parasitic nematodes are obligate parasites as they are unable to reproduce without sustained feeding on living 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 help preserve the nematode population during periods 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.

#### 13.4 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 lesions.

#### 13.5 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* spp) and needle

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 and/or in depth, excessive root branching, injured root tips causing short, stubby clusters of roots, an open root system devoid of rootlets and curling 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.

#### 13.6 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 produce. 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 ectoparasitic 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.

### 13.7 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.

### 13.8 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 world-wide 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 areas 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, feet of man and animals, farm tools, wind and the washing of rain water.

### 13.9 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 may involve complex host-pathogen interactions from chemicals introduced by the nematode resulting in an physiological change in the host or chemical substances produced by the plant in response to nematode attack.

13.9.1 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 invokes a host response involving the development of giant cells in vascular tissue of the root which are used as a food source by the nematodes. Root swelling and the gall formation results from a rapid increase in the size and number of adjacent cells.

13.9.2 Root-lesions 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.

13.9.3 The stem nematode (*Ditylenchus dipsaci*)

Feeding on cells of bulbs and above-ground plant parts results in the dissolution 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.

#### 13.9.4 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 vigour 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.

#### 13.9.5 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.

#### 13.10 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. Crops developed for 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.

#### 13.11 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, favour 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 population 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.

#### 13.12 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 laborious 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.

13.11.1 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.

13.11.2 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 significant 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 numbers 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 rotation are:

- (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 nematode and increase another,
- (d) adequate knowledge of the nematode-plant resistance relationship is often unavailable and

13.11.3 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, improve 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.

13.11.4 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 cover 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.

13.11.5 Time of planting to control plant-parasitic nematodes:

Certain kinds of plant-parasitic nematodes are susceptible to desiccation 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 increasing on early weed growth.

13.11.6 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 desiccation.

#### 13.11.7 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 the food supply which create cycles of microorganism growth and activity. Plant-parasitic nematode populations are usually reduced by the biotic competition and increased soil fertility from the organic matter allows a healthier plant to make rapid growth thus minimising the effects of nematode attack.

#### 13.11.8 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. Crotonaria 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.

#### 13.11.9 Antagonistic crop 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.

#### 13.11.10 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 favor 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.

13.11.11 Clean planting stock to control plant-parasitic nematodes:

Exclusion of plant-parasitic nematodes through the use of nematode-free planting stock is an effective practice to limit nematode spread. Transplants can be grown in ground beds freed of nematodes by heat or chemicals and 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.

13.11.12 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.

13.11.13 Biological control of plant-parasitic nematodes:

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 but little of practical or economic value has emerged.

13.11.14 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 oven or over an open fire. Brush piled 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.

13.11.15 Exclusion to control plant-parasitic nematodes:

Many kinds of plant-parasitic nematodes are already wide-spread 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.

13.11.16 Chemicals to control plant-parasitic nematodes:

The development of an effective soil fumugant 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 system 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, labor, time, pest and disease control measures and irrigation. Where 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.

#### 13.12 Plant-parasitic nematodes associated with maize plants:

Considering that maize is one of mankind's major sources of protein and carbohydrate and is a major factor in the economies of some countries the study of nematode pests of the maize plant has received scanty attention. Only minor segments of the world's maize growing areas have been explored for plant-parasitic nematodes. The nematode species and their locations reported in the literature are listed in Table 1.

Table 13.1: Plant-parasitic nematodes on maize with their reported geographical distribution.

<u>Nematode:</u>	<u>Location:</u>
	USA
<i>Belonolaimus gracilis</i>	Argentina, Africa (north & south)
<i>Ditylenchus dipsaci</i>	Australia, Belgium, Brazil, Canada France, USA, USSR, West Germany, Yugoslavia
<i>Dolichodorus heterocephalus</i>	USA
<i>Gymnotylenchus zae</i>	India
<i>Gymnotylenchus cayenessi</i>	Egypt, Nigeria
<i>Helicotylenchus digonicus</i>	USA
<i>Helicotylenchus dihystrer</i>	USA
<i>Helicotylenchus microcephalus</i>	Nigeria
<i>Helicotylenchus pseudorobustus</i>	Nigeria, USA
<i>Hemicycliophora parvana</i>	USA
<i>Heterodera avenae</i>	Canada, France, India, USSR
<i>Heterodera punctata</i>	Mexico
<i>Heterodera zae</i>	India
<i>Hoplolaimus galeatus</i>	USA
<i>Hoplolaimus indicus</i>	India
<i>Hoplolaimus einhorsti</i>	Malagasy Republic
<i>Longidorus maximus</i>	West Germany
<i>Meloidogyne arenaria</i>	USA
<i>Meloidogyne incognita</i>	India, Nigeria, USA
<i>Meloidogyne javanica</i>	USA
<i>Meloidogyne thomasi</i>	South Africa
<i>Paratylenchus projectus</i>	USA
<i>Pratylenchus brachyurus</i>	Brazil, Nigeria, Rhodesia, USA
<i>Pratylenchus crenatus</i>	USA
<i>Pratylenchus delattrei</i>	India, Malagasy Republic
<i>Pratylenchus minyus</i>	Canada
<i>Pratylenchus hexincisus</i>	USA
<i>Pratylenchus loosi</i>	Sri Lanka
<i>Pratylenchus penetrans</i>	Canada, Japan, USA
<i>Pratylenchus scribneri</i>	USA
<i>Pratylenchus thornei</i>	Europe
<i>Pratylenchus zae</i>	India, Panama, Puerto Rico, USA
<i>Radopholus similis</i>	USA
<i>Rotylenchus reniformis</i>	USA (Hawaii)
<i>Scutellonema clathricaudatum</i>	Nigeria
<i>Trichodorus christiei</i>	USA
<i>Trichodorus porosus</i>	Puerto Rico
<i>Tylenchorhynchus brevidens</i>	USA
<i>Tylenchorhynchus claytoni</i>	Puerto Rico, USA
<i>Tylenchorhynchus dubius</i>	USSR
<i>Tylenchorhynchus maximus</i>	USA
<i>Tylenchorhynchus zae</i>	India
<i>Xiphinema americanum</i>	USA

13.12.1 Pratylenchus spp. The root-lesion nematodes:

Disease. *Pratylenchus* spp. attack the root systems of maize causing a reduction in the numbers of fine feeder roots. The larger coarse roots show symptoms of lesions and frequently a rot from secondary invaders. Often maize grown on soils heavily infested with the root-lesion nematode will not show any symptoms to the casual observer although yields are being reduced.

Crop losses: The root-lesion nematode can reduce maize grain yield 25% or more even when above ground symptoms are absent. The general reduction in the efficiency of the root system becomes a plant growth-limiting factor.

Biology: Root-lesion nematodes are termed migratory nematodes at all stages, adults and juveniles, enter and leave roots or move about within roots.

Nematode development and reproduction occurs at no fixed site. Mature females deposit eggs within root tissue or in soil. Generally the life cycle takes from twenty to sixty-five days depending on the species. One or two eggs may be laid per day which may hatch in as little as five, or more than sixteen days.

Symptoms: Symptoms are characterized by growth limitations imposed by the root-pruning effect of root-lesion nematode attack. Small feeder roots are destroyed or prevented from developing. Cortical lesions, small initially, enlarge by nematode feeding at the lesion periphery. Other organisms become involved as secondary invaders. Greatly enlarged lesions result in complete girdling destroying the function of the root.

Other host plants: Root-lesion nematodes have a broad host range covering field crops, vegetables, fruit and tree crops, ornamentals and many weeds

The host list for individual species of *Pratylenchus* would be lengthy but not all plants are equally good hosts. *P. brachyurus*, *P. crenatus*, *P. delatereci*, *P. hexincisus*, *P. loosi*, *P. Neglectus*, *P. penetrans*, *P. scribneri*, *P. thornei*, and *P. zae* have all been reported as parasites of maize.

Distribution: Root-lesion nematodes are common in cropped soils and world-wide in distribution. *P. brachyurus*, *P. coffeae* and *P. zae* reportedly only occur in the world's warm regions while the others appear in the cooler zones or in higher altitudes in the tropics.

Control: Control measures include crop rotation with poor host or non-host crops. Weed control during and between maize crops would be of great benefit. Root-lesion nematodes are effectively killed by soil fumigants but the economics of their use pretty well remove them from consideration.

#### 13.12.2 *Belonolaimus gracilis*, The sting nematode:

Disease: *Belonolaimus gracilis*, causes stunting of maize especially in light sandy soils. Maize plants severely stunted in the seedling stage of growth do not recover resulting in reduced or no yield in grain. The nematode feeds ectoparasitically along succulent roots and on root tips inhibiting epical root growth. Cells in attacked root tips, including meristematic cells, become mature, enlarged and vacuolate. Root tips may become distorted and destroyed in soils with dense populations of *B. gracilis*. Injured roots have dark, shrunken lesions along the root axis and at the tip. Lesions in an advanced stage of development may girdle the root destroying that portion of the root below the lesion. It is characteristic in maize for proliferation of roots to occur above the injured areas.

Crop losses: Grain loss may be total or nearly so in stunted plants which usually occur in spots in infested fields. In fields with older infestations and a history of cropping favourable to the sting nematode the spots may have increased in size and have become so numerous as to cover the entire area.

Biology: *B. gracilis* is primarily an external parasite of maize roots. Feeding and reproduction take place outside the root. Feeding is generally at root tips and along the sides of succulent roots. The more dense populations are found in light sandy soils which provide a more favourable habitat than heavier soils.

Symptoms: Sting nematode injury to roots usually is characterized by a lack of small feeder roots leaving the large coarse roots. The coarse roots often terminate with gall-like enlargements caused by the repeated forming of new rootlets and their tips then being killed by the sting nematode. Above ground symptoms are retarded growth seen frequently as spots throughout the field with little or no recovery of the more heavily attacked plants.

Other host plants: *B. gracilis* is a parasite of numerous economic plants of which pepper, groundnut, mellons, soybean, cotton, beans, cowpea, and strawberry are among the more important.

Distribution: *B. gracilis* is known to occur only in the south-central and eastern states of the United States of America.

Control measures: The sting nematode can be effectively controlled by the use of soil fumigation although the economics of chemical control generally restricts their use in maize and other low value crops. Cultural control involving non host crops in the cropping sequence depress field populations of the sting nematode.

13.12.3 *Ditylenchus dipsaci*, The stem nematode:

Disease: *Ditylenchus dipsaci*, the stem nematode (also known as the bulb and stem nematode) is an endoparasite that invades parenchymatous tissues.

Mechanical injury is generally slight. Plant damage results from the effects of nematode salivary secretion on the cells of invaded tissue. Infected plants may exhibit basal swelling, dwarfing and twisting of stalks and leaves.

Crop losses: Grain yields are reduced or no grain is produced in plants distorted and stunted by the stem nematode. Destruction of tissue in the stem base may cause toppling and broken stems in heavy winds.

Biology: *D. dipsaci* invade the plant at the base of the stem and the foliage. Salivary secretions containing pectinase results in the breakdown of middle lamellae between cells causing cells to separate forming enlarged inter-cellular spaces in which the nematodes live. The nematodes migrate within the tissues and feed on cell contents. Localized cell hypertrophy and hyperplasia result in basal swelling, twisting of stalks and leaves and dwarfing of the plant. Cell destruction in the stem base may reduce root development resulting in broken stems and lodged plants when exposed to high winds.

The stem nematode lives as an internal parasite in the stem and leaves of maize and is rarely found in roots. The nematode may proceed through several generations within the host emerging to enter the soil when unfavourable living conditions develop within the plant. Depending on temperature, host suitability and other factors development from egg to sexually mature adults take twenty-four to thirty days. One female stem nematode lays about 200 eggs during her life time. When adverse conditions are encountered larvae pass into a quiescent state. This quiescent state gives protection from high

or low temperatures, by-products of decay and, particularly, drying. Stem nematode larvae have been revived after being stored in a dry state for a period of several years. Stem nematode survival in moist soil in the absence of a host plant is eighteen to twenty-four months.

#### 13.12.4 Stem nematode 2:

Symptoms: Plants are stunted, internodes are shortened and leaves and stalks are twisted, deformed and puffy. Root development is often reduced so that winds are frequently a factor contributing to crop loss. Plant tissue may become brittle with premature drying before harvest.

Other host plants: About 375 different host plants have been reported for stem nematode. The presence of biological races often restricts the transfer from one host plant to another. The 'rye strain' of the stem nematode attacks maize, oats, marigold, bean, pea, tobacco, onion flax, clovers and a number of weeds.

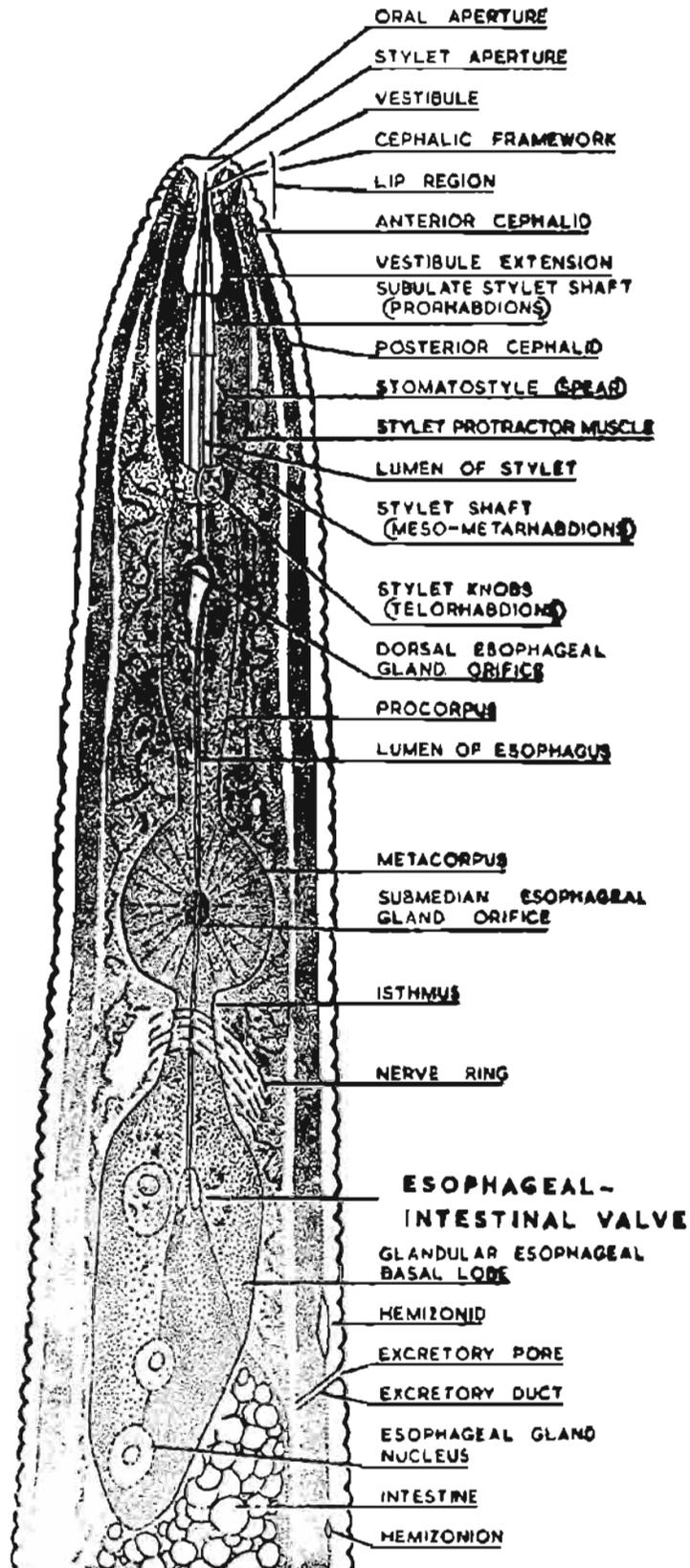
Distribution: *D. dipsaci* has been reported from North & South Africa, North and South America, Europe, Australia and Siberian USSR.

Control measures: Stem nematode control involves sanitation, cultural practices including crop rotation and weed control, the planting of clean seed and soil free of the nematode.

#### 13.12.5 Miscellaneous plant-parasitic nematode associated with maize:

As noted in Table 1, there are numerous other species of plant-parasitic nematodes associated with and attacking maize. Some species are only of importance in local situations while little is known of other species.

Investigations in Ibadan, Nigeria have shown *Zea mays* to be an excellent host for three species of the spiral nematode and the root-knot nematode is commonly observed in field planting of *Zea mays*.



