NATIONAL OPEN UNIVERSITY OF NIGERIA
FACULTY OF AGRICULTURAL SCIENCES
DEPARTMENT OF CROP AND SOIL SCIENCE

COURSE CODE: CRP 513
COURSE TITLE: PLANT PEST AND DISEASE MANAGEMENT
CREDIT UNITS: 2 UNITS

Course Team:

Dr. Kwanashe Adobe, ABU Zaria (Course Developer)
Dr. Kwanashe Adobe , ABU Zaria (Course Writer)
Prof. Grace E. Jokthan, NOUN (Programme Leader)
Dr. Prof. M. A. Wailare, KUST, Wudil (Course Editor)
Dr. Aliyu Musa, NOUN (Course Coordinator)

National Open University of Nigeria
Headquarters
14/16 Ahmadu Bello Way
Victoria Island, Lagos

Abuja Office
5 Dar es Salaam Street
Off Aminu Kano Crescent
Wuse II, Abuja

e-mail: centralinfo@nou.edu.ng

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INTRODUCTION

Pest and Disease Management (CRP 513) is a three credit course for 500 level students of Bachelor of Science (BSc.) degree (Crop Production Programme). The course consists of three modules which deal with definition, description, concepts of pest and pest management Methods of pest control and Plant disease management. This course guide tells you briefly what the course is all about, and how you can work through its units.

COURSE ARRANGEMENT

The course consists of modules in units and a course guide. The course guide tells you briefly what the course is about, what course materials you will be using and how you can work with these materials. In addition, it advocates some general guidelines for the amount of time you are likely to spend on each unit of the course in order to complete it successfully. It gives you guidance in respect of your Tutor-Marked Assignment in the assignment file. There will be regular tutorial classes that are related to the course. It is advisable for you to attend these tutorial sessions. The course will prepare you for the challenges you will meet in the field of crop protection.

COURSE AIMS

The course aims to provide you with an understanding of crop protection principles as regards insect pests and diseases. These concepts encompass definitions of pest and their status as crop loss agents, damage and its varied nature, economic considerations in pest management. An understanding of the different management methods will also be discussed.

COURSE OBJECTIVES

To achieve the aims set out, the course has a set of objectives. Each unit has specific objectives which are included at the beginning of the unit. You should read these objectives before you study the unit. You may wish to refer to them during your study to check on your progress. You should always look at the unit objectives after completion of each unit. By doing so, you would have followed the instructions in the unit. Below are the comprehensive objectives of the course as a whole. By meeting these objectives, you should have achieved the aims of the course as a whole. In addition to the aims above, this course sets to achieve some objectives.

Thus, after going through the course, you should be able to:

- Explain the concept of pest management and their population dynamics.
- Identify and determine the damage status and threshold of a pest.
- Understand the different management strategies available.
- Explain how the disease pyramid influences disease spread.
- Understand and deploy the concept of pest exclusion, eradication, resistance and prevention.
- Understand the concept of Integrated Pest Management (Insect and disease).

WORKING THROUGH THIS COURSE

To complete this course you are required to read the study units carefully and read other recommended materials. You will be required to answer some questions based on what you have read in the Content to reaffirm the key points. At the end of each module there are some Tutor- Marked Assignments (TMA) which you are expected to submit for Marking. The TMA forms part of your continuous assignments. At the end of the course is a final examination.

THE COURSE MATERIALS

The main components of the course are:

1. The Course Guide
2. Study Units
3. References/Further Reading

TUTOR-MARKED ASSIGNMENTS (TMA)

There are tutor Marked assignments and self-assignment in each module. You would have to do the TMA as a revision of each module. This would help you to have broad view and better understanding of the subject. Your tutorial facilitator would inform you about the particular TMA you are to submit to him for Marking and recording. Make sure your assignment reaches your tutor before the deadline given in the presentation schedule and assignment file. If, for any reason, you cannot complete your work on schedule, contact your tutor before the assignment is due to discuss the possibility of an extension. Extensions will not be granted after the due date unless there are exceptional circumstances. You will be able to complete your assignment questions from the Contents contained in this course material and References/Further reading; however, it is desirable to search other References/Further reading, which will give you a broader view point and a deeper understanding of the subject.

FINAL EXAMINATION AND GRADING

The final examination for the course will be 2hrs duration and consist of six theoretical questions and you are expected to answer four questions. The total Marked for the final examination is 70 Marked. The examination will consist of questions, which reflect the tutor marked assignments that you might have previously encountered and other questions within the course covered areas. All areas of the course will be covered by the assignment. You are to use the time between finishing the last unit and sitting for the examination to revise the entire course. You might find it useful to review your Tutor Marked Assignments before the examination. The final examination covers information from all parts of the course.

STUDY UNITS

The study units in this course are as follows:

MODULE 1: DEFINITION, DESCRIPTION, CONCEPTS OF PEST AND PEST MANAGEMENT

Unit 1: Introduction to Pest Management and Population Dynamics (Concepts)
Unit 2: Pest Damage

MODULE 2: METHODS OF PEST CONTROL

Unit 1: Introduction
Unit 2: Legislative methods
Unit 3: Physical Methods
Unit 4: Cultural control
Unit 5: Biological control
Unit 6: Chemical methods
Unit 7: Integrated pest management (IPM)

MODULE 3: PLANT DISEASE MANAGEMENT

Unit 1: Introduction to Plant Diseases
Unit 2: Disease Management

MODULE 1: DEFINITION, DESCRIPTION, CONCEPTS OF PEST AND PEST MANAGEMENT

Unit 1: Introduction to Pest Management and Population Dynamics (Concepts)

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1.0 Introduction

Before contemplating taking any management measures against an insect species on a crop, the species must be correctly identified; then, presuming its biology is known, it should be clearly established that the species in this particular context is a pest, and that it could be profitable to attempt population control. In this section the various terms used to describe pests are defined. It should be noted that some terms are more or less synonymous, but they are all well established in the literature. For example a *major* pest is very often a *serious* pest, and all *economic* pests are serious.