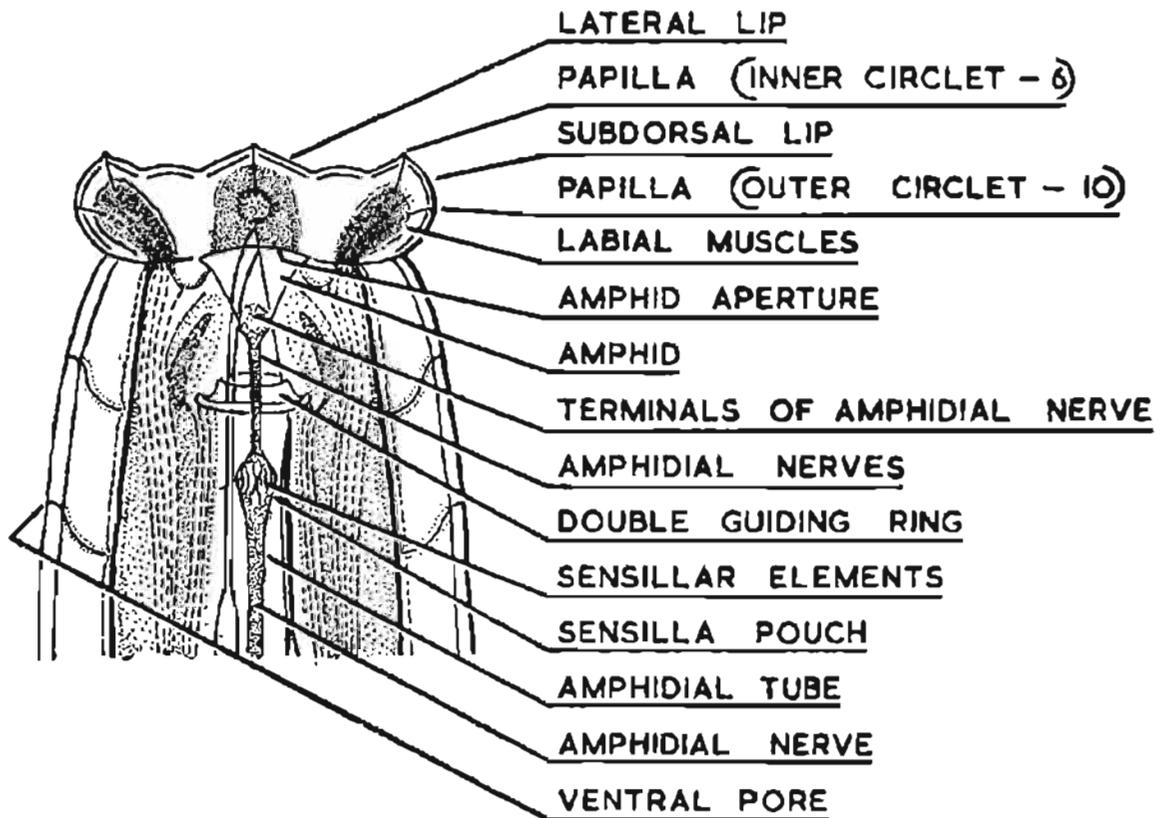


Fig. 13.2

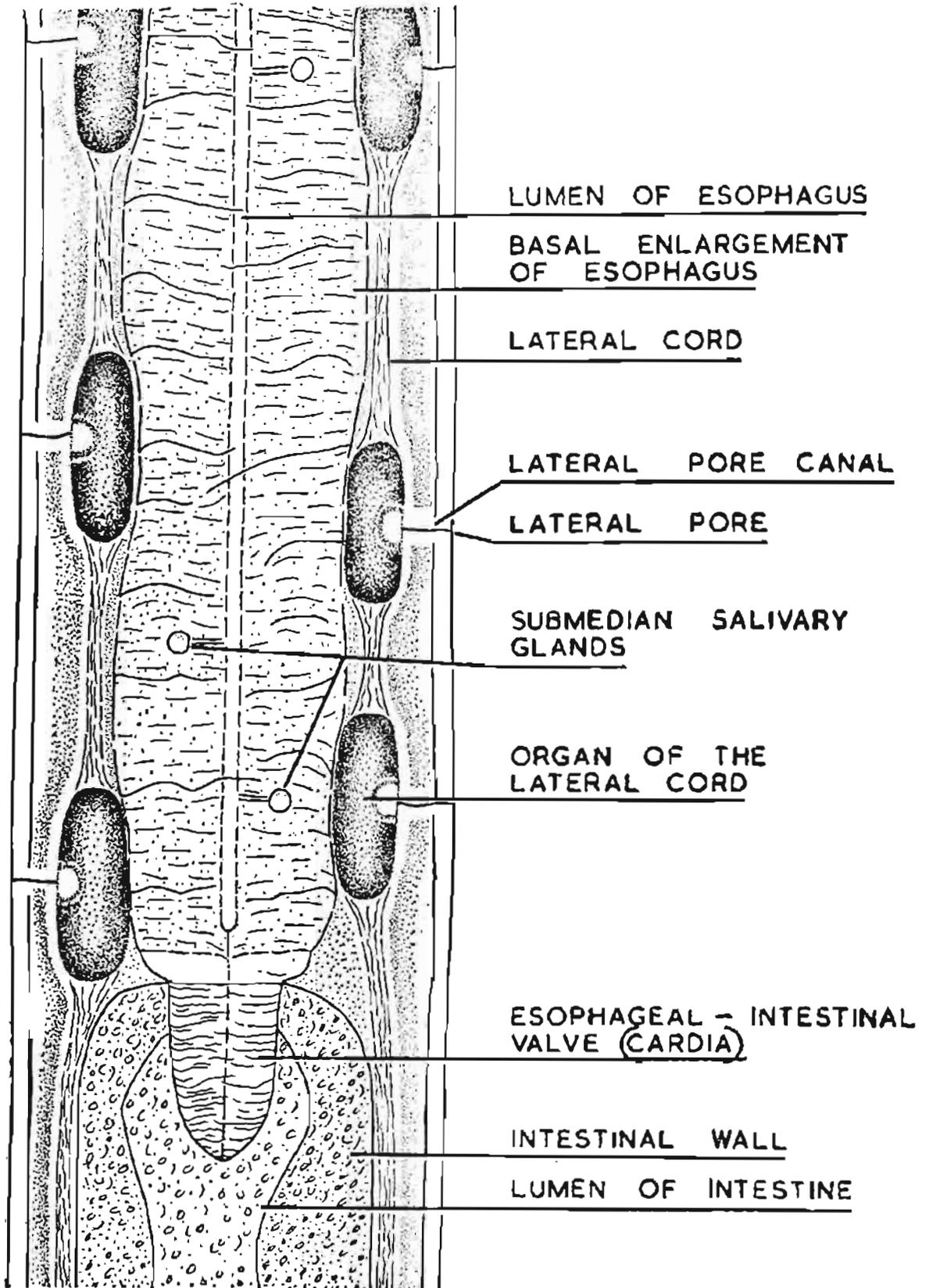


Fig. 13.3

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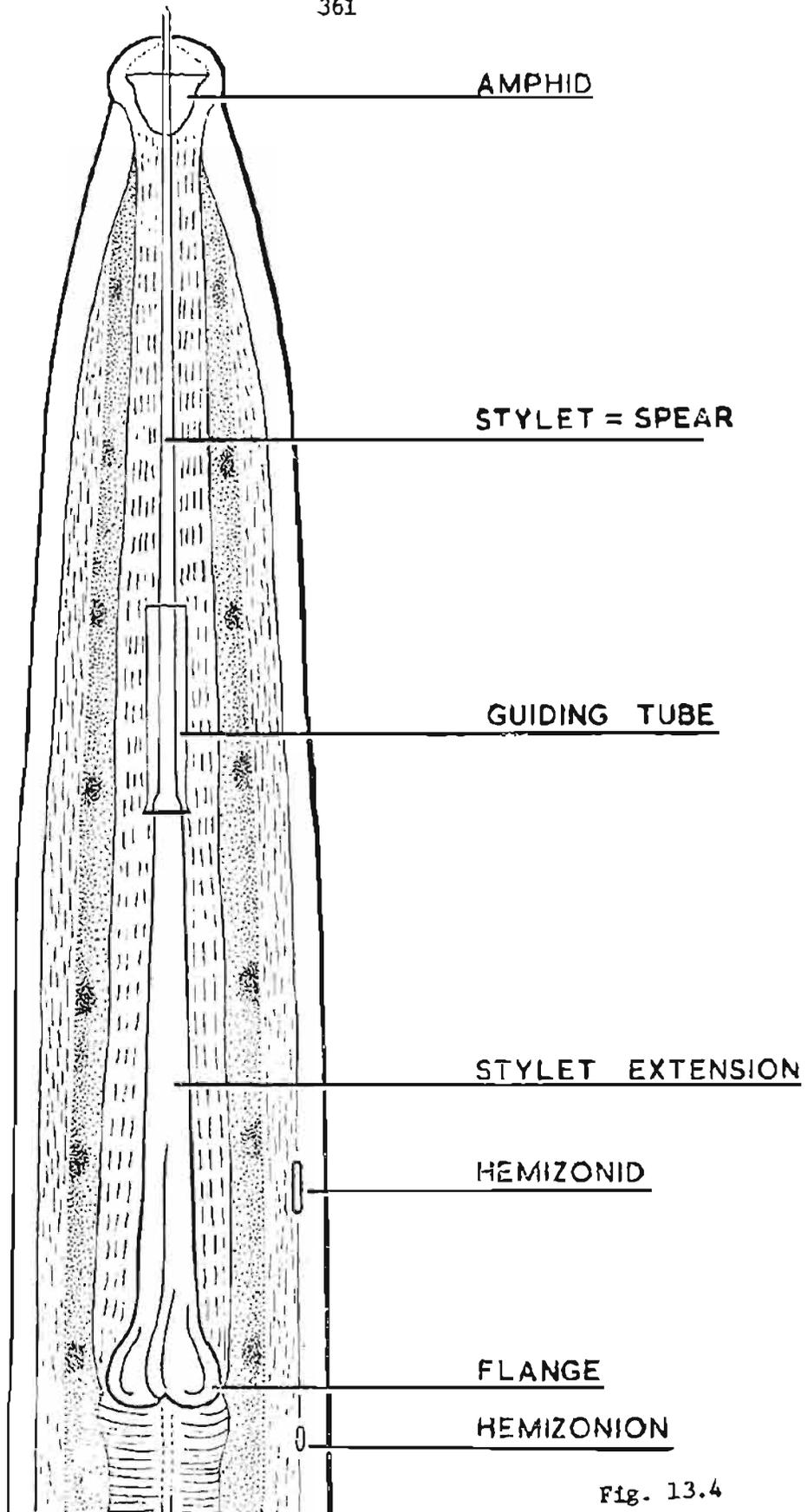


Fig. 13.4

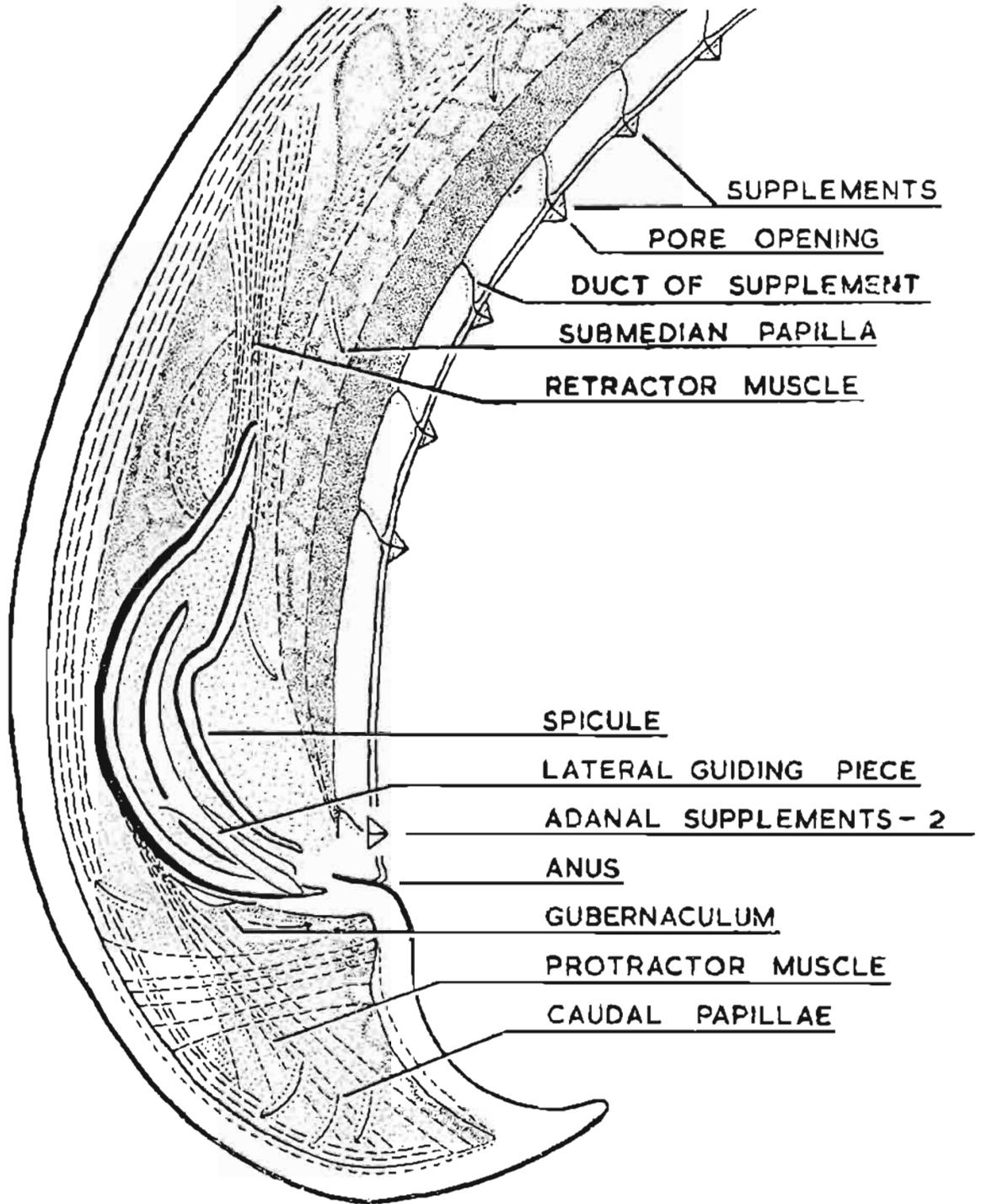


Fig. 13.5

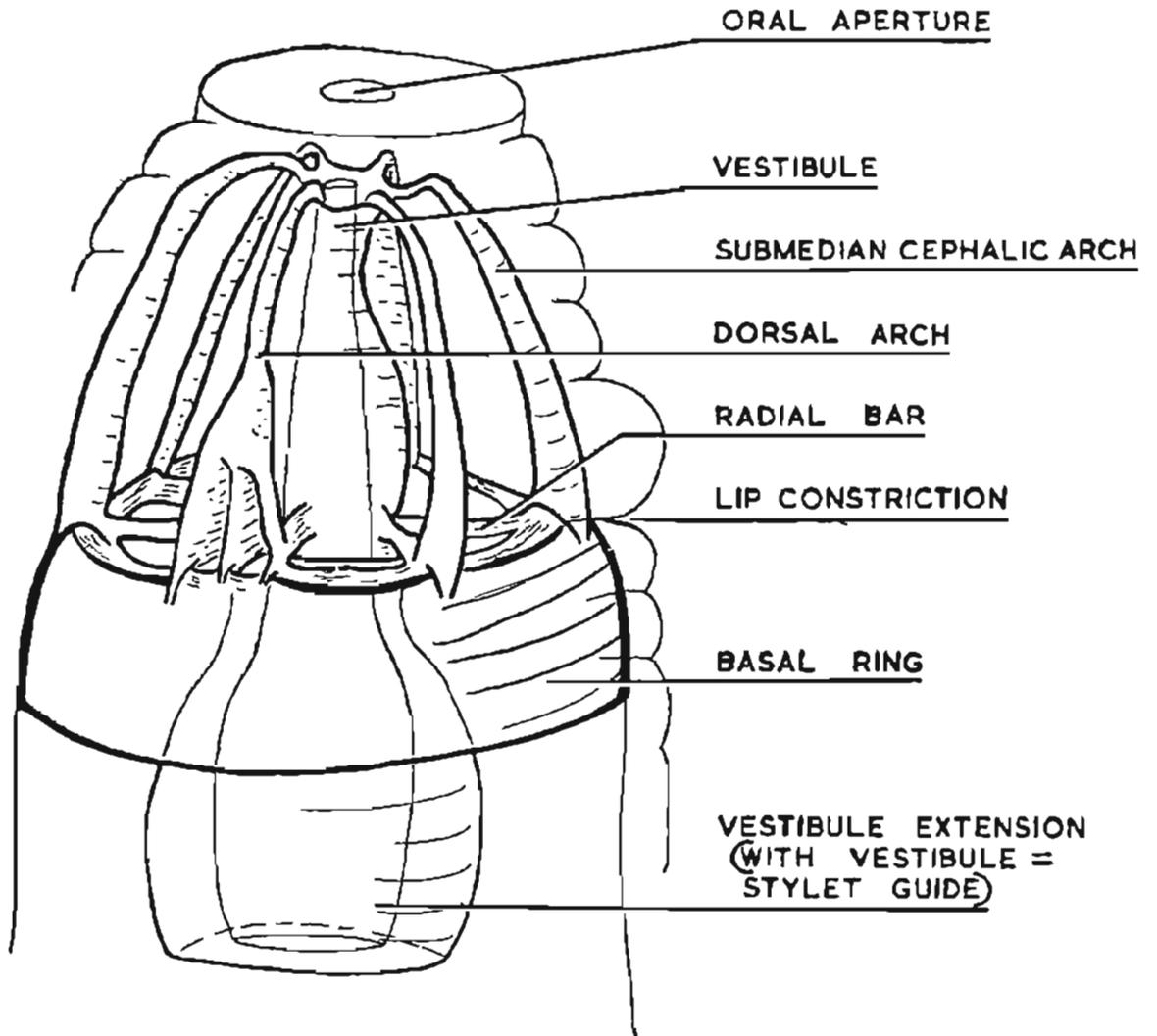


Fig. 13.6

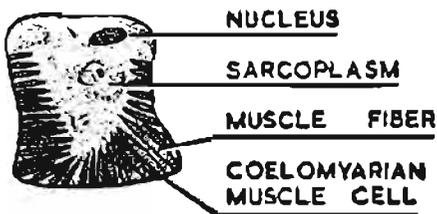


Fig. 13.9

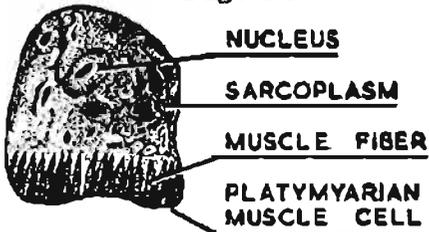


Fig. 13.8

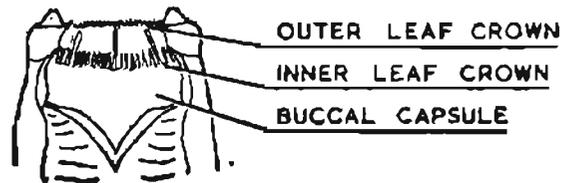


Fig. 13.12

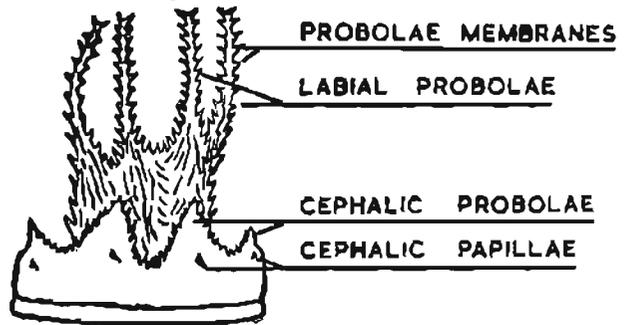


Fig. 13.11

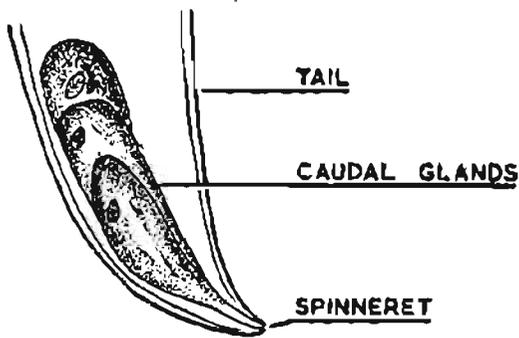


Fig. 13.7

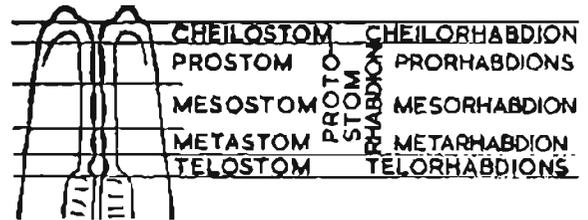


Fig. 13.10

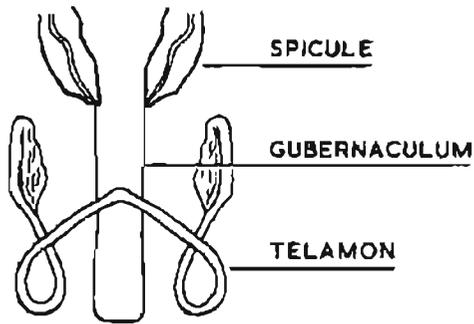


Fig. 13.14

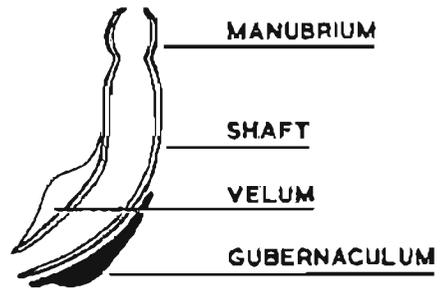
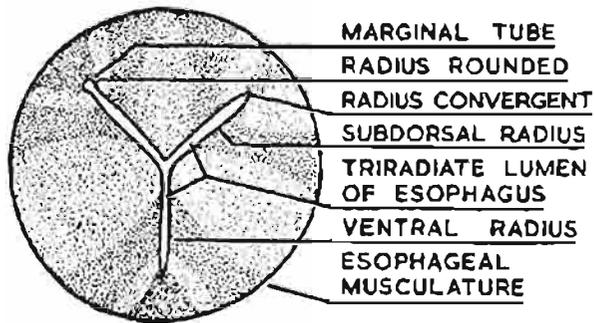


Fig. 13.16



CROSS SECTION OF ESOPHAGUS PRECORPUS

Fig. 13.13

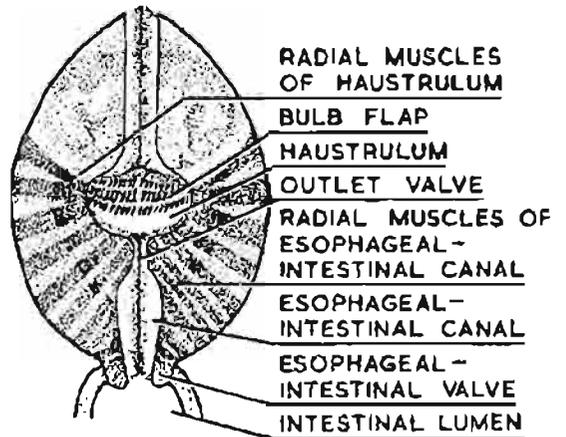


Fig. 13.15

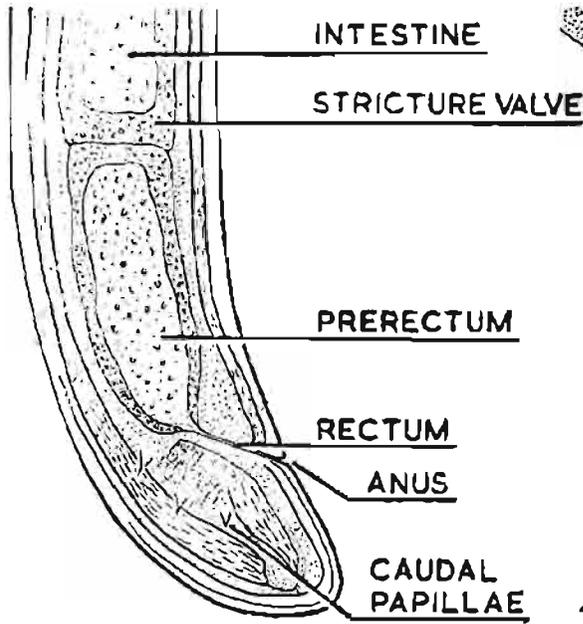


Fig. 13.18

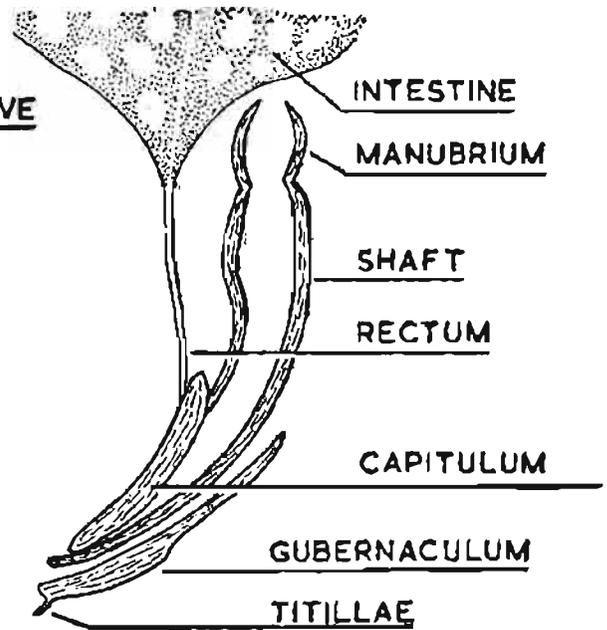


Fig. 13.20

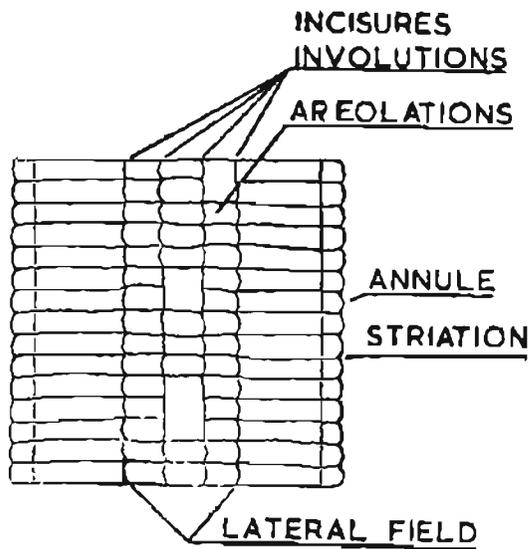


Fig. 13.17

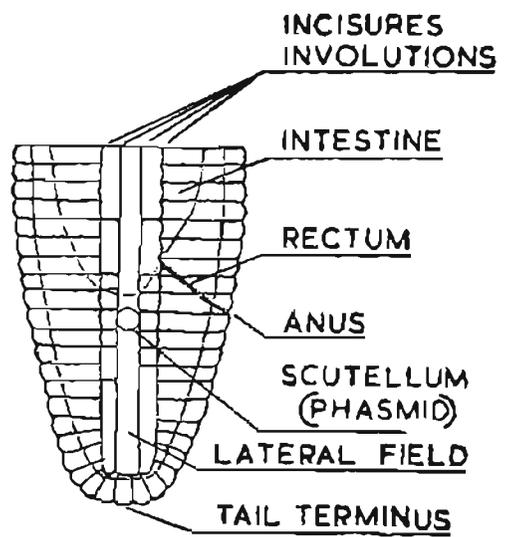


Fig. 13.19

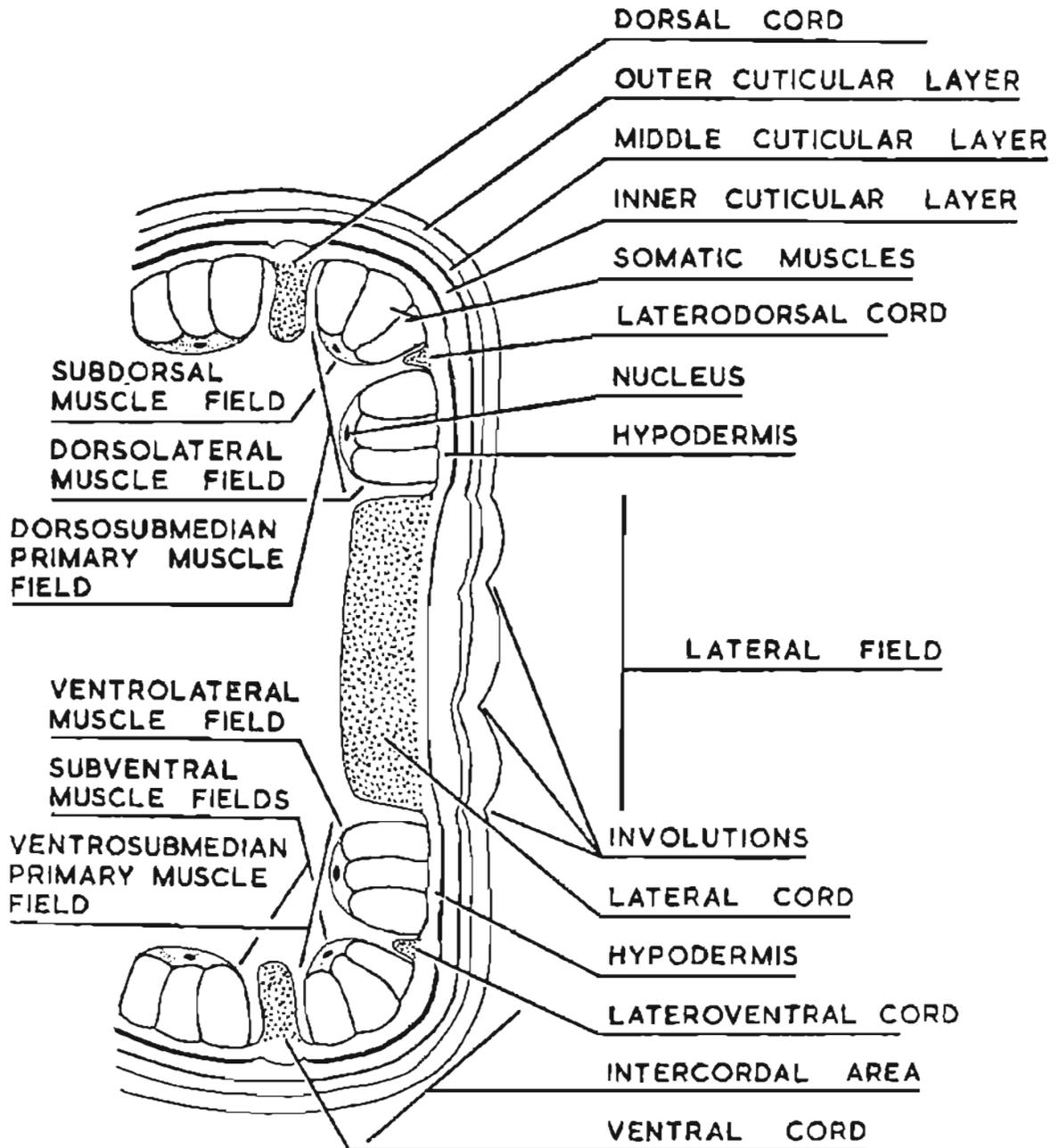


Fig. 13.21

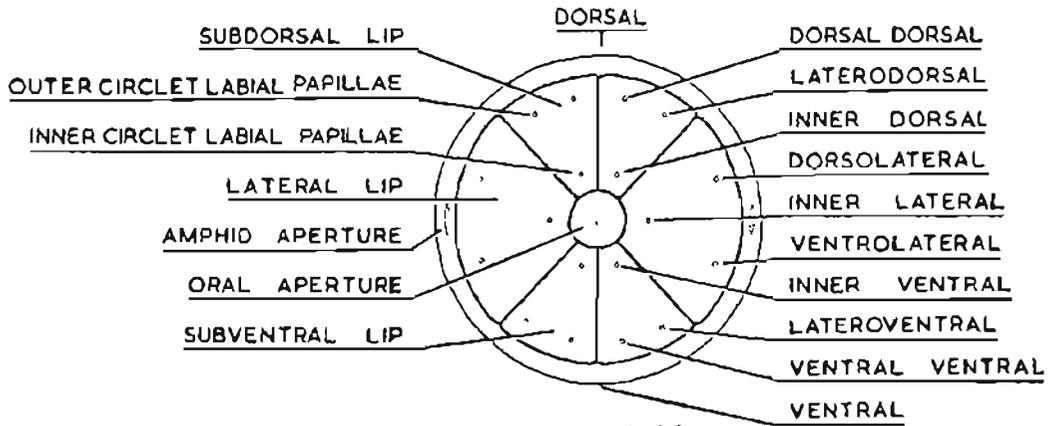


Fig. 13.23

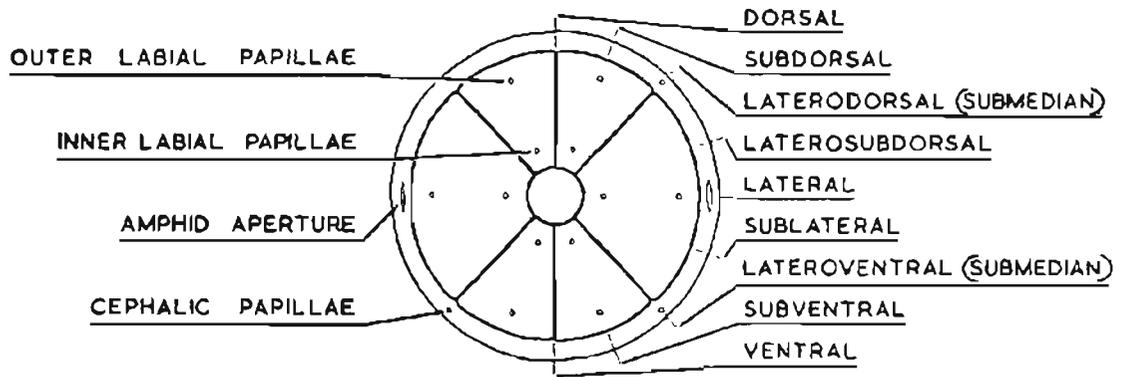


Fig. 13.22

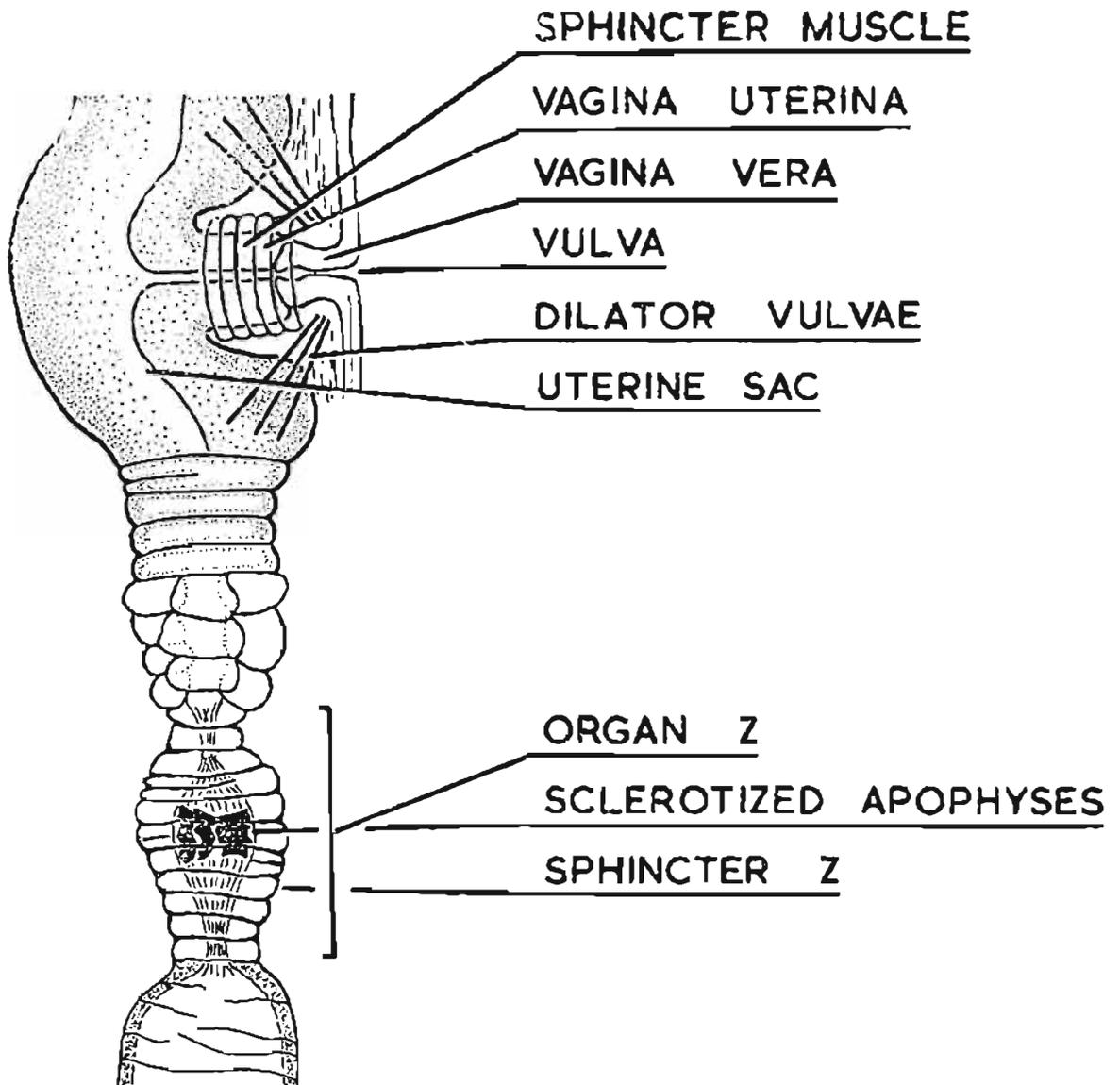
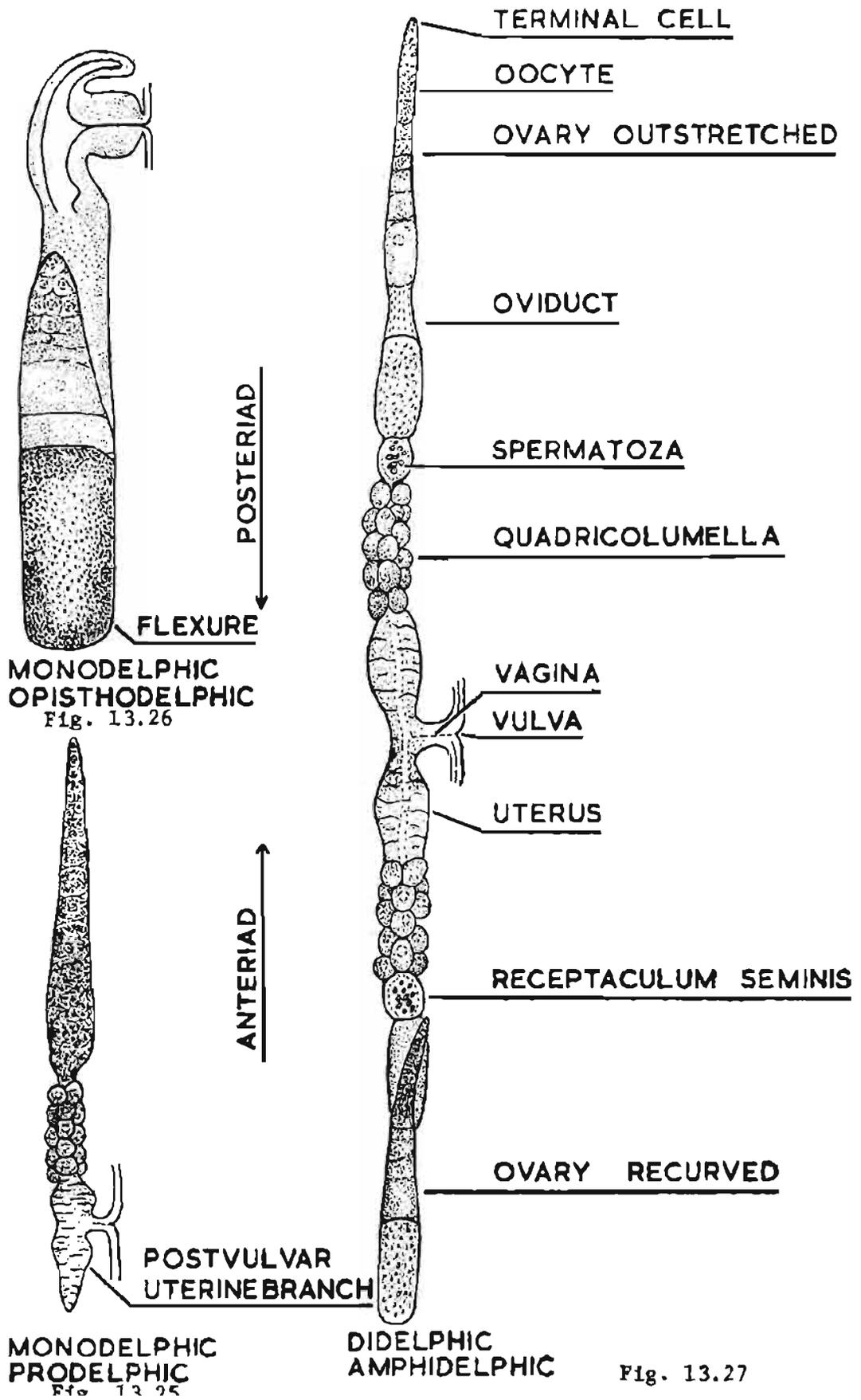