1.1 Pest

The definition of a pest can be very subjective, varying according to many criteria; but in the widest sense any animal (or plant) causing harm or damage to man, his animals, his crops or possessions, even if just causing annoyance, qualifies for the term pest. From an agricultural point of view, an animal or plant out of context is regarded as a pest (individually) even though it may not belong to a pest species. For instance cattle on a farm are a pest, but caged in a paddock it is not, and is in fact a valuable national asset there. Similarly, volunteer cabbage plants growing in a field with onions have to be regarded as ‘weed’ pests. Many insects belong to generally accepted *pest species*, but individual populations are not necessarily always pests; that is, of course, not necessarily *economic pests*.

1.2 Economic pest

In agriculture, we are concerned when the crop damage caused by insects leads to a loss in yield (quantity) or quality, resulting in a loss of profits by the farmer. When the yield loss reaches certain proportions the pest can be defined as an economic pest. Clearly the value of the crop is of paramount importance in this case, and it is difficult to generalize, but as a general guide for most crops it is agreed that most species reach *pest status* when there is a 5–10% loss in yield. Obviously a loss of 10% of the plant stand in a cereal or rape field (note that this is not the same as a 10% loss in yield!) is not particularly serious, whereas the loss of a single mature tree of *Citrus*, apple or peach is important.

1.3 Economic damage

This is the amount of damage done to a crop that will financially justify the cost of taking artificial control measures, and will clearly vary from crop to crop according to its basic value, the actual market value at the time and other factors.

1.4 Economic injury level (EIL)

This is the lowest population density that will cause economic damage, and will vary between crops, seasons and areas. But it is of basic agricultural importance that it is known for all the major crops in an area. The major components in a simplified equation (from Pedigo *et al*., 1986):

EIL = (C/V) (1/L)

C = Pest Management Costs (₦ per unit measure)
V = Market Value of Product, Managed Resource, etc. (₦ per unit measure)
L = Loss Caused to Product, Managed Resource, etc., per Pest (loss per unit measure per pest)

Although this equation is only a simplified version, it is easy to see how considering costs, values, and losses can assist the pest manager in determining when the pest is actually causing economic losses. The ease of determining the values of C, V, and L will vary with the pest management situation. To date, EIL values have primarily been determined for agricultural crops. However, the specific values in the equation will vary with many factors including geographic region, production practices, and market fluctuations. Despite these variables, it is still helpful for a pest manager to assess what these costs, values, and losses might be for his/her specific situation, and then to consider these values when making pest management decisions.

For example, the EIL of some cotton pest are mentioned below

Thrips	8 per leaf
Whitefly	5 per leaf
Aphid	5-7 per leaf
Mites	10-15 per leaf

Spotted Boll Worm	5-10% infestation
Pink Boll Worm	5-10% infestation
Army Worm	at the time of appearance

1.5 Economic threshold

It is desirable that control measures be taken to prevent a pest population from actually causing economic injury. The economic threshold is the population density of an increasing pest population, at which control measures should be started to prevent the population from reaching the economic injury level.

1.6 Pest complex

The normal situation in a field or plantation crop is that it will be attacked by a number of insects, mites, birds and mammals, nematodes and pathogens which together form a complicated interacting *pest complex*. The control of a pest complex is complicated and requires careful assessment, especially as to which are the *key pests*, and careful integration of the several different methods of control which may be required. This, of course, makes the process of evaluation difficult, and generally, much money and time is usually wasted on uneconomic pest control, either through carelessness or lack of knowledge.

1.7 Pest load

This is the actual (total) number of different species (and numbers of individuals) of pests found on either a crop or an individual plant at any one time, and, as already mentioned, this would usually be a pest complex, but could also be a mono-specific population, although this would be rare.

1.8 Key pests

In any one local pest complex it is usually possible to single out one or two major pests that are the most important; these are defined as key pests, and are usually perennial and dominate control practices. A single crop may have one or more key pests, which may or may not vary between crop type, cultivation areas and seasons. It is of course necessary to establish economic thresholds for these key pests in order to be certain when to apply control measures, for it has been often observed that the mere presence of a few individuals of a key pest species in a crop may cause undue alarm and lead to unnecessary pesticide treatment. Key pests owe their status to several factors, including their usually high reproductive potential, and the type of damage they inflict on the host plant (e.g. Stem borer on Maize; Boll Weevil on cotton).

1.9 Serious pest

This is a species that is both a major pest and an economic pest of particular importance, being very damaging and causing considerable harm to the crop plants and a large loss in yield. It almost invariably occurs in large numbers.

1.10 Major pest

These are the species of insects and mites that are either serious pests of a crop (or crops) in a restricted locality, or are economic pests over a large part of the distributional range of the crop plant(s). Thus the species here regarded as major pests usually require controlling over a large part of their distributional (geographical) range, most of the time. In any one crop, in one location, at one time, there is usually only a rather small number (say 4–8) of major pests in the complex that actually require controlling. For example, although the pest spectrum for cotton worldwide is 1360 species, on any one cotton crop there will probably only be about five species requiring population control. Usually for most crops in most localities the major pest species remain fairly constant from year to year, but several entomologists have commented recently that in some areas they have observed that the major pest species complex has been gradually changing over a long period of time. So over a period of some 10–50 years it is expected that the complement of major pests for a crop may change. It must be remembered that evolution continues all the time, though it is not often obvious, and that in an artificial environment, such as agriculture, it can be expected that evolution will be accelerated.

1.11 Minor pests

These are the species that are recorded feeding or ovipositing on the crop plant(s) but usually do not inflict damage of economic importance; often their effect on the plant is indiscernible. They may be confined to particular crop plants or may prefer other plants as hosts. Many (but not all) pests listed as minor pests are potentially major pests. Many species that are major pests of one crop will occur in a minor capacity on other crops. Sometimes a major pest of a particular crop in one part of the world (e.g. Africa) will be a minor pest on the same crop in a different part (e.g. Australia).