Fig. 13.24



MONODELPHIC  
OPISTHODELPHIC  
Fig. 13.26

MONODELPHIC  
PRODELPHIC  
Fig. 13.25

DIDELPHIC  
AMPHIDELPHIC

Fig. 13.27

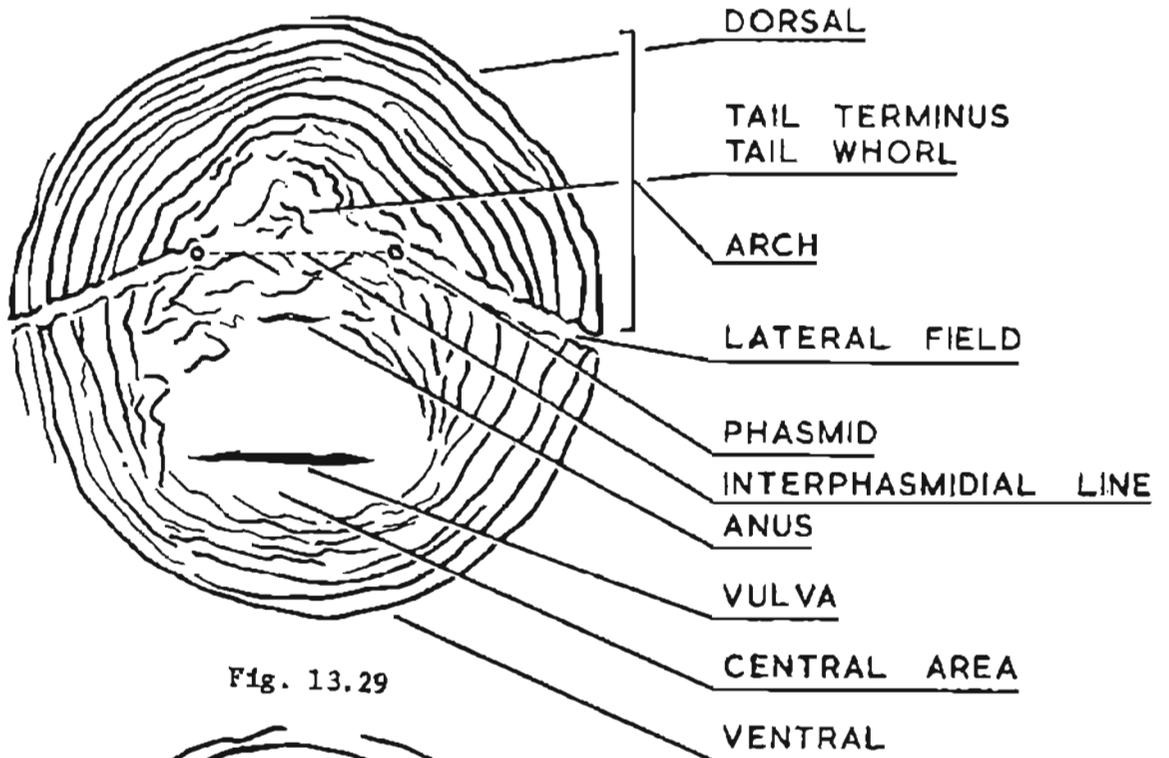


Fig. 13.29

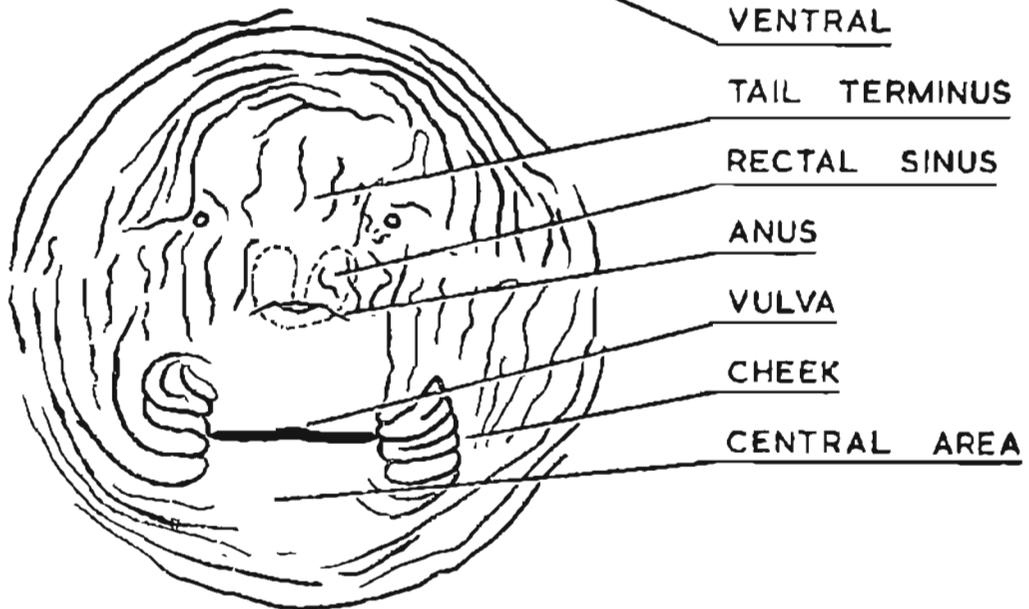
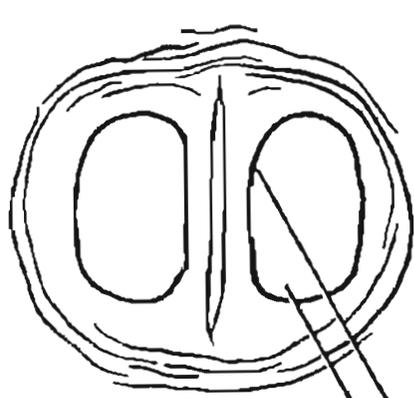
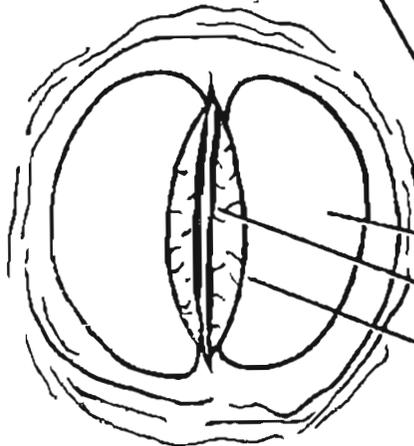


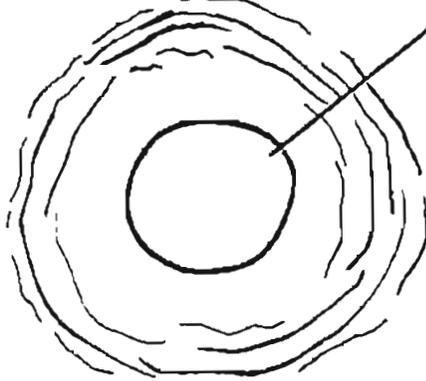
Fig. 13.28



**BIFENESTRATE**  
Fig. 13.32

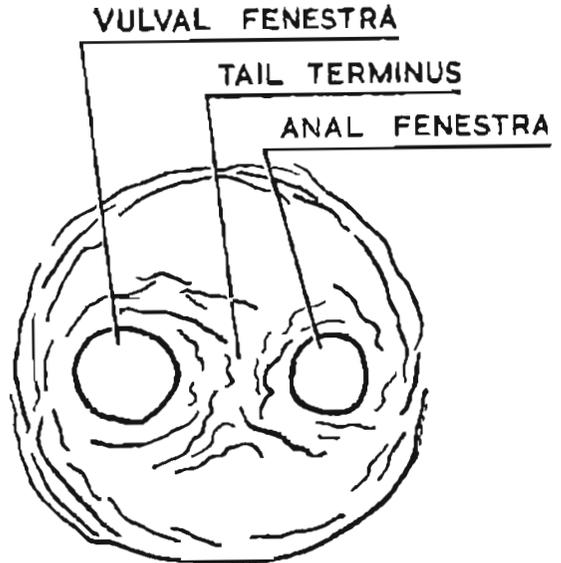


**AMBIFENESTRATE**  
Fig. 13.31



**CIRCUMFENESTRATE**

Fig. 13.30



**TERMINAL VIEW OF CYST**  
Fig. 13.34

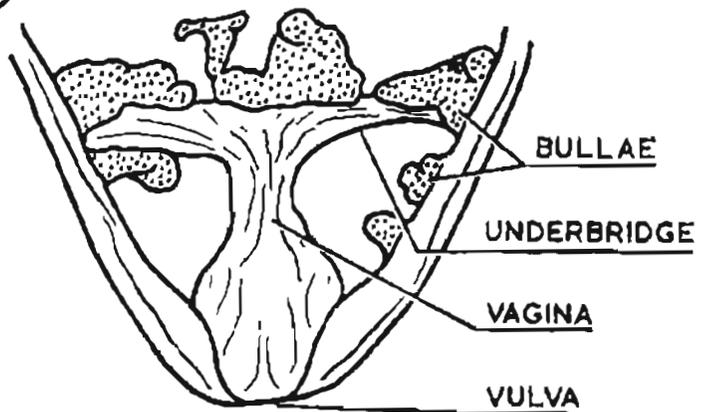
**BROAD VULVAL BRIDGE**

**SEMIFENESTRAE**

**VULVAL SLIT**

**WALL OF VAGINA**

**FENESTRA**



**CYST VULVAL CONE**  
Fig. 13.33

**BULLAE**

**UNDERBRIDGE**

**VAGINA**

**VULVA**

## CHAPTER 14

### INTEGRATED PEST MANAGEMENT IN MAIZE PRODUCTION

Integrated pest control is a pest management system that in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury.

Integrated control is applied pest control that combines and integrates cultural and chemical measures into a single unified pest control program. Chemical control is used only where and when necessary, and in a manner that is least disruptive to beneficial regulating factors of the environment.

Cultural control practices are based mainly on the maximum reduction of the carry - over of pests from one crop to the next. Ways to achieve this include such practices as crop rotation, destruction of stubble or other plant debris, shortening of the growing season by homogenous planting dates and early harvesting, and the sowing of trap crops.

Recent advances in pest control have greatly increased crop yields as well as their quality. They have also provided for the elimination of pestiferous and disease bearing insects. But after a period, the continuous use of these insecticides has produced serious ecological disturbances in the ecosystem. The insect parasites and predators were killed, particularly when wide-spectrum insecticides such as DDT,, with a long residual effectiveness were employed. With their natural checks greatly reduced, other insects of minor importance became major pests. A somewhat similar problem

may be developing in the use of herbicides. A primary weed may be controlled, but it may be succeeded by a secondary weed which may become of major importance.

The most serious problem arising from the long use and continuous use of insecticides has been in the development of resistance in many species of insects. Changing the type of insecticide has helped, but in time some insects have become resistant to them and also their combinations. Supplemental control measures for such insects must be developed.

Environmental pollution is of concern. The widespread use of insecticides has killed birds, fishes and other forms of wildlife. Suggestions have been made that the use of all pesticides be eliminated. But this is not presently feasible with the greater demand for more food and the need for protection from pestiferous and disease-bearing arthropods. Conversely, some producers desire destruction of every injurious insects within a crop unit. This, too, is hardly applicable. Thus crop protection workers face pressures from all sides. All groups need to reach a compromise and develop a comprehensive program of insect control.

Insecticides of a more selective nature and with less residual effectiveness need to be employed. More careful supervision may be necessary, and only those applications essential for the production of satisfactory yields of crops should be made.

#### 14.1 Integrated pest management in Africa:

A number of reasons favour the implementation of integrated pest control in Africa:

- (1) The physical environment in the mostly tropical and subtropical areas is generally conducive to the development of pests throughout the year.

This creates optimum possibilities for the effective functioning of biotic elements of regulation that are naturally occurring in relative abundance.

- (ii) The agro-ecosystems, with relatively few exceptions, have not yet been subjected to intensive pesticide application, so the control system can develop from a relatively undisturbed base. Moreover, the latter fact avoids the revision of an already established system of principles, and vested interests. One might add the following arguments.
- (iii) Most production in the developing countries in Africa is for local consumption and the criteria for purely external (cosmetic) quality may not be as extreme as in developed countries. This may reduce the need for almost total absence of pests in many situations.
- (iv) Large acreages are still opened for agricultural production in many parts of Africa; thus plant protection techniques based on integrated pest control could be implemented from the very beginning, avoiding "competition" with established practices.

#### 14.2 Progress in integrated pest management in Africa:

The discussion of Integrated Pest Control in Africa is limited to the Arab Republic of Egypt which so far is the only country in Africa where such programs have been applied on a large scale. The crops involved are cotton, maize, rice and sugar cane.

Integrated Pest Control in Egypt was developed as a consequence of the recognition that chemical insecticides are not the ultimate solution for the control of most pests attacking major crops. The problems encountered were insect resistance, and environmental pollution in the densely populated Nile Valley.

These drawbacks were especially apparent in cotton where resistance often led to insufficient control of the leafworm *Spodoptera littoralis*. Heavy infestations by *Heliothis armigera* occurred in 1974. Population increases were already noticed in the two preceding years, whereas the insect was virtually absent in earlier periods (Georghiou, 1975).

The major pests of maize include the corn borers: *Sesamia cretica*, *Chilo aganemmon* and *Ostrinia nubilalis*; the cotton leafworm, *Spodoptera littoralis*; and the corn aphid *Rhopalosiphum maidis*. Until 1965 as many as four insecticide applications were carried out during the growing season, but losses were still considerable.

Studies on the relationship between sowing dates and borer infestation showed that maize sown between mid-May and mid-June escaped most of the attack. Further experimentation confirmed this and sowing dates were fixed accordingly. This was completed by the establishment of economic thresholds above which spraying would be done. Implementation of the above findings has led to the following results:

The area of maize treated with insecticides against borers decreased from 692,000 acres in 1964 to an average of 22,000 acres by 1978, losses were reduced over the same period from 10.7% to about 3%; overall yields increased from 1.12 ton per acre to 1.64 ton per acre (factors other than crop protection alone also played a role in this respect); infestations by mites *Tetranychus* sp. which often occurred when pesticides were regularly used have almost disappeared (Brader, 1979).

REFERENCES

Brader, L. (1979): Integrated pest control in the developing world.

Ann. Rev. Entomol. 24: 225-54.

Georghiou, G.P. (1975): A further study of insecticide resistance in the cotton leafworm (*Spodoptera littoralis boisd*) and its monitoring in the Arab Republic of Egypt. Consult. Rep. Rome: FAO, AGP DP/EGY/71/591. 26pp.

## CHAPTER 15

### HARVESTING AND STORAGE

Good harvesting, threshing, cleaning and drying practices are important for the success of any storage method a farmer may use.

#### 15.1 Harvesting methods:

Soon after a crop ripens, it will start to dry out whilst still in the field. But even when the grain can be allowed to dry in the field, there is often too much moisture in the air, or even rain, and the grain does not lose a lot of its moisture.

In harvesting the cobs can either be broken by hand from the plant or the whole plant can be cut with a cutlas. Where the entire plant is harvested, they are often stacked in shocks in the field to allow the grain to dry further. In some countries with mechanized farming, the crop is harvested by using a combine.

#### 15.2 Drying methods.

In small scale production, farmers will store small quantities over fire places and in the roofs of houses. For slightly larger scale production, they will harvest the crop when it is reasonably dry and then store it in freely ventilated stores or "granaries" which will allow for the air to pass through the crop and continue the drying process. When removed from the field it can be protected from birds, rodents and being blown over during heavy rain.

It has been found that maize cobs could be placed in a narrow crib of some 60cm in width, even when the moisture content is as high as 35%. It will not be infected by fungi and by November/December in West Africa, will be dry enough for shelling and then storage. This gives the farmer a chance to

plant another crop during the August/November period of the short rains. The crib then is a combined drying and storage structure.

In the dry zones, the grain can be shelled immediately after harvesting and stored without additional drying being necessary. In the humid zones the crop can be dried and stored in a crib or traditional ventilated granary. It can be protected in the crib from rodents by use of rat guards and from insects by use of an insecticide. The currently most useful insecticides for use with cob maize (dehusked) is pirimiphos-methyl applied monthly in liquid form on the outside of the crib through the use of a simple domestic spray pump. It has a fumigant effect and not directly applied to all the cob and is thus very safe.

### 15.3 Maize shelling methods:

Several methods are available for shelling maize and include:

- (i) shelling by hand;
- (ii) shelling by internally ribbed tubes ;
- (iii) beating cobs with stick;
- (iv) using single intake disc (hand operated);
- (v) using double intake disc (which is either hand operated, pedal operated or engine driven).

For the small producer (less than 10 tonnes per annum) the most economical method would be the use of the system of beating the cobs by stick which is of course the common current technique.

The output of the internally ribbed tubes (approximately 150kg/day) is very demanding in labour and is really only suitable for domestic purposes.

The output of the single intake disc is obviously no greater than beating the cobs with a stick, so that its capital outlay is out of proportion to its benefits as far as output is concerned.

A farmer producing 10 tonnes of maize could possibly be advised to acquire a twin intake sheller and undertaking contract work on neighbouring farms. The decision as to whether he would have it engine driven would depend largely on the volume of outside work he can acquire.

#### 15.4 Cleaning:

No matter what method the farmer uses for harvesting and threshing, he should aim for clean, whole grain. Where the grain 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, husks and dust. The grain is then sieved. The pieces smaller than the grain kernels 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 kernels.

This screening technique can be used even when a machine is not 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 methods 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 grain and powder are blown aside by the wind. But the heavier stones and pieces of earth fall with the grain. For good cleaning, winnowing must be done over and over. Some grain is always lost.

What is a safe moisture content for storage?

Maize cobs and other crops can be stored at over 30% moisture content in freely ventilated structures. Grain of all crops need to be below 15% moisture content for storage in jute bags, and below 12% for storage in silos (in bulk).

15.5 Storage of grain on a large scale:

One has the choice of storage in silos (bulk) or in jute bags. Storage in silos is a specialized business requiring expensive handling equipment and other drying equipment to ensure that the moisture content is below 12% before storage.

Storage in jute bags is the most adaptable. The grain can be stored when the moisture content is just below 15%, which is usually achievable in November/December in humid West Africa. The jute bags can be stacked in a warehouse, which can also be used for other crops, fertilizers etc. Some precautions need to be taken when storing bags in a warehouse.

- (i) The bags must be placed on dunnage and not directly on the floor or against walls, so as to avoid dampness penetrating the sacks.
- (ii) The warehouse must be rat proof and also preferably, insect proof.
- (iii) The grain must be protected from insect attack. This can be done by fumigation or the spraying of the top of each layer of bags with Pirimiphos-methyl (actellic 50 E.C.)
- (iv) The bags must be regularly inspected and retreated if insect activity becomes noticeable.

15.5.1 Seed Storage:

The method of drying and storage of grains described so far can also be

used for seed storage although the viability of the seed may slightly deteriorate in certain instances. If one's finances allows for it, more expensive methods for drying and storage can be adopted. In dry areas where drying is no problem the grain can be placed after reaching a moisture content below 12% in metal drums, fumigated and sealed until required for use. The drums should be protected from the heat of the sun.

In more humid areas, the grain will need to be dried down from 15% to below 12%. A simple batch drier could be used for this purpose. Care should be taken that the drying air is not heated above  $45^{\circ}\text{C}$  (approx.  $120^{\circ}\text{F}$ ), otherwise it will affect viability of the seed. Storage after drying could be in metal drums as described above.

Seed grain could also be stored, providing it is below 12% moisture content, in plastic bags. It has the advantage over jute bags in that it will prevent the entrance of moisture and insects to the grain. It should be fumigated before sealing of the plastic bags and stored in a rat-free environment.

In very specialized seed production schemes, where very valuable seed is to be preserved, rooms in which the temperature and humidity is controlled are used.

#### 15.6 Types of mechanical driers (illustrated overleaf in Figure 15.1)

(i) Bin drier: This type includes tunnel driers and pot-hole (sack) driers and is a batch type drier useful for small lots or where many small lots must be dried separately.

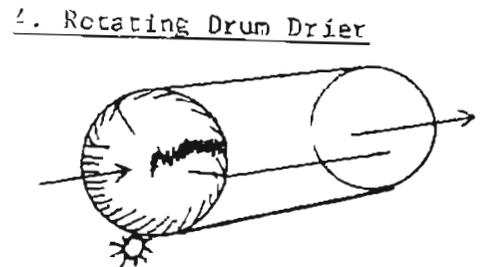
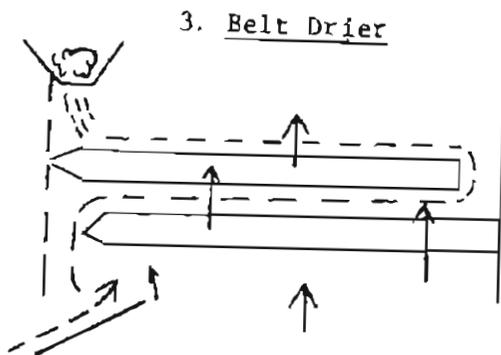
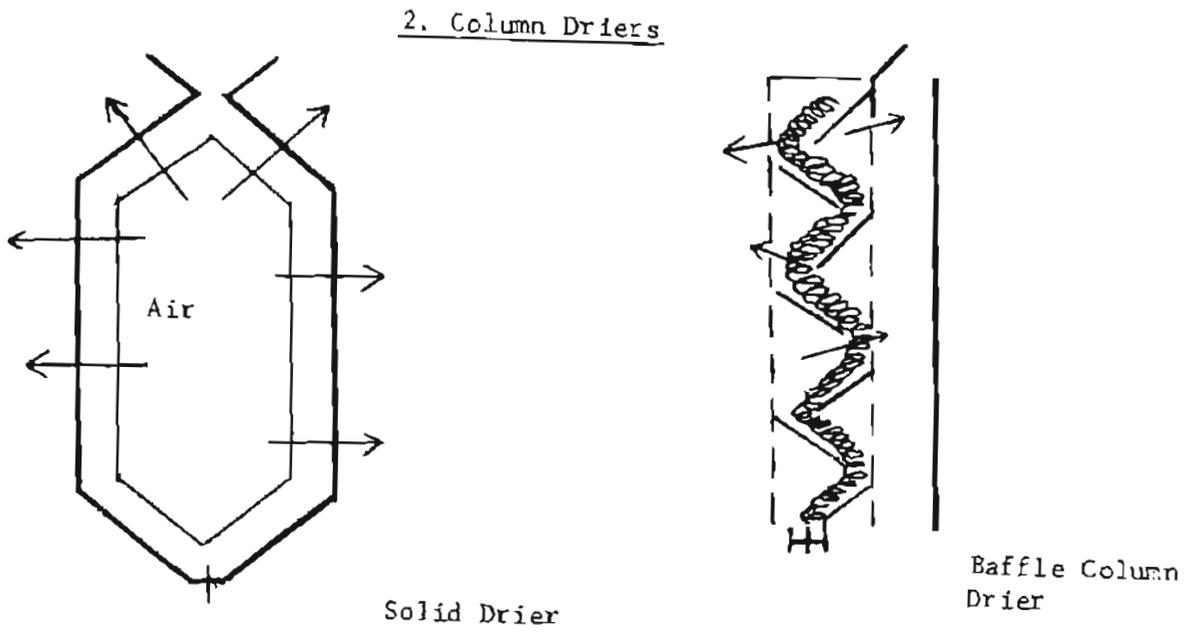
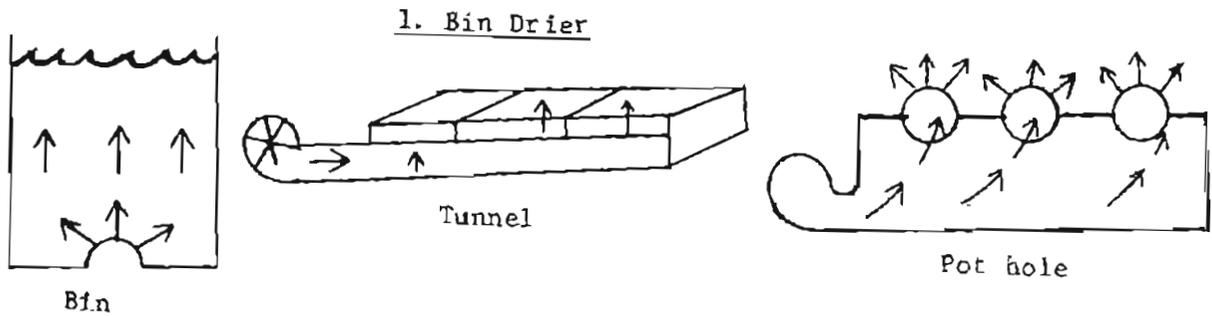


Figure 15.1: Types of driers.

The air is pushed or pulled through the grain and may go from bottom to top or vice versa. In bin driers, the depth of the grain is limited because the power required to force air through the grain is equal to the cube of the depth and in deep bins the entering air picks up moisture from the grain and cools (heat is required to change the liquid moisture to a vapour) and may even deposit moisture on the last layer of grain as it leaves (if the air flow rate is too low) thus causing mould and deterioration of this layer.

(ii) Column drier: Column driers are usually for continuous flow of large lots or quantities of similar quality grain with two columns of 20-38cm thick grain flowing past an air chamber. The grain either flows in a solid column or the grain is turned by baffles as it descends the column to allow uniform drying of all the grains. The rate of moisture removal is regulated by the speed of the flow of grain in the column.

(iii) Belt drier: This is a method for high temperature drying of grain, not for seed, where the hottest air first contact the driest grain.

(iv) Rotating drum drier: By lifting and dropping grain through the air flow all sides of each grain is exposed to the drying air and presumably resulting in more rapid drying. This is usually a batch drier but could be adopted to continuous flow drying.

#### 15.7 Testing grain for moisture content?

Grain that is too moist will heat in storage. All stored grain should be examined frequently to see if it is heating. Heat build-up deep within the grain is a serious danger signal. Unfortunately, waiting until you can feel the heat in the grain is waiting too long.

Various electrical moisture testing devices are sold. They are seldom available when and where needed. Most of them are complicated and expensive.

#### 15.7.1 Grain moisture content determinations.

$$\% \text{ Moisture Content (Wet basis)} = \frac{\text{Fresh weight} - \text{dry weight}}{\text{dry weight}} \times 100$$

$$\% \text{ Moisture Content (dry basis)} = \frac{\text{Fresh weight} - \text{dry weight}}{\text{Fresh weight}} \times 100$$

Sampling. Take many samples from the bulk, mix and subdivide.

Familiarize with cone probe and sampling spears for grain stored in bags or silos.

#### 15.7.2 Common moisture determination methods:

- (i) Biting, rattling, feeling and observation - needs experience
- (ii) Mix grain with dry salt (non-iodized sodium chloride). If the salt goes lumpy, the moisture content of the grain is over 15% - a simple quick method indicating whether the grain is ready for storage in sack (but not necessarily in bulk).
- (iii) Portable moisture meters. (a) The Cera Tester - robust portable, operates on unground grain, tends to read approx. 5% high with hybrid maize. Inaccurate for moisture contents over 22%.  
(b), The Marconi Moisture Meter: More delicate, portable and operates with ground grain. Inaccurate for moisture contents over 22% but otherwise accurate, providing good care is taken.  
(c) The stem hygrometer: Measures the relative humidity surrounding the grain and the dial reading is calibrated to read moisture content directly. Not very accurate but useful for measuring moisture content of bulk or bag grain.

(iv) Oven methods: The most accurate method available and used primarily in experimental work or for calibrating field instruments that are portable.

Two basic methods are used:

(a)  $130^{\circ}\text{C}$  ( $266^{\circ}\text{F}$ ) oven temperature for ground grain: should take 1-2 hours before all moisture removed.

(b)  $100^{\circ}\text{C}$  ( $212^{\circ}\text{F}$ ) oven temperature for whole grain samples: should take 72 to 96 hours for removal of moisture.

Note: (i) Crops containing volatile elements need to be dried at a low temperature.

(ii) Most crops deteriorate in drymatter if kept in an oven for over 96 hours.

(iii) Sample size is important, as well as characteristics of different crops. It is advisable to do repeated weighings and further drying until no further weight loss occurs. Confidence and accuracy in ones own technique is thereby developed.

(iv) To avoid moisture absorption whilst cooling and weighing a sample, it should be covered with a glass or similar plate.

#### 15.8 Storage methods:

Each farmer has some method of storing his grain. Any improvement in this storage method must be made by steps the farmer sees as the right ones for his situation and need.

Whichever kind of storage method a farmer uses there are certain principles upon which every method is based. Every storage container, no matter what it looks like or what it is made of, should:

(i) keep grain cool and dry,

(ii) protect grain from insects,

All storage methods try to do the above three things. But to do these things requires the following good storage practices:

- (i) Drying grain well (to 12-13% moisture content before putting it into storage.
- (ii) Putting clean grain only into containers which have had all old grain, dust, straw and insects removed.
- (iii) Keeping the grain cool and protected from large changes in outside temperatures. This can be done in a number of ways:- by using building materials which do not easily pass on changes in outside temperatures to the stored grain, by keeping or building storage containers away from direct sunlight, by painting the containers white.
- (iv) Protecting the grain from insects by following rules for cleanliness and drying, by applying insecticides and/or by putting the grain into airtight storage.
- (v) Water proofing the buildings and containers as much as possible. This is done both by the way the building is constructed and by applying materials which keep water from soaking into the building material. Storage buildings should be built on well-drained locations. They should not be placed where they will be flooded by ground water run-off during heavy rains.
- (vi) Making sure containers are rodent-proofed in all possible ways.
- (vii) Checking the grain regularly while it is in storage to make sure it is not infested, and following recleaning instructions to destroy insects, if they are found when the grain is checked.

15.8.1 Methods of storing maize:

- (i) Maize has been stored in basket-like granaries made of grass, reeds, bamboo strips, or small branches.
- (ii) Maize can be stored in the improved maize crib
- (iii) Maize can be stored in sacks
- (iv) Maize can be stored in air-tight plastic containers and in metal drums.
- (v) Maize can be stored in metal silos and also in concrete silos.

15.8.2 Factors affecting choice of storage method:

At every level of storage - i.e.

- domestic - subsistence
- farm - cash cropping
- community - commercial
- centralised- national

there will be a number of different storage methods which can be used. The suitability of a particular method will depend on a number of factors including:

- the scale of operations (as above)
- value of the commodity
- capital and running costs
- availability of materials and expertise
- climate conditions
- pest problems.

The following is a summary of some of the considerations relevant to each type of structure with particular stress on the techniques for pest control possible within each system. The methods described should not be taken as recommendations;

Traditional Cribs:

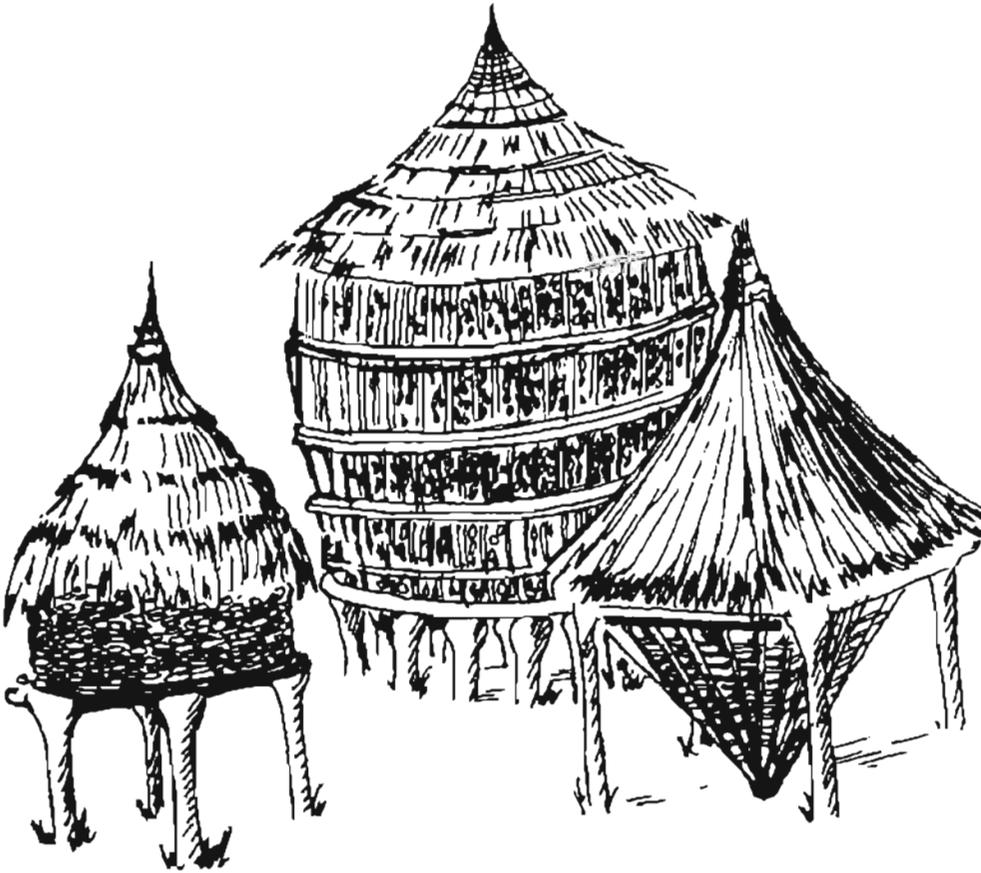


Figure 15.2: An illustration of some traditional cribs

They are characterised by lower levels of ventilation as of 'improved' designs; maize often stored in the husk, sorghum and millet on the head.

Crop must remain longer in the field to dry sufficiently to avoid moulding and losses in the field due to birds, rodents and 'lodging' will be severe, especially in humid areas.

Crib itself may not be secure against rodents. Husk (for maize) may provide considerable protection against insects for traditional varieties; if an insecticide is used its efficiency may be reduced by the presence of the husks (evidence conflicting).

In a 'closed' type of crib - e.g. basketwork - insecticide may be relatively persistent, but there is no scope for reapplication (poor penetration). The capital cost of structure are low and durability may be poor.

(ii) Improved cribs:

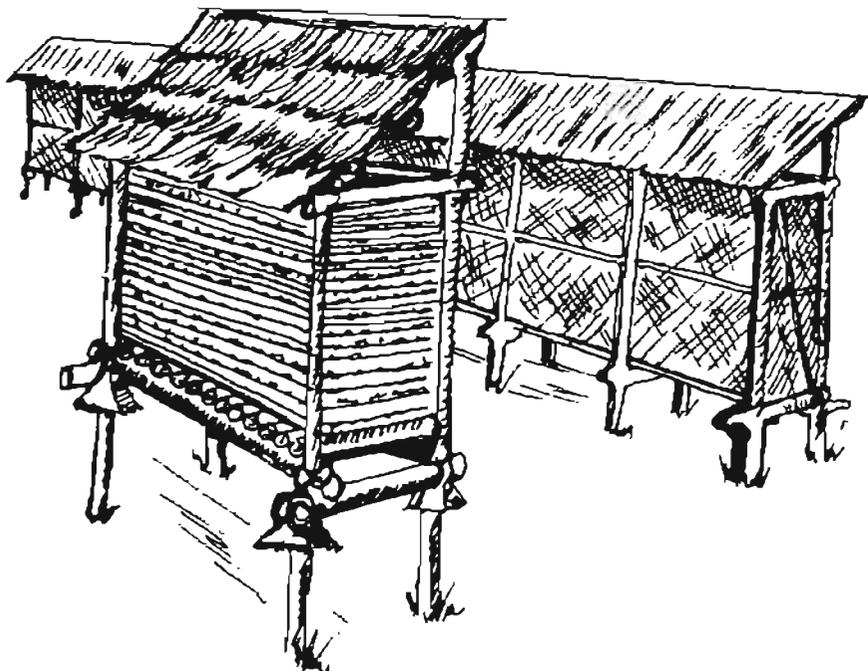


Figure 15.3: An illustration of improved cribs.

They are highly ventilated, allowing harvest at high moisture content.

Early harvest reduces field loss.

Can protect against rodents. Ventilation virtually eliminates mould problem; though there may be some superficial germination in very wet conditions.

Husks must be removed, because of the high moisture content, exposing grain to insect attack; an insecticide treatment with dust or spray will be necessary in most localities. Insecticides admixed initially will tend to breakdown

Capital costs are low to moderate, depending on materials chosen; and recurrent costs involves only insecticides and labour for its applications.