1.12 Potential pest

This term is used occasionally in the literature and refers to a minor pest species that could become a major pest following some change in the agroecosystem. Only a relatively small proportion of the species listed as minor pests are really potential pests in this sense, because of their basic biology.

1.13 Secondary or sporadic pest

These are species whose numbers are usually controlled by biotic and abiotic factors which occasionally break down, allowing the pest to exceed its economic injury threshold.

1.14 Pest populations

A most important point to remember is that an insect is only an actual pest (in practice) at or above a certain population density, and most control measures are aimed only at reducing this population to a lower level.

2.0 Tutor Marked Assignment

a. Define the terms pest, economic pest, economic damage and economic threshold.

b. i. Explain Economic Injury Level (EIL) as it relates to administration of management measures.

ii. Give and explain the formula for calculating EIL.

c. Differentiate between major, minor, potential and sporadic pests.

3.0 References/Further Reading

Oldroyd, H. (1968). Elements of Entomology, 312 pp. Weidenfeld & Nicolson: London.

Pury, J. M. S. de (1968). Crop Pests of East Africa, 227 pp. Oxford University Press: E. Africa.

Unit 2: Pest Damage

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Unit 2: Introduction

The single most important aspect is the relation between the damage done by the pest and the part of the plant harvested. *Direct damage* is when the part of the plant to be harvested is the part attacked, such as the leaves of tobacco, fruits of tomato and apple, tubers of potato and sweet potato; in these cases clearly the damage is more important. *Indirect damage* is when the part of the plant damaged is not the part to be harvested. Examples include the roots of tobacco and wheat, leaves of sugarbeet, potato and apple. In these cases it is usually possible to ignore quite surprisingly high levels of pest infestation, as these infestations may only have a marginal effect on the crop yield.

1.1 Direct effects of insect feeding

Biting insects may damage plants as follows.

(a) Reduce the amount of leaf assimilative tissue and hinder plant growth; examples are leaf-eaters, such as adults and nymphs of locusts and *Epilachna* and larvae of *Plutella*, *Pieris*, *Plusia* (Lepidoptera) and sawfly larvae.

(b) Tunnel in the stem and interrupt sap flow, often destroying the apical part of the plant; these are stem borers and shoot flies, such as *Zeuzera* in apple branches, *Cephus* in wheat, *Ostrinia* in maize, *Atherigona* in maize and sorghum.

(c) Ring-bark stems, for example some Cerambycidae.

(d) Destroy buds or growing points and cause subsequent distortion or proliferation, as with Fruit Bud Weevils (*Anthonomus* spp.) on shoots of apple, pear, etc.

(e) Cause premature fruit-fall, as with Cherry Fruit Fly, Codling Moth, Apple Sawfly.

(f) Attack flowers and reduce seed production, as with the blossom beetles (*Meligethes* spp.) and Japanese Beetle.

(g) Injure or destroy seeds completely, or reduce germination due to loss of food reserves; examples are Hazelnut Weevil, Maize Weevil, Pea and Bean Bruchids, Pea Pod Borers, and Bean Pod Borers.

(h) Attack roots and cause loss of water and nutrient absorbing tissue, as with wireworms and various chafer larvae (Scarabaeidae) and other beetle larvae in the soil.

(i) Remove stored food from tubers and corms, and affect next season's growth; examples are cutworms and wireworms in potato, and Potato Tuber Moth larvae.

Insects with piercing and sucking mouthparts may damage plants as follows.

(a) Cause loss of plant vigour due to removal of excessive quantities of sap, in extreme cases wilting and foliage distortion results, as in the stunting of cotton by *Bemisia* (Whitefly), and aphids on many plants.

(b) Damage floral organs and reduce seed production, for example capsid bugs (Miridae) and other Heteroptera (Wheat Shield Bugs, Chinch Bugs, etc.).

(c) Cause premature leaf-fall, as do many diaspidid scales.

(d) Inject toxins into the plant body, causing distortion, proliferation (galls) or necrosis; examples are seen in capsid damage on bean leaves and shoots, and the stem necrosis on plants by *Helopeltis* and other Heteroptera.

(e) Provide entry points for pathogenic fungi and bacteria, as does *Dysdercus* on cotton bolls (for fungus *Haemospora*) and other bugs.

1.2 Indirect effects of insects on crops

(a) Insects may make the crop more difficult to cultivate or harvest; they may distort the plant and cause the plant to develop a spreading habit which makes weeding and spraying more difficult. They may delay crop maturity, as do the bollworms on cotton, and grain in cereals may become distorted or dwarfed.

(b) Insect infestation results in contamination and loss of quality in the crop; the quality loss may be due to reduction in nutritional value or marketability (lowering of grade). Loss of yield in a crop is obvious but a nutritional quality loss is easily overlooked; this is the type of damage done to stored grain by *Ephestia cautella* and *Tribolium*. A more common loss of quality is the effect of insects on the appearance of the crop, for example skeletonized or discoloured cabbages have a lower market value than intact ones. Attacked fruit is particularly susceptible to this loss in quality, as seen by skin blemishes and hard scales on citrus fruit and capsid damage on apples. Contamination by insect faeces, exuviae, and corpses all reduce the marketability of a crop, as do black and sooty moulds growing on the honeydew excreted by various homopterous bugs. A major problem in the tropics is 'stickiness' of cotton lint caused by honeydew from Cotton Whitefly; the sticky cotton is difficult to gin, and its value is diminished.

(c) *Transmission of disease organisms*
(i) Mechanical transmission, also termed passive transmission, takes place through feeding lesions in the cuticle. Sometimes the pathogen (usually fungi or bacteria) is carried on the proboscis of the bug or sometimes it is on the body of the tunnelling insects. Examples are seen in the case of the *Scolytus* beetles which transmit Dutch Elm and other fungal diseases.