(iii) Silos:

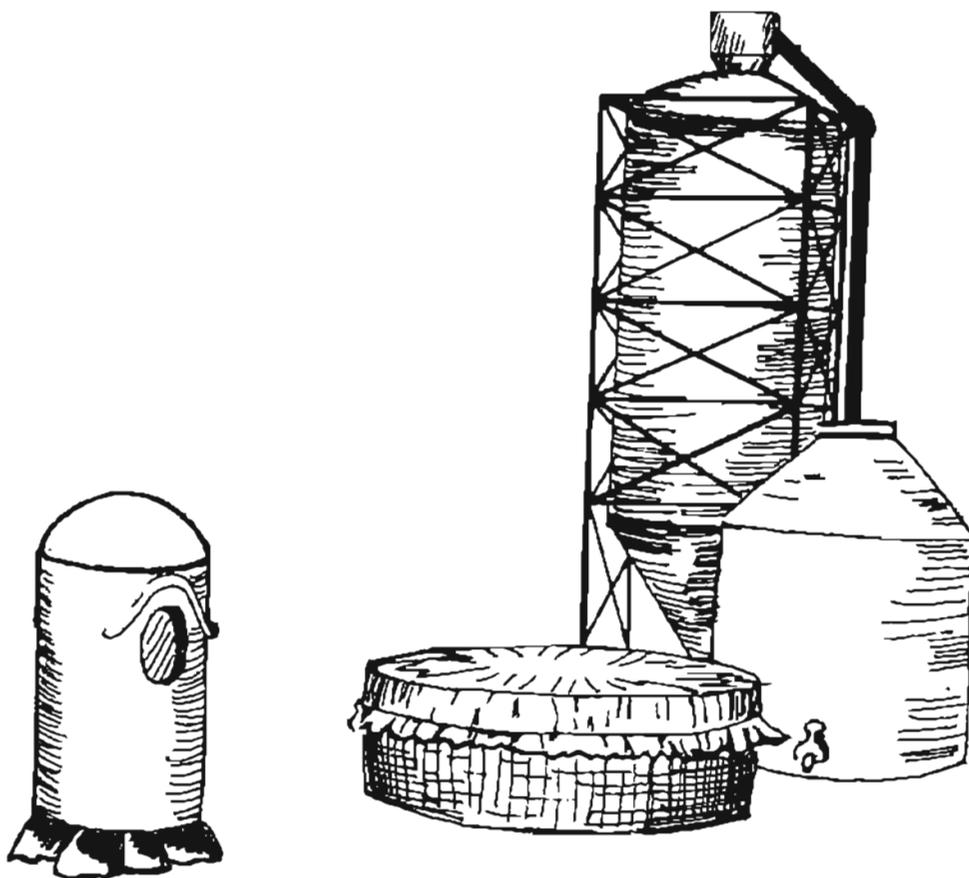


Figure 15.4: An illustration of Silos structures.

These are unventilated structures, storing bulk grain (traditional or improved). Produce must be very dry initially - artificial drying obligatory in humid zone. Rodent damage can be eliminated. Moulding very likely in humid zone; daily heating and cooling promotes moisture migration and local caking which spread rapidly. Requires frequent inspection to guard against caking - may require artificial ventilation (not feasible at rural level) or emptying and redrying. Insect control potentially good; suitable structure can be

fumigated initially and sealed against reinfestation; admixed insecticides (dust) should be comparatively persistent. Low moisture content will mean slow insect development. With good management can be effective, but with poor management there is risk of rapid and total loss of the crop.

Larger scale installations require bulk-handling equipment.

Capital cost: high to very high (dependant on materials);

recurrent cost of drying may be high, and considerable labour demand involved in collecting fuel at harvest time.

(iv) Warehouses:

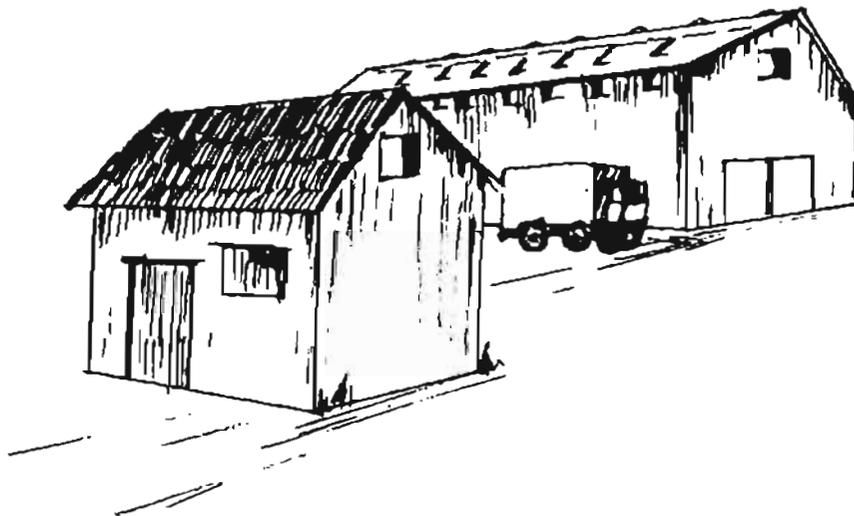


Figure 15.5: Warehouses for grain storage. (are bag-stores in general)

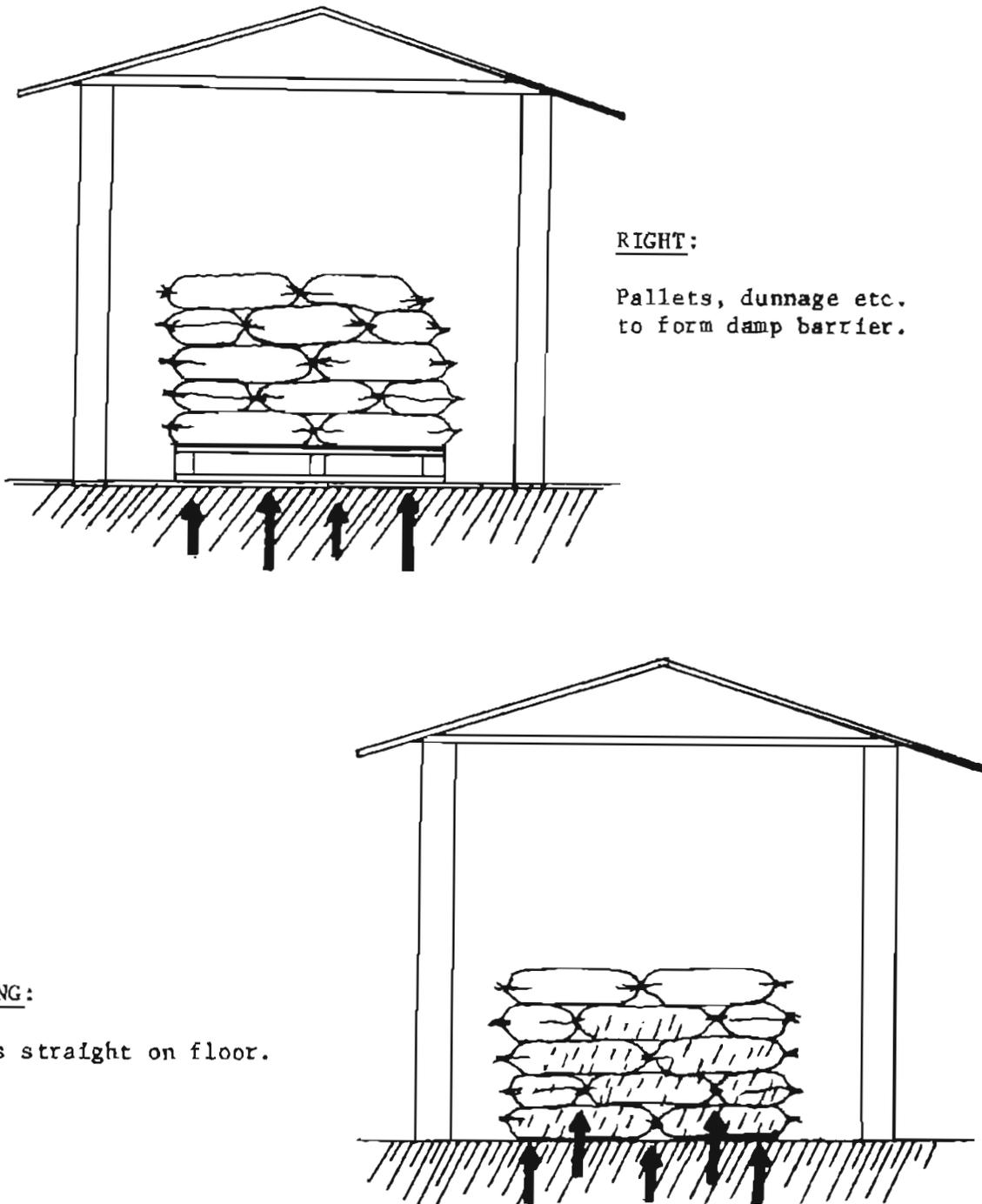
Requires some drying initially, but higher tolerance than bulk storage. Rodent control possible.

Bagged produce can be moderately well-protected against pests; for valuable produce it may be feasible to fumigate and prevent reinfestation; spraying will be much more effective than in ventilated structures; insecticides will be comparative persistent. Handling does not necessarily require specialized

15.9: Care of Produce in a Warehouse:

The four most important points to remember:

1. Prevent damp from the floor reaching the produce



RIGHT:

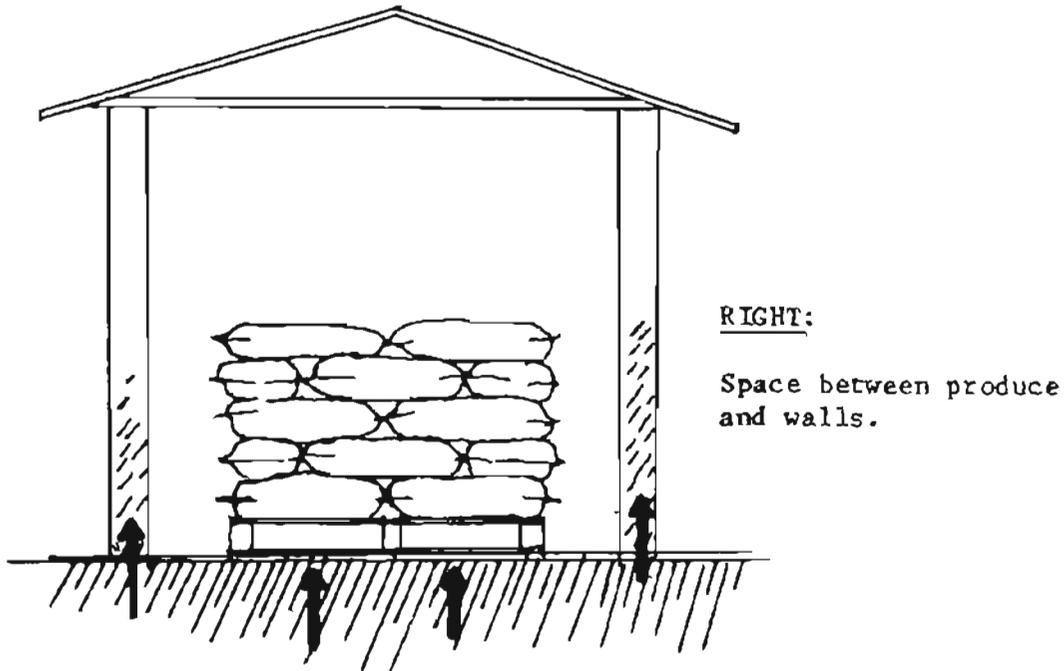
Pallets, dunnage etc.  
to form damp barrier.

WRONG:

Bags straight on floor.

Figure 15.6: Illustration of correct method of storing grain in a warehouse

2. Prevent damp from walls reaching the Produce



WRONG:  
Produce touch walls.

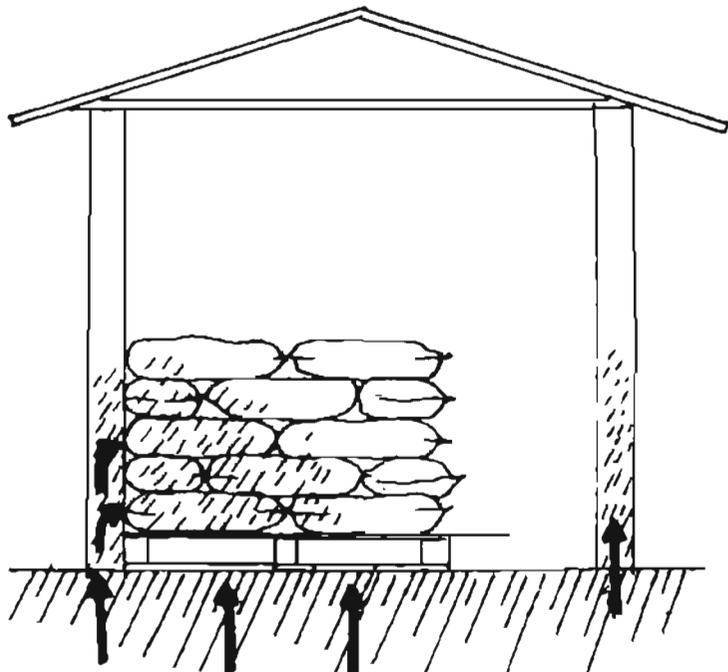
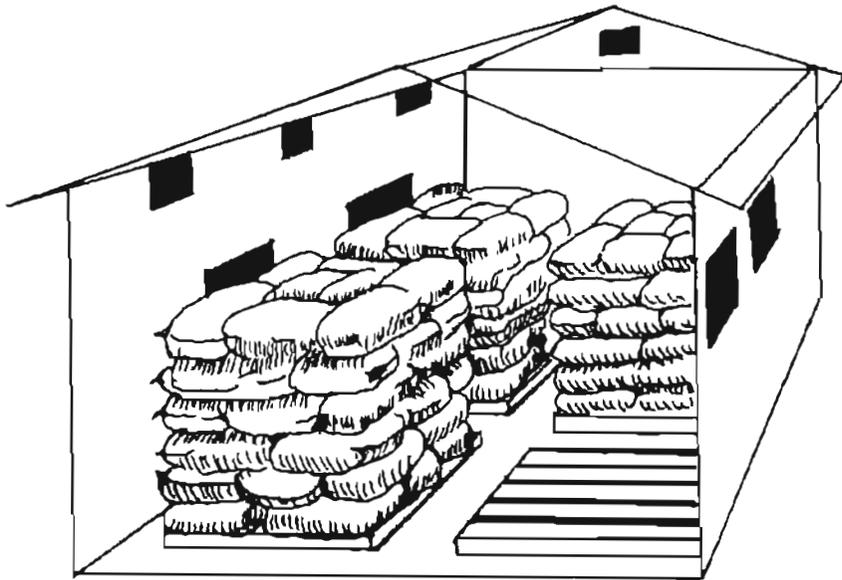


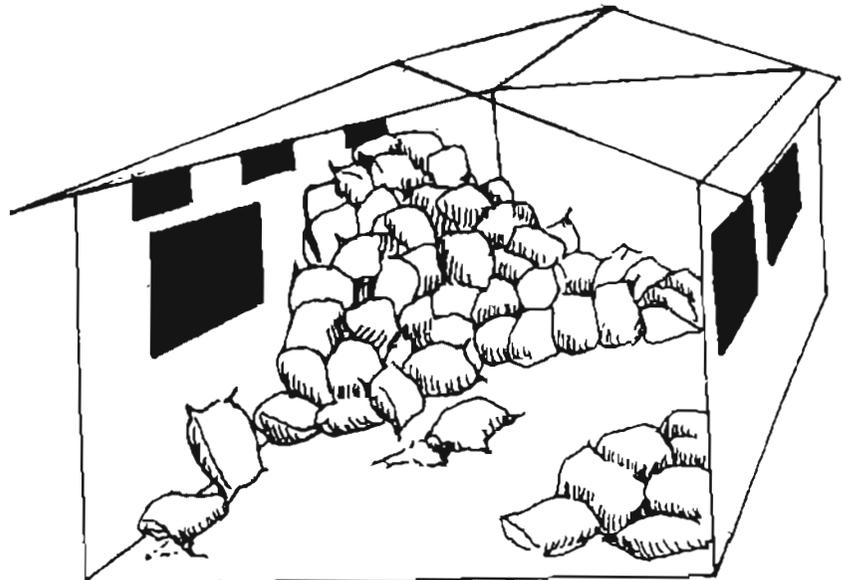
Figure 15.7: Illustration of correct method of storing grain in warehouse.

3. 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



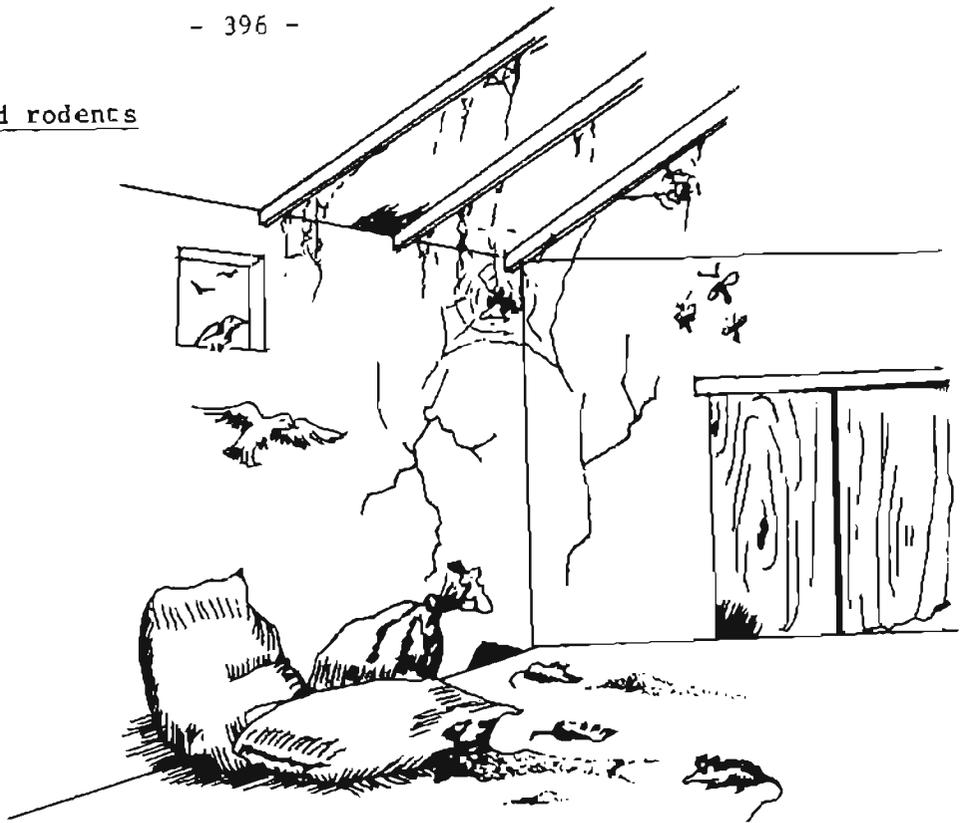
RIGHT



WRONG

4. Control insects and rodents

WRONG



RIGHT

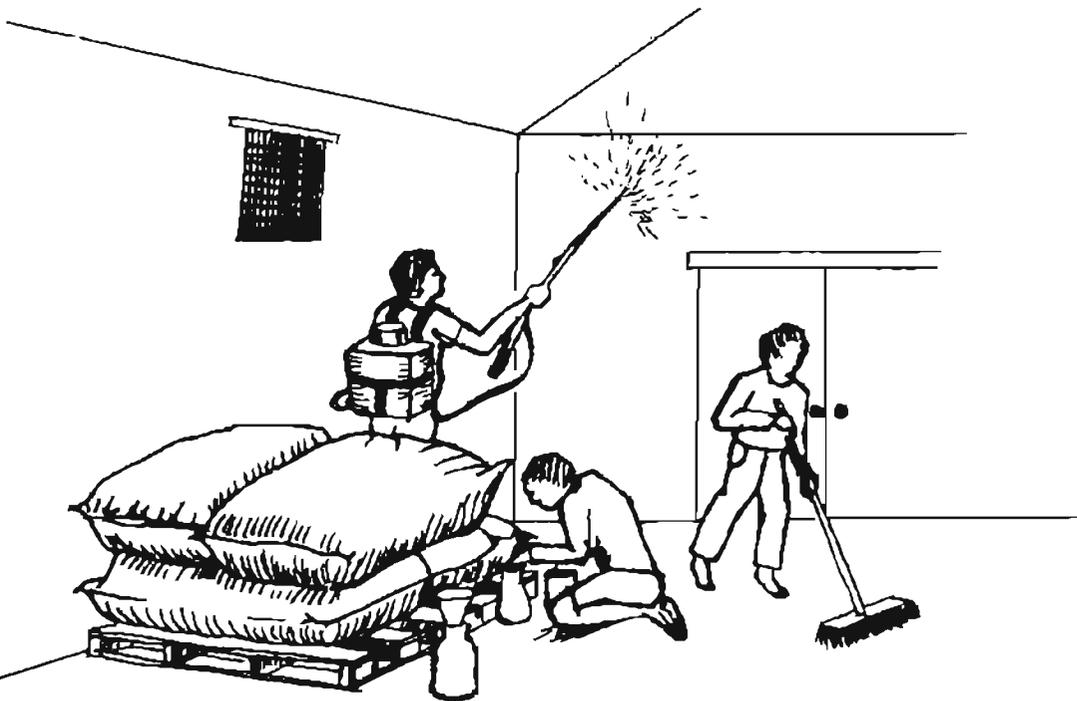


Figure 15.9: Control of insects and rodents in storage

- (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.

15.10: Warehouse management practices:

1. 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.

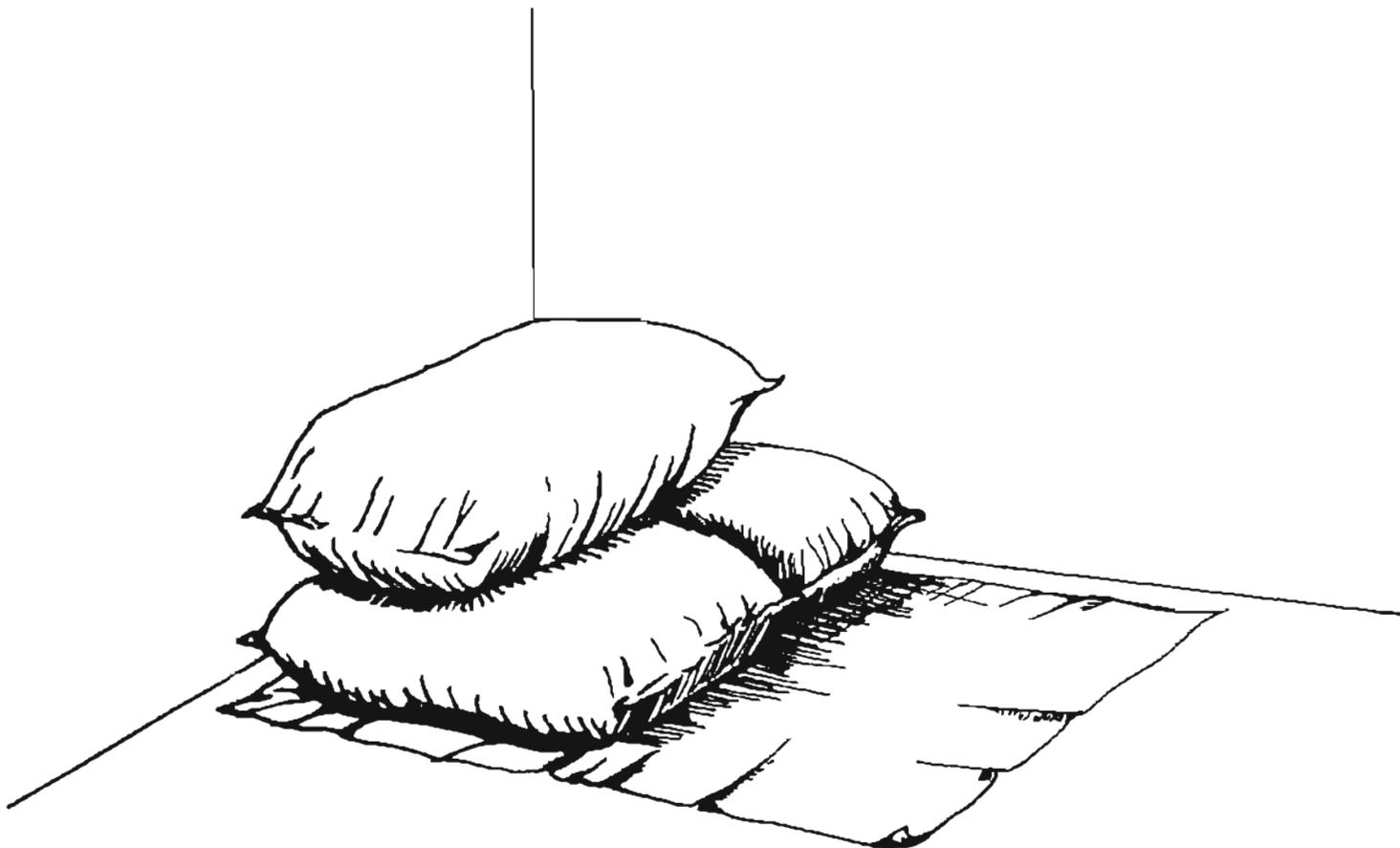


Figure 15.10: Dunnage material for warehouse floors

Alternately, one could simply lay down straight poles on the floor and place the sacks on them as is shown.

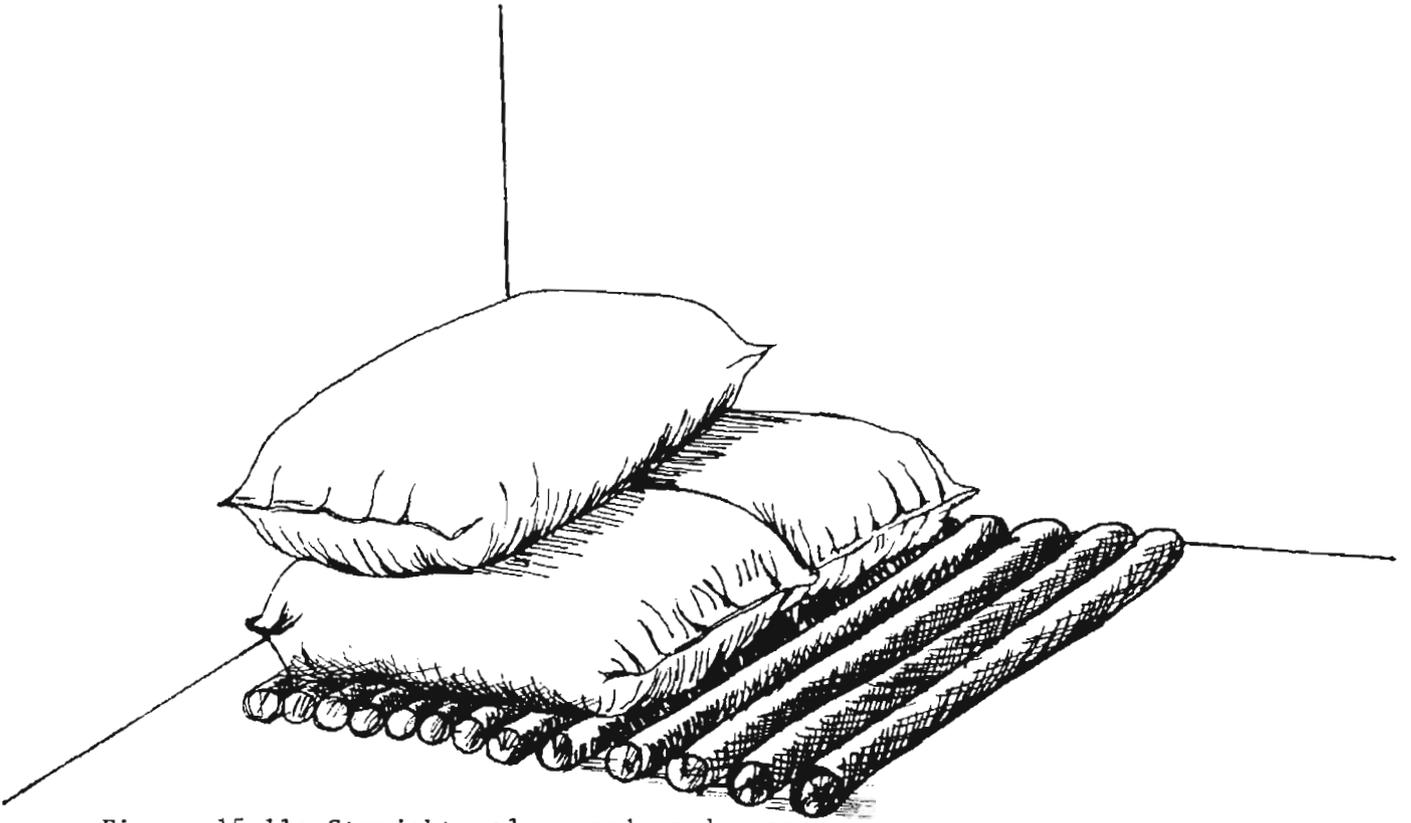
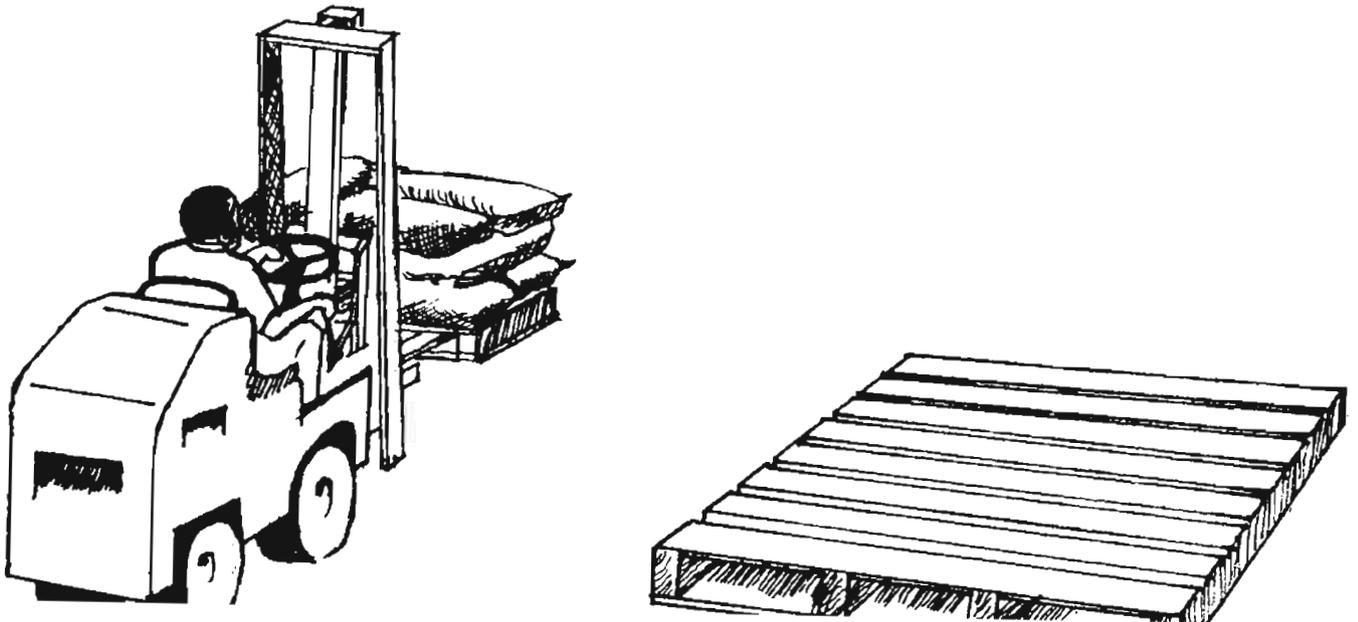


Figure 15.11: Straight poles used as dunnage:

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.





15.12 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 eccentric axle as shown below.

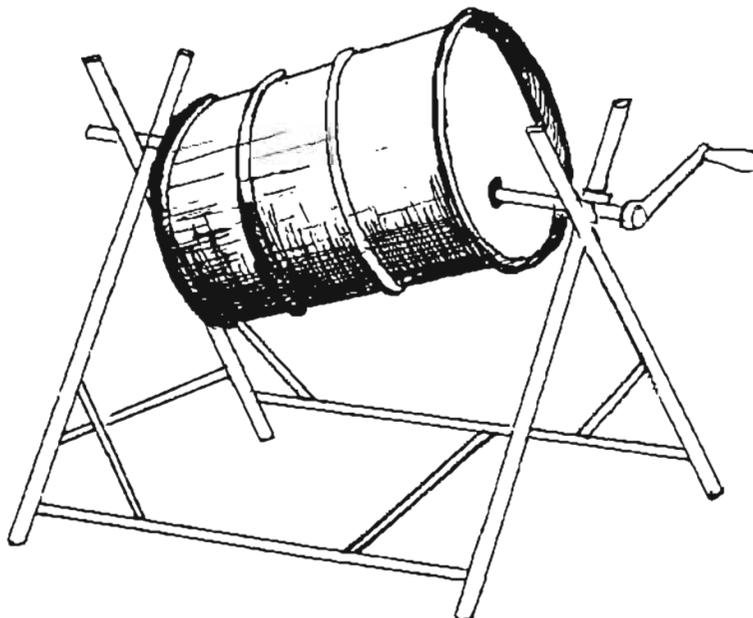


Fig. 15.12. Drum with grain.

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.

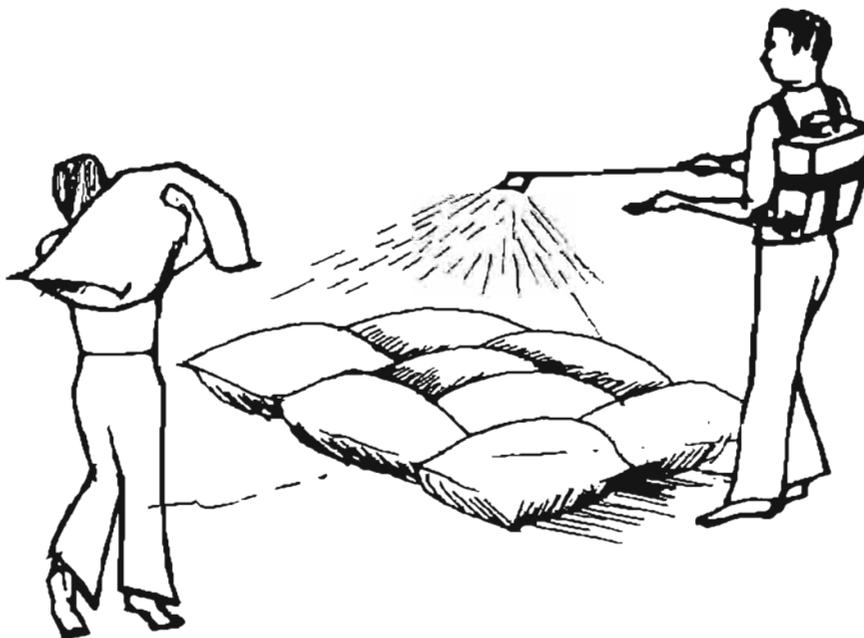


Figure 15.15: Spraying and dusting of sacks with insecticide.

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.

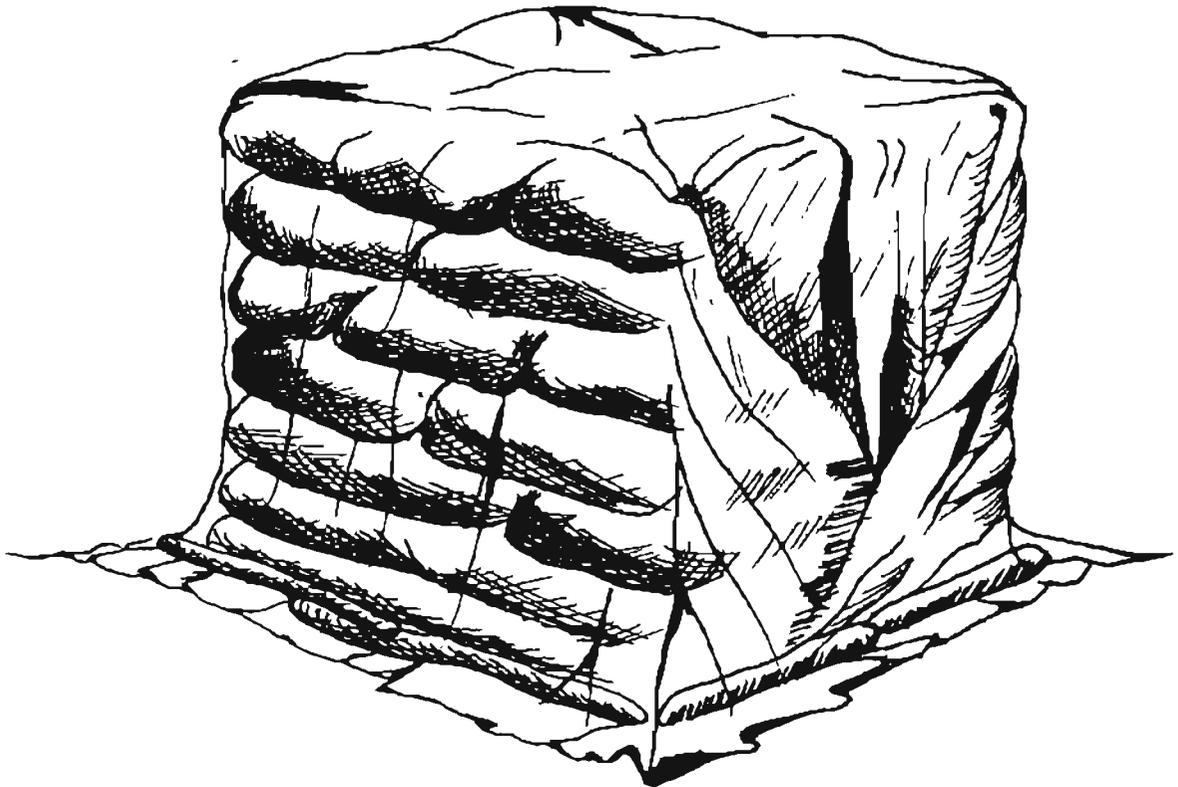


Figure 15.16: Fumigation of bags of grain.

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.

### 15.13 Insect pest problems in storage:

In the humid tropics farmers face the likelihood of extensive and sometimes total loss of cereals and grain legumes during storage. This loss represents a major constraint on increased agricultural production and animal husbandry. Insect damage results in:

- (i) Actual weight loss of the commodity. Estimates vary widely but, in the humid tropics, it would not be unusual, without treatment, to lose 40-50 percent of the weight of grain over an entire storage season.
- (ii) Loss in quality and so an additional loss in market value due to contamination with insect debris, increase dust content etc.
- (iii) Promotion of mould development in poorly ventilated conditions. Insects, moulds and the grain itself, produce water in respiration i.e. the breakdown of carbohydrate substrate, which in humid conditions without adequate ventilation, mould "caking" can occur and spread rapidly, causing severe loss.
- (iv) Reduced germination in seed stored for planting. Some storage pests preferentially attack the embryo, and thereby exacerbating the problem.
- (v) Reduced nutritional value. This is more serious when the embryo of cereals is attacked

#### 15.13.1 Sources of infestation:

- (i) Infected residues - both on the farm and in the home
- (ii) Fabric of storage structures - many storage pests can survive for long periods without food, or feeding only on minimal accumulation of flour and debris.
- (iii) Natural habitats.

### 15.13.2 Initiation of infestation

Infestation begins in the field for a number of storage pests. Maize and sorghum attacked mainly by maize and rice weevils - *Sitophilus* species, cowpeas and other grain legumes by bruchids.