(ii) Biological transmission. Most viruses depend upon the activity of an insect vector for transmission. The vector is usually also an intermediate host, as is the case with most aphid and whitefly hosts. Diseases transmitted in this manner include Cucumber Mosaic, Tobacco Mosaic and Turnip Mosaic.

1.3 Pest damage assessment and crop yields

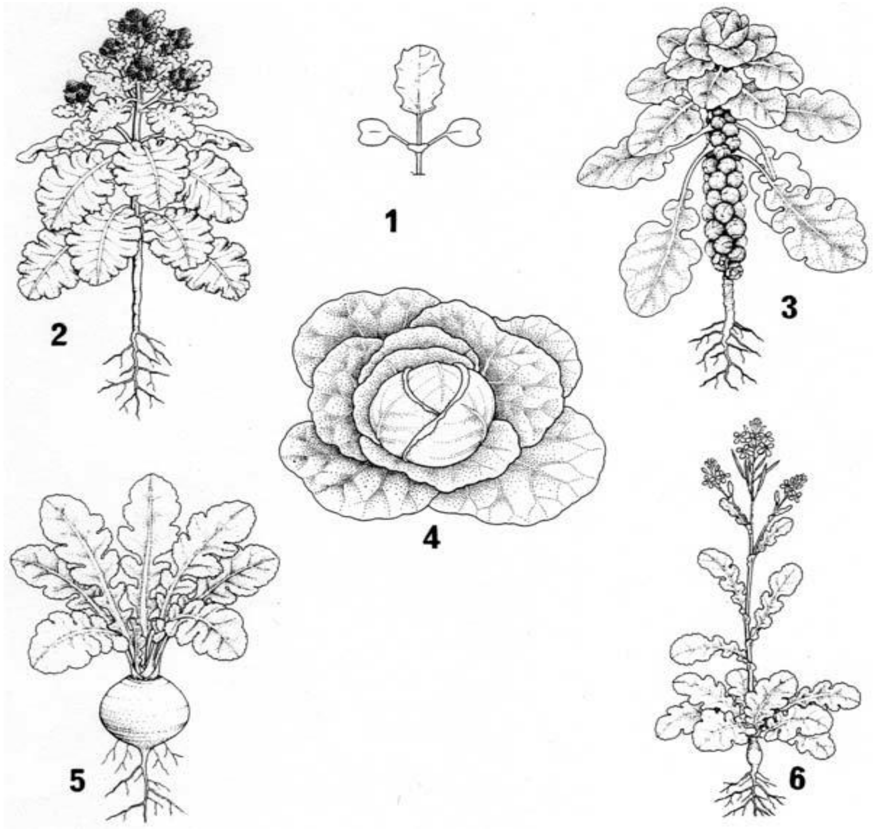
The ultimate aim of agriculture is to produce a sustained economic yield of crop produce, so it becomes of prime importance to understand the effect of the insect pest population on the subsequent yield or harvest. Obviously, if the pests are causing no crop loss their presence on the plants and the damage they cause may be ignored, and in the context of ecological stability they should be left alone! However, most pest populations produce some damage of significance, but the damage assessment in relation to possible or expected yield loss is difficult. The total number of interacting factors responsible for determining crop yield is quite overwhelming, and any decision as to the probable effect of any single factor, such as the population of one insect pest species, is problematical. However, the gradual accumulation of empirical data over many years has resulted in our being able to make various generalizations about some pest populations and their probable effect on crop yield. These results are used to define economic injury levels (and economic thresholds) for some pests on some crops in different parts of the World. In general, many more data are required for many more pests on the more important crops, especially those in the tropics.

1.4 Part of plant body damaged

Some types of damage are obviously more important than others, depending upon the part of the plant body damaged and the part harvested; if the two are the same then clearly the damage is more serious. A single Codling Moth larva can effectively destroy a single apple or peach, and a relatively small number can ruin an entire crop. On the other hand an apple tree can accommodate a large number of foliage-eating caterpillars, sap-sucking bugs, and root-eating beetle larvae, with no discernible loss of yield. In general, root crops can stand considerable leaf damage without appreciable yield loss; pulses and most cereals can likewise tolerate leaf eating, root-eating and sap-sucking (with a few exceptions) at a moderate level. Vegetables such as cabbage, lettuce, celery, etc., may have their outside leaves removed at harvest, prior to sale, so damage to the outer leaves is relatively unimportant. It has long been known that many crop plants can tolerate partial defoliation without discernible loss of yield; two well-documented cases are cucumbers attacked by Red Spider Mite, where 30% of leaf cover has to be damaged before there is an effect on yield, and sugarbeet, where young crops suffer little loss of yield unless defoliation exceeds about 50%. In summary, damage which can be ignored on one crop may be of considerable economic importance on another (even closely related) crop, so damage assessment is different for each crop grown.

For example Fig. 1 shows five different *Brassica* crops together with a seedling; should the seedling be killed by Cabbage Root Fly, cutworm, or white grub, then the damage is usually serious for the entire future plant is lost and there is a large gap left in the field which encourages weed development (except rape). With Broccoli the flower heads are eaten, so damage to lower leaves, and some root damage can be ignored. Brussels sprouts are lateral buds harvested over the winter period, so late caterpillar defoliation in the autumn may be of no consequence, but a single Cabbage Root Fly inside a button for freezing is serious damage. The many types of Cabbage are grown for the 'heart', so all the outer leaves may be damaged without affecting the saleability of the heart. Turnip is one of the cruciferous root crops and will tolerate considerable leaf damage, but even slight Cabbage Root Fly damage may spoil the appearance of the root. Rape is becoming more and more important in many regions as a source of seed for oil extraction, and in this crop it is the flower and pod pests that are important (as they are also for the other crops grown to seed); small numbers of plants destroyed have no effect on final yield because of the density of the crop.