In maize, field infestation may be reduced by good husk cover, this may break down:

- (i) In "improved" high-yielding varieties where the husk is not properly closed at the tip.
- (ii) With attack by *lepidopterous* pests (e.g. stem borers) which make holes in the sheaths and allow penetration via the damaged silks.
- (iii) With bird and rodent attack.

Field infestation may be accompanied by severe moulding in humid areas. Infestation in the store, then, will come from insects carried from the field (including larvae developing within the grains) and by active migration from other infested stores.

### 15.13.3 Build-up in store:

In the humid tropics, conditions in stores are near optimal for development of pest species. At 27 - 30°C and 70 - 80 percent relative humidity on appropriate grain substrates, rates of increase are potentially very high i.e. 25 times per month for the rice weevil (*Sitophilus oryzae*), 50 times per month for the bean weevil (*Calosobruchus maculatus*), 70 times per month for the red flour beetle (*Tribolium castaneum*).

Development rates can be greatly slowed by dry conditions and there may be some control by "natural enemies", but in general a pest problem can be expected throughout the storage season in the humid areas.

#### 15.14 Sampling and identification of storage insect pests of Maize.

It has been estimated that about 10% of the world's annual cereal production is lost after harvest, mainly due to the activities of storage insects. Maize is one of the commodities which can be seriously attacked in storage and a number of the modern high-yielding varieties currently being introduced are particularly susceptible to damage by storage insects. Apart from the maize actually consumed by the insects, there may be a serious reduction in the quality of the product, involving a further economic loss. Therefore, EFFECTIVE INSECT CONTROL CAN SAVE MONEY.

##### 15.14.1 Sampling of insects:

###### 1. Why do we need to sample?

- (a) To detect an infestation: The EARLY detection of insect infestation and its prompt treatment is crucial to preventing serious loss. Control measures will be more effective against low populations of the pests.
- (b) To assess the effectiveness of control measures: This is necessary firstly to enable you to choose between various alternative methods of control - local conditions, such as the amount of rainfall or the dominant pest species, can greatly affect the relative merits of different chemicals and the method of application. Secondly, you must ensure that you have killed the insects - ineffective applications of insecticides help to encourage the development of resistance, as well as allowing continued damage to your stored maize.

2. Points to remember:

(a) Take representative samples: This means collecting material from different parts of the store - for instance, in a crib, take samples from the middle as well as the surface. The infestation may well not be uniformly distributed and, since many storage insects avoid light, there may be no sign of infestation on the surface, especially during the early stages of attack.

(b) Sample before and after treatment: Pay particular attention to the relative numbers of live and dead insects. Without comparing the results you will not know whether the insecticide has done any good.

(c) Other indication of infestation: You will often be able to find certain evidence of insect infestation before you find live insects. In particular look for:

'Flour' and dust produced by insect feeding; this may be obvious under a crib or beneath dunnage supporting bagged maize  
Emergence holes in grain; the larvae of many storage insects develop completely within the grain and when the adult emerges it leaves a conspicuous round hole.

'Cobwebs', the larvae of stored products moths produce silk as they move and this may be seen as cobweb-like accumulations on cobs or bags of shelled maize.

2. Methods of sampling:

(a) For Crib-stored Maize:

(i) Iowa Corn Probe: The Probe consists of a double tube - the outer bearing a row of teeth which removes the grain from the cobs, while the inner tube collects the sample. Use in conjunction with a large plastic funnel to collect the sample into a container; mark the collection jar/tin so as to

obtain a standard-size sample (100g maize would be sufficient in a heavy infestation but for lighter infestations it might be necessary to collect 500g or more to obtain a representative sample); work quickly to minimise the number of insects escaping.

(ii) By hand: Push the surface cobs on top of a crib to one side; collect the cobs below, placing them rapidly into a plastic bag and then closing the neck securely; five cobs should be a sufficient sample for serious infestations but, again, a larger sample may be necessary for a lighter infestation; shell the maize without removing it from the bag; you can then either take a standard-sized sample, as for the probe or count the total number of insects for the five, or more, cobs collected.

(b) For shelled maize, stored in bags:

'Thief Probe': The Probe allows sampling without undoing the sacks and without serious damage to the material of the sack. Simply push the probe into the sack, angled upwards, agitate gently allowing the grain to flow through the centre of the hollow probe into a collecting jar; again in this case, collect standard-size samples. Remove the probe and scrape the fibres of the sack to close the hole.

In all three methods a sieve can greatly speed the counting of the insects collected; hold the sieve over a funnel standing in a second collecting jar, pour in the grain and shake vigorously. With a mesh size of 10 per inch (equivalent to holes of 2.5mm diameter) the maize grains will remain in the sieve while the insects fall through. Ready-made sieves of the type demonstrated are unlikely to be available locally but a simple alternative can be made by attaching suitable mesh to a light wooden frame. Failing this, sieves intended for domestic use with an appropriate mesh size may be available.

### 15.15 Identification of insects:

It is important to be able to identify the main pest species for two reasons. Firstly, so that you can decide whether the insects that you find are in fact likely to be damaging, and so whether a control is necessary. Secondly it will enable you to choose appropriate control methods: the treatments using Actellic and Phostoxin, which you have seen demonstrated, seem to be widely effective; however, other controls that you may see recommended elsewhere may be more selective. To take a simple example, chemicals recommended for spraying on the walls of warehouses against stored products moths may be totally ineffective against beetle pests.

Unfortunately, most of the insect pests of stored maize are small and initially difficult for the non-specialist to identify. A wide variety of species are important in different localities - for instance, N.S.P.R.I. (The Nigerian Stored Products Research Institute) record fourteen species as being important pests of stored maize in different parts of Nigeria, and so far a total of 32 species have been recorded from the cribs that you have seen at IITA. The best way to learn to identify the pests is to build up your own reference collection; usually only two or three species are important pests in a particular area and you will quickly be able to recognise those which are significant in your area. . Species which seem to be important but which you are unable to identify may be sent to your nearest country research station or to IITA for identification.

The accompanying notes are intended only as an introduction to the most easily recognized species. Of these, two are very much more widely important than the others: *Sitophilus zeamais* and *Sitotroga cerealella*, the former

typical of the wetter areas, the latter in the more arid. Both are 'primary' pests, that is to say, species which are able to initiate infestation of previously undamaged grain. Both are easily recognisable in the field and you should make sure that you are familiar with at least these two. The other species given here are either important secondary pests (i.e. species which are unable to attack intact grain but which may seriously add to the damage caused by primary pest species) or primary pests that occur sporadically and may become important in particular localities or seasons.

#### 15.15.1 Identification and occurrence:

##### Major primary pests:

*Sitophilus zeamais* (Curculionidae), the maize weevil, is distinguishable from all the other common storage beetles by the forward extension of the head into the long beak, or 'rostrum', characteristic of all weevils. The beetle is c.4mm long, dark brown in colour and sometimes has four lighter spots on the wing cases. *Sitophilus oryzae*, the rice weevil, also occurs sometimes on stored maize; it is very similar to *S. zeamais* and can only be distinguished with certainty using a microscope.

*Sitophilus* is the most important pest of stored maize in the tropics, infesting initially on the ripening crop in the field and then building up and causing serious damage in store. The primary damage caused by this species often makes possible the introduction of secondary pests, such as the flour beetles, and so its early control is doubly important.

*Sitotroga cerealella* (Gelechiidae), the angoumois grain moth, is a small cream or fawn-coloured moth, sometimes with a small black spot on the forewing, the wings are very narrow and fringed with long bristles; the sharply-pointed tip of the hind wing is characteristic.

*Sitotroga* replaces *Sitophilus* as the main pest in the more arid areas. Damage may be very serious in maize stored on the cob, however it is more limited with shelled grain as the moths do not penetrate more than a few inches from the surface. Damage is caused entirely by the developing larvae as the adults do not feed.

Widespread Secondary Pests:

*Carpophilus* Spp (*Nitidulidae*), sap beetles, include several species that affect stored maize. They are small, active beetles which may be brown or black in colour, sometimes with orange-brown patches on the wing cases. They are distinguishable from other storage pests by the fact that the last two segments of the abdomen are not covered by the wing cases and are clearly visible from above. In the related *Brachypeplus* species, which are also found sometimes on stored maize, three abdominal segments are visible.

*Carpophilus* spp., like *Sitophilus*, are able to infest maize in the field at a high moisture content and then persist in storage. They are usually regarded as doing comparatively little damage but may be present in very large numbers.

*Tribolium Castaneum* & *Gnatocerus Maxillosus* (*Tenebrionidae*), the red flour beetle and the horned flour beetle, are both elongate, reddish brown beetles; the latter is distinguishable by the small, upward-pointing horns on the head of the male and is usually somewhat lighter in colour. Other flour beetles, *Tribolium confusum*, *Gnatocerus cornutus* and *Palorus* spp. also occur in stored maize on occasions, all are similar in shape and colour but only *G. cornutus* is easily recognised, due to rather larger horns only carried by the male.

Flour beetles, as their name implies, are usually only important in maize that has already been somewhat damaged, or in milled products; however *T. castaneum* tends to attack the embryo of the grain selectively which may affect the quality in some circumstances.

Sporadically occurring pests:

*Rhinopertha Dominica* (Bostrichidae) is a small, almost cylindrical beetle, with the head 'tucked' under the thorax so that it is invisible from above; the thorax has a prominent pattern of tubercles, as shown. *Dinoderus* spp. (also Bostrichidae) are also sometimes found in maize; they have a similar cylindrical shape but are markedly shorter and stouter.

The Bostrichidae are adapted to boring into hard substances such as wood and are capable of attacking previously undamaged maize where they can cause serious damage. Bostrichidae may also sometimes be found attacking the frame of the crib itself.

*Araecerus Fasciculatus* (Anthribidae), called the Nutmeg weevil (though in fact not strictly a weevil), is somewhat larger than most storage beetles, up to c. 6mm long. It is a rather stout beetle, greyish-brown in colour and with relatively long antennae and legs.

*Araecerus* is most commonly found as a pest of coffee and cocoa beans but on occasions may become abundant on stored maize.

*Oryzaephilus mercator* (Silvanidae), the saw-toothed grain beetle, is a small dark-brown beetle, markedly elongate in shape. It is recognisable by the six prominent teeth on each edge of the thorax.

*Oryzaephilus* is a widespread pest of rice and oilseeds but, like the previous species, may occur in numbers on stored maize.

*Cathartus Quadricollis* (Silvanidae), the square-necked grain beetle has a similar elongate shape to *Oryzaephilus*, but is light brown in colour and the thorax has smooth edges. Several other Silvanidae, e.g. *Silvanus* spp. are sometimes found; most are similar in shape to *Cathartus*, but often the thorax margin is very finely toothed. The silvanidae in general can be distinguished from the flour beetles, which they superficially resemble, by their build, narrower and markedly flattened bodies.

*Ephestia Cautella* (Pyralidae), the tropical warehouse moth, has grey-brown forewings, with two indistinct darker bands, and rather paler hind wings. The wings are fringed with bristles but these are relatively much shorter than in *Sitotroga*. Other Pyralid moths may occur on stored maize: these include other *Ephestia* spp. (which are difficult to distinguish). *Plodia interpunctella* (in which the forewing is pale cream at the base and red-brown for the outer half), and *Corcyra cephalonica* (which is a larger moth, with uniformly grey wings, but similar in shape).

These moths are commonly found on cereals and other commodities, especially when stored in warehouses. In such situations it is important if fumigating the commodity under sheets to simultaneously spray the walls and roof of the structure; if you do not do this the maize will be rapidly reinfested by moths which have escaped the fumigation.

#### Other Insects:

In addition to the adult beetles and moths discussed above, you will come across a variety of other insects in stored maize. These include:

- (i) The larvae of the beetles and moths. These are in fact responsible for more damage than the adults but, as many are rather similar in appearance, it is easier to identify the pest species from the adults present. The larvae may be active and free-living, as in the flour

beetles, or may develop entirely within the grain, as in *Sitophilus*. Thorough fumigation with Phostoxin will kill all larvae as well as the adults, but some insecticide treatments may be ineffective, especially against larvae of the latter type developing within intact grain. A persistent insecticide will kill the emerging adults but toxicity may fall considerably during the larval development period (one to two months, depending on species), especially in a well-ventilated structure such as a crib. This is another factor favouring the use of a treatment such as spraying with actellic, which can be repeated at intervals.

- (ii) Parasites and predators of storage pests: These fall into two main groups. Firstly there are small wasps which parasitise the eggs and larvae of the pests. There are several common species but they are difficult for the non-specialist to identify. Most are 2mm or less in length, with four transparent wings. They may be present in large numbers and if seen on the outside of the crib they provide strong evidence of a pest infestation within. Secondly there are a number of beetles and hemipteran bugs (*Heteroptera*) that, although not specialised to storage conditions are often found in small numbers in cribs living as predators or scavengers.

Ideally we would like to exploit these natural enemies of pest species as a biological control (as has been done for some field pests) but, unfortunately, their impact seems usually insufficient to maintain storage-pest populations below a damaging level. Moreover, they are very susceptible to the insecticides used to control the pests.

Mites:

Mites belong to the class *Arachnida* (sub-class *Acarina*) and may be distinguished from insects by the possession of eight legs and an apparently unsegmented body. Those found on stored products are extremely small, c. 2 to 1mm in length, and are easily overlooked; if present, they will be most obvious in the 'flour' produced by insect attack.

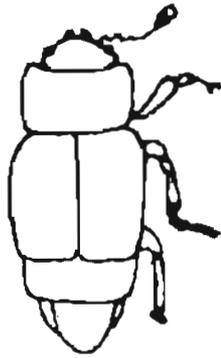
Some species are predators on the eggs of moths or on other mites but many are serious pests. The types are difficult to distinguish but the pest species are smaller than the predatory ones (it usually requires a hand lens to see them), whitish in colour, and slow-moving.

Their importance as pests of stored maize has not been properly investigated but if found in very large numbers they should probably be regarded as pests. Phostoxin fumigation kills mites but other insecticides may be less effective, if you have a problem with mites it is important to choose a chemical which specifically states that it is effective against mites - i.e. an Acaricide.

It should be stressed that there are many species of insects that you are likely to find in stored maize and a number of them may be doing serious damage. Only your own experience and careful observation can tell you which are the significant pests in your particular situation.



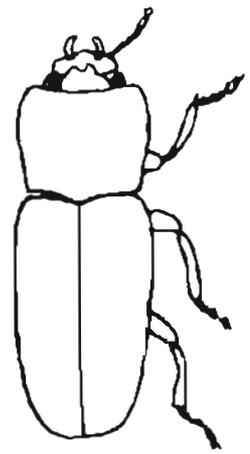
*Sitophilus zeamais*



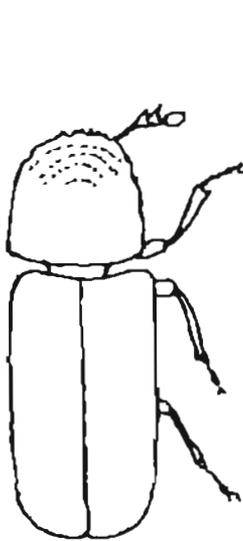
*Carpophilus sp.*



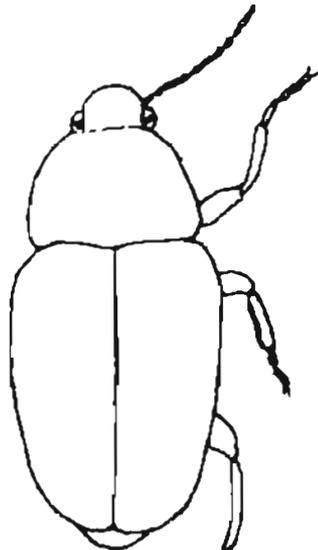
*Tribolium castaneum*



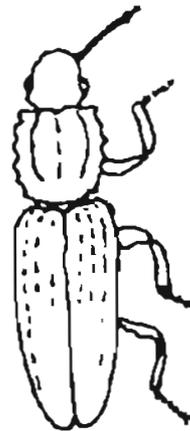
*Gnathocerus maxillosus*



*Rhizopertha dominica*



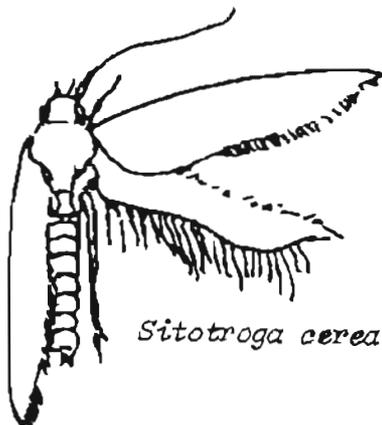
*Araecerus fasciculatus*



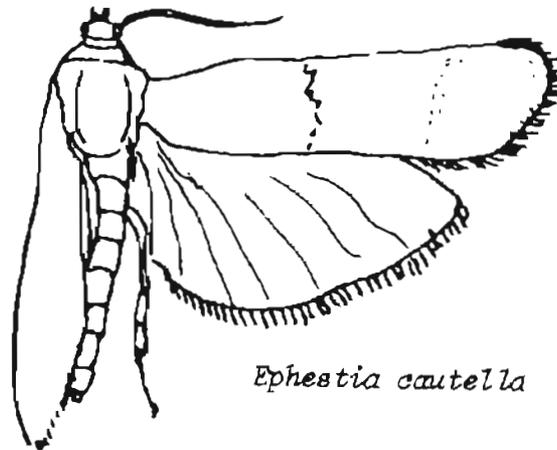
*Oryzaephilus mercator*



*Carthartus quadricollis*



*Sitotroga cerealelia*



*Ephestia cautella*

Figure 15.17: Some storage insect pests of maize.

15.16 Controlling storage insects without insecticides:

Traditional methods:

Farmers have been fighting insects for hundreds of years. They accept the fact that insects are going to eat and destroy a certain amount of their grain. Some of the insect control methods that farmers have used are:

- (i) Sunning: Insects leave grain which is placed in hot sunlight. They do not like heats higher than  $40-44^{\circ}\text{C}$ . The sunning process, however, does not always kill eggs and larvae which are inside the kernels of grain.
- (ii) Mixing local plants with grain. In many areas, farmers mix local plants with grain. Information about which plants and which parts of the plants should be mixed with grain is passed on within the family: the plants differ from one part of the world to another. Such natural control methods, or methods which provide active control without insecticide, need to be looked at more closely and research on these plants should be encouraged.
- (iii) Mixing sand or weed-ash with grain. This is another natural control method. Some farmers mix sand or wood-ash with threshed grain to keep insects from breeding. The sand scratches the covering or cuticle of the insects body and the insect loses moisture through scratches. If the grain is dry, insects will not be able to get enough moisture to replace the moisture lost through the scratches, and they will die.
- (iv) Smoking. Some farmers store unthreshed grain on raised wooden platforms. They build small smoky fires under the platforms. Other farmers store harvested grain in the roof of the building or shelter used

for cooking. Both of these methods use the smoke and heat of fires to kill and drive insects out of the grain. The heat from the fires also helps to keep the grain dry and protects the grain from new insect attacks.

(v) Storing in airtight containers: This is the process of putting grain into closed container so that no air can enter the grain. Insects in the grain then die because there is not enough air containing oxygen. In some areas, farmers store grain in very dry underground pits which can be made quite airtight. Other types of airtight storage containers can be more difficult to build and maintain.