Fig. 1. A. Examples of five closely related crops (*Brassica* spp.) which have different parts of the plant body harvested, and also a generalized seedling.
1. *Brassica* seedling
2. Broccoli (*B. oleracea* var. *botrytis*), grown for flower heads
3. Brussels sprouts (*B. oleracea* var. *gemmifera*), grown for lateral buds
4. Cabbage (*B. oleracea* var. *capitata*), grown for 'heart', i.e. telescoped main shoot
5. Turnip (*B. rapa*), grown for swollen root
6. Rape (*B. napus*), grown for seeds as a source of oil



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5. Turnip (*B. rapa*), grown for swollen root
6. Rape (*B. napus*), grown for seeds as a source of oil

1.5 Pest infestations

There are two basic ways in which pest infestation (or damage) can be assessed. The *incidence* of the pest (or damage symptoms) is generally the proportion of plants in a sample which are host to the pest (or which show damage symptoms), and is usually expressed as a percentage. The *severity* of the infestation is a measure of the size of the pest population on the plants, or the extent of the damage done, and is often measured as so many insects per plant, per bush, per 10 leaves, egg masses per plant, etc. And of course the total damage caused to a crop is a combination of severity of infestation together with *duration* (time). In ecological studies of populations of both plants and animals, several methods of assessment are employed. These are based upon the proportion of area covered within the habitat (for plants), or the number of animals seen or sampled, in relation to area, or proportion of plants examined (sampled). Botanists are able to use more precise systems for plant population assessment because of the immobility of the organisms, and the three most widely used methods employ between 4 (Raunkiaer, 1934), 6 (Braun-Blanquet, 1927) and 11 (Domin) abundance categories. But for small, highly mobile insects the latter level of precision is not feasible, especially when different recorders are being used. It is advocated that the use of four abundance/frequency categories for population size assessment, without the use of lengthy or detailed sampling procedures, and this approach would seem to be appropriate for assessing field populations of insect pests on crops.

These categories of abundance are as follows:

abundant (a)	=	very common (VC)
frequent (f)	=	common (C)
occasional (o)	=	uncommon (U)
rare (r)	=	rare (R)

1.6 Damage assessment

The term *injury* is used to connote slight (i.e. non-damaging) effects of insects feeding or other activities on the growth or appearance of crop plants; and *damage* is injury resulting in a measurable loss of yield or reduction in quality. This distinction would be most useful, but to date in the literature these two terms are used more or less synonymously, and of course the term 'economic injury level' is well established. The extent of crop damage is usually proportional to the numbers of insects present, and would accordingly be rated as follows:

very severe (VS)	= 1	or 1
		2
severe (S)	= 2	3
mild (M)	= 3	4
very mild (VM)	= 4	5
		6

In some systems of recording a numerical categorization is used, and a six-point scale seems to be quite popular; presumably in this case number 6 (and 'very mild') come under the 'injury' category of Bardner & Fletcher (1974) and would be detectable but not of any economic importance. With simple damage, such as leaf lamina being eaten or apples infested with Codling Moth larvae, damage can be expressed easily as proportion of lamina destroyed or percentage of fruits infested per tree. In some systems numbers of pests present are correlated empirically against expected loss of yield (percentage), on a scale of no loss (0%) to total loss (100%). Because each crop has its own growth characteristics (see below), and the vast diversity of types of pests and pest damage and all the other factors involved with crop production, it is not possible to generalize extensively. Damage assessment will remain different for each crop and sometimes also for each major locality as the pest complex usually varies regionally. It is however generally agreed that for most purposes a damage assessment scale of not more than six levels is preferable, for easy recognition in the field by Non-experts, and it is recommended that a large number of small samples be taken rather than a small number of large samples; this also caters better for the uneven pest distribution within the crop, which is usual.

2.0 Tutor Marked Assignment

a. Giving examples, differentiate between direct and indirect damage

b. Differentiate between incidence and severity of insect pest infestation.

c. Describe the four frequency scale for population size assessment.

d. Differentiate between injury and damage.

e. Describe the concept of the damage assessment scale.

3.0 References/Further Reading

Oldroyd, H. (1968) Elements of Entomology, 312 pp. Weidenfeld & Nicolson: London.

Pury, J. M. S. de (1968) Crop Pests of East Africa, 227 pp. Oxford University Press: E. Africa.

MODULE 2: METHODS OF PEST CONTROL

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UNIT 1: Introduction

There is a large number of different methods of pest (including disease) control available to the crop protectionist, but careful deliberation is required in making a choice of methods. In general the orientation of the control project is towards the crop plant population rather than individual plants, so that low levels of pest infestation are acceptable provided that damage levels are low. Obviously with some expensive horticultural crops the welfare of each individual plant is of concern.

The choice of method(s) to be used depends on several factors.
(a) Degree of risk – some crops in some fields are at *high risk*, because in that area serious pests are invariably present in large populations. In such situations *preventative* measures (sometimes called insurance measures) may be justified. Similarly a high risk area may be predicted by sampling and forecasting techniques.
(b) Nature of pest and disease complex – usually several (or many) different pests and pathogens will be interacting on the crop in the form of a pest complex. Key pests will dominate the control strategy. With many crops between four and eight major pests will require control at any one time. Ideally the method(s) used will control several pests (and sometimes pathogens also) simultaneously.
(c) Nature of the crop and agricultural system – e.g. height of crop and spacing.
(d) Economic factors – e.g. cost of chemicals and specialized equipment.
(e) Ecological factors – e.g. extent and type of natural control, and availability of water.

Obviously it is vitally important that the pests be correctly identified and that their general biology is known. The system of classifying control measures which follows is based upon the mode of action, and is widely used by plant pathologists.
(a) Exclusion – including quarantine, use of disease-free seed and planting material; designed to keep (new) pests and diseases out of an area or crop.
(b) Avoidance – uses cultural control methods and sites free of infection, and resistant crops.
(c) Protection – use of chemicals mostly, as protectants, therapeutants and disinfectants; physical protection may be included; anticipated protective measures are termed preventative.
(d) Eradication – for an outbreak of a pest or disease in a new area; uses soil sterilization, fumigation, heat treatment, insecticidal saturation, etc.
Generally it is more useful, from a pest viewpoint, to regard control measures according to their basic nature, as follows:

(a) legislative methods
(b) physical methods
(c) cultural control
(d) crop plant resistance to pest attack
(e) biological control
(f) chemical control
(g) integrated control
(h) integrated pest management (pest management)
(i) eradication

Tutor Marked Assignment

a. List the factors considered in choice of control measures and discuss any two.
b. Classify control measures based on mode of action.
c. List five methods of pest control.

References/Further Reading

Oldroyd, H. (1968) Elements of Entomology, 312 pp. Weidenfeld & Nicolson: London.

Pury, J. M. S. de (1968) Crop Pests of East Africa, 227 pp. Oxford University Press: E. Africa.

Unit 2: Legislative methods

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2.0 Introduction

These are obviously methods of control where government legislation (laws) has been passed so that certain control measures are mandatory, with failure to comply being a legal offence. These are extreme measures and only apply to certain very serious pest situations of national importance.

2.1 Phytosanitation (quarantine)

When the major crops were distributed around the world from their indigenous areas, initially they may have been free of their native pests and diseases (particularly crops grown from seed). But over the years many reintroductions have been made and gradually the native pests and pathogens have spread also, until now when some pests and diseases are completely sympatric with their host crops. However, there is still a large number of pests and diseases that have not yet spread to all parts of the crops' areas of cultivation. For example, the early success of coffee in Brazil (S. America) was due to the absence of Coffee Rust, Antestia Bugs, and Coffee Berry Borer, which remained behind in E. Africa; but this advantage has now been lost as in recent years both Rust and Berry Borer have become established in S. America. Similarly the success of rubber as a crop in S.E. Asia is due in part to the absence of its native South American Leaf Blight. FAO (Food and Agriculture Organization of the United Nations) have organized a system of international plant protection with respect to the import and export of plant material. The world is divided into a number of different geographical zones for the basis of phytosanitation; each zone has its own regional organization for coordination. There is now an International Phytosanitary Certificate, an essential document required for importation of plant material into almost every country of the world.

Disease-free and pest-free plants can usually be imported, provided they are accompanied by appropriate documentation from the country of export, but certain plants (and fruits) are completely prohibited because of the extreme likelihood of their carrying specific noxious pests or pathogens. Other categories of plants are allowed to be imported (and exported) after routine treatment to eradicate possible pests; such treatment usually consists of fumigation (e.g. fumigation of fruits using ethylene dibromide). Sometimes the plants have to be kept in quarantine isolation for a period of time to check that no symptoms develop (as with domestic pets and rabies quarantine). Specific import regulations vary from country to country according to the nature of the main agricultural crops.

From time to time, the introduced pests/pathogens have devastated crops and even created famine conditions in different parts of the world. The Ireland famine of 1845 was the result of an almost total failure of the potato crop due to the introduction of the late blight pathogen (*Phytophthora infestans*) from Central America. Introduction of powdery mildew (*Uncinula necator*), Phylloxera and the downy mildew (*Plasmopara viticola*) in quick succession about the middle of 19th century from America virtually annihilated the grape vine industry of France. The chestnut blight (*Endothia parasitica*) was introduced into the US on the nursery stocks imported from the Orient about 1906. Within 25 years, the American chestnut was almost exterminated as a forest tree causing an estimated loss of 1000 million US dollars. In Sri Lanka, coffee was replaced by tea as a plantation crop because of the widespread epiphytotics of coffee leaf rust (*Hemileia vastatrix*) in 1868. Also, about 20,000 hectares of coconut plantation was devastated by the introduced coconut leaf minor (*Promecotheca cumingi*) during the late 1960s.

In India also, several pests and diseases got introduced from time to time, some of which, like late blight of potato, banana bunchy top, bacterial blight and streak diseases of paddy, have since become widespread. Some others like golden nematode and wart disease of potato and downy mildew of onion are still localized in certain parts of the country.

The above examples only highlight the risks involved in inadvertent introduction of serious pests/diseases along with the planting material imported without adequate safeguards. Plant quarantine can provide such safeguards. Plant quarantine measures aim at providing protection to the agriculture of a country or region against the likely ravages of alien pests/pathogens should they get introduced and established. These measures are of particular importance and relevance to countries like India whose economy is largely based on agriculture. Quarantine not only helps to ward off the threats of exotic pests, but also aim to eliminate and prevent further spread of pests/pathogens (both indigenous and introduced) with restricted distribution within the country (domestic quarantine). Government quarantine offers services which are beyond the capabilities of individual beneficiaries or that are difficult to obtain in some other way at a lesser cost'. Thus, plant quarantine, in real sense, serves as a national service by preventing the introduction of exotic pests/pathogens/weeds and their further spread. However, such endeavours could succeed only with the active support of all-the administrators, general public, farmers, scientists, communication media, customs and others.

2.2 Pest/pathogen detection techniques

Success or failure of plant quarantine measures would depend, to a great extent, on the ability of plant quarantine officials to detect pests and pathogens that may be associated with the introduced planting material. For quarantine purposes, techniques should be sensitive enough to detect even trace infections. This is particularly important in case of pests/pathogens with very high multiplication rate like certain pycnidial fungi, downy mildews, bacteria and also viruses when the insect vectors are efficient.

A wide variety of pests and pathogens (insects, mites, nematodes, fungi, bacteria, viruses, viroids, spiroplasma, etc.) and weeds are the objects for quarantine consideration. Similarly, planting material also may be introduced in a variety of forms, i.e., true seed, corms, bulbs, rhizomes, suckers, runners, budwood, scions, cuttings and rooted plants. Therefore, detection techniques would vary depending on the type of material, the host species and the type of pests/pathogens involved. Many a times, more than one technique would have to be used.

2.3 Detection Techniques

Detection techniques may broadly be classified into two groups:

(a) generalized tests which would reveal a wide range of pests/pathogens; and

(b) specialized or specific tests which are used to detect specific pests/pathogens.

2.3.1 Generalized tests

A very widely used method is the inspection of dry seed with the naked eye or under the low power of microscope. This method would reveal a wide range of free moving insects, their eggs and larval stages, mites on or with the seed, weeds, soil, infected/infested plant debris, fungal fructifications like sclerotia, smut and bunt balls, nematode galls, discoloured or deformed seeds mixed with seed; oospore or bacterial crusts, acervuli, pycnidia, sclerotia and even free spores of rusts, smuts and many other fungi on the seed surface. Examination of dry seed under UV or NUV light may reveal infections of certain fungi and bacteria through emission of fluorescence of different colours. Examination of seed washings may reveal surface contamination by rusts, smuts, downy mildews and a large number of other fungi.

Most commonly used incubation methods for the detection of fungi are the common moist blotter and agar tests wherein seeds are incubated on these media for a specific length of time (generally about a week) at a suitable temperature under alternating light and dark cycles. These two media reveal a wide range of internally seed-borne fungal and some bacterial pathogens in a wide variety of crops. Seedling symptom test and the grow-out test are quite versatile and reveal the symptoms produced by any category of plant pathogens including fungi, bacteria and viruses. Grow out test is the simplest of the tests extensively used for the detection of viruses. However, some viruses may be carried symptomlessly in the plant and, therefore, it should be used in combination with other tests like indexing on indicator test plants and serology.

2.3.2 Specialized tests

Insects

X-ray radiography has been used very successfully all over the world for the detection of hidden infestation (with no apparent sign of infestation on the seed surface) of insects, particularly seed infesting chalcids and bruchids. Seed transparency test (boiling the seeds in lactophenol to make them transparent) may also be used for the detection of hidden infestation and extraction of the insects for identification. X-ray radiography is also very effective in salvaging infested seed lots.

Nematodes

For the detection of seed-borne nematodes, seeds are soaked in water for about 24 hours. This makes the nematodes active, which then come out of the seed into the water, or the seeds may be teased out with the help of forceps and a needle and examined for detection of nematodes under a stereo microscope. In rooted plants, the accompanying soil and plant debris may similarly be soaked in water and nematodes may be extracted for identification using nematological sieves or tissue paper.

Fungi, bacteria and viruses

Serological tests are very effective for the detection and identification of viruses and bacterial pathogens and are being used in various plant quarantine stations with great success. Phage-plague technique is still more sensitive for bacterial pathogens as even strains of bacteria can be identified. Indicator test plants are also very helpful as they may reveal pathogenic races within a species of a fungus, bacterium and specific strains within a virus. Modifications of the generalized incubation tests (agar and blotter tests) have also been used for the detection of specific plant pathogens. Deep-freezing blotter test and 2,4-D blotter test are very efficient for detection of black-leg pathogen (*Phoma lingam*) in crucifer crops. Potato-dextrose-oxgall agar is useful for the detection of *Septoria nodorum* in wheat.

In the case of vegetative propagules, laboratory methods may suffice for the detection of insects and mites, nematodes, majority of fungi and certain bacteria. However, for the detection of systemic fungal pathogens, bacteria, viruses, viroids, isolation growing for a season or a year or more in quarantine glass-houses/net-houses is required. Availability of glass-houses/net-houses in large number is an expensive proposition, but the quarantine safeguards afforded by them to any country are worth that expenditure.

2.4 Quarantine regulations

Plant quarantine regulations are promulgated by the national and the state governments to prevent the introduction and spread of harmful pests and pathogens. Plant quarantine will be justified only when the pest has no natural means of spread and when they are based on biological considerations only, i.e., pest/pathogen introduction risks and the available safeguards.

In general, risks are more with the introduction of vegetative propagules than with true seed. In case of true seed, risks are more with deep-seated infections than with the surface borne contamination of pests/pathogens. Again, risks are far greater with pathogens like viruses, downy mildews, smuts and many bacteria carried inside the seed without any external symptoms. When vegetative propagules are introduced, rooted plants, and other underground plant parts like rhizomes, suckers, runners, etc. carry higher risks than budwood, scions and un-rooted cuttings. In any case, bulk introductions are always risky as thorough examination and treatment in such cases is very difficult and planting area is far too large to prevent the establishment and spread of the introduced pest/disease.

Based on these factors, plant quarantine regulates the introductions as follows:
1. Complete embargo/prohibition: When the pest risk is very high, the safeguards available in the country are not adequate and, therefore, import is prohibited.

2. Post-entry quarantine: The risk is very high but adequate safeguards in the form of post-entry isolation growing facilities are available.

3. Restricted: Pest risk is not high and import permit is required stipulating conditions for entry, inspection and treatment.

4. Unrestricted: Import permit is not required, and material may enter without restriction.
While formulating quarantine regulations, local conditions like crop spectrum and environmental conditions are also to be considered. Since quarantine regulations are designed to break the life cycle of the pest/pathogen involved, the presence of alternate or collateral hosts in the country of import and their introduction should also be taken into account.

2.5 Tutor Marked Assignment

1. Discuss the concept of quarantine/phytosanitation.
2. Why is pest detection critical for effective pytosanitation?
3. Discuss the specialized test used to detect
    i. Insects
    ii. Nematodes
    iii. Microbes (Fungi, Viruses and Bacteria)
4. Explain the quarantine regulations that guide cross boundary introductions.

2.6 References/Further Reading

Oldroyd, H. (1968) Elements of Entomology, 312 pp. Weidenfeld & Nicolson: London.

Pury, J. M. S. de (1968) Crop Pests of East Africa, 227 pp. Oxford University Press: E. Africa.

Unit 3: Physical Methods

Content **Pg.**

3.0 Introduction

These refer to methods of mechanical removal or destruction of the pest, and are usually unimportant in most countries owing to the high cost of labour. They are still of use in some countries and for particularly valuable crops.

3.1 Mechanical

Hand-picking of pests was probably one of the earliest methods of pest control and is still a profitable method for the removal of some caterpillars from young fruit trees. The killing of longhorn beetle larvae boring in branches of some bushes is recommended by the pushing of a springy wire (e.g. bicycle spoke) up the bored hole and spiking the insect. The use of mechanical drags, which crush insects on the ground, has been made against armyworms (*Spodoptera* larvae), but this practice is now generally outmoded. Banding on fruit trees is particularly effective against caterpillars and ants, which gain access to the tree by crawling up the trunk. Spray-banding of the apple trunks is practised against the wingless females of Winter Moth and other Geometridae which typically climb the lower parts of the trunk from the soil. An earlier method of locust control was to herd the hoppers into a large pit which was afterwards filled in with soil. Armyworms when on the move can often be trapped in trenches dug across their line of marching, and when trapped they are easily destroyed by burning, filling the trench or spraying with chemicals. In parts of Asia, especially in gardens and on smallholdings, it is common practice to place bags around large fruits (e.g. grapefruit, pomelo, pomegranate and jackfruit) to deter fruit flies (Tephritidae) from oviposition. In rural areas and in the forests the bag is usually woven from grass or raffia, but in more suburban situations paper bags and polythene may be employed. Occasionally a single fruit may be left unprotected so that the local fruit-flies will concentrate their egg-laying upon this one fruit which can later be destroyed. In temperate smallholdings and gardens it is a common practice to build a large cage of wire or string (now often plastic) netting over a fruit bed, but this protection is usually against fruit-eating birds rather than insects; such a cage may be portable and temporary or may be a permanent construction. This idea is now being developed on quite a large scale throughout the world, particularly for the protection of seed-beds and also for particularly valuable crops that may be at risk locally Greenhouses in temperate situations provide complete physical protection for a crop, but the main purpose is to modify the temperate climate to provide a suitable hot/moist microclimate for the cultivation of exotic crops or local crops out of season. Nowadays the use of polythene tunnels has become very widespread (fig. 4.5) as these are effective and much cheaper to erect than the traditional glasshouses. The cultivation of protected crops has now become very sophisticated and in many respects is a separate branch of horticulture.

3.2 Use of physical factors

The use of lethal temperatures, both high and low, for insect pest destruction is of importance in some countries. (Often high temperatures are lethal for temperate pests, and low temperatures for tropical pests.) The use of cool storage in insulated stores for grain is practised in Asia and Africa. The purpose of this method is not the actual destruction of the pests, which may occur when lethal temperatures are employed, but the drastic retardation of development following the reduction of the metabolic rate. Kiln treatment of timber for control of timber pests is very widely practised in many countries. Plant bulbs are often infested with mites, fly larvae (Syrphidae) or nematodes, and hot-water treatment (dipping) can be a very successful method of control if carefully carried out. The drying of grain, which is widely practised for a reduction in moisture content, usually results in lower infestation rates by most pests. The heating of cotton seed to kill the larvae of Pink Bollworm (*Pectinophora gossypiella*) is an effective control. In different parts of the World hermetic storage of grain is being developed as a standard long-term storage method. The stores are now of several different basic types and generalization is not feasible; the principle involved is that only a small quantity of air is enclosed within the sealed bin, the oxygen in which is quickly used up by the respiration of the pests and the subsequent carbon dioxide accumulation quickly results in the death of all contained pests, both arthropod and microbial. On-farm storage of grain is being carried out in some areas using butyl silos; the addition of small quantities of diatomite fillers increases the effectiveness of this control, as the abrasive effect removes the outer waxy covering of the epicuticle of the insects, resulting in greater water loss (and possible dehydration) and greater ease of insecticide penetration through the cuticle.

3.3. Use of electromagnetic energy

The radio-frequency (long wavelength radiations) part of the spectrum has been extensively studied in the development of radio communications, radar, etc., and it has been known for a long time that absorption of radio-frequency energy by biological material results in heating of the tissues. Control of insect pests by such heating is only practicable in enclosed spaces of small or moderate size (food stores, warehouses, timber stores). The nature of absorption of radiofrequency energy by materials in a high-frequency electrical field is such that for certain combinations of hosts and insect pests their dielectric properties are favourable for differential absorption of energy, hence the insects can be killed without damaging the host material. Timber beetles in wood blocks have been killed in this manner, but whether this treatment offers any real advantage over normal kiln treatment is doubtful. Use of infrared radiation for heating purposes is very much in its infancy. Many insects show distinct preferences for visible radiation of certain wavelengths (i.e. certain colours), as well as the long recognized attraction of ultra-violet radiation for various nocturnal insects, especially Lepidoptera. Ultra-violet light traps have, on occasions, significantly lowered pest populations in various crops, but have also failed when used against other pests. Mercury vapour lamps are mostly being used for pest monitoring, especially for various night-flying

Lepidoptera (Codling Moth, Pea Moth, rice stem borers, etc.), and for this purpose their use is now very widespread. In some countries, such as China, electricity lines are laid extensively throughout agricultural areas and ultra-violet light traps are used in large numbers. Aphids and some other plant bugs are attracted to yellow colours; this is possibly because most aphids feed either on young or senescent leaves, presumably because these are the plant parts where active transport of food material occurs. The young leaves are photosynthesizing rapidly and the sugars formed are transported away in the phloem system to be stored as starch grains in older leaves, tubers, etc. As leaves become senescent, the stored starch is reconverted into soluble sugars for transportation prior to leaf dehiscence. Senescent leaves are usually yellowish in colour and young foliage is often a pale yellowish-green. So the attraction of aphids to yellow colours seems fairly obvious, but why so many flies (especially Anthomyiidae) and some months are similarly attracted to yellow is not obvious. This attraction for the colour yellow by so many insects is exploited in the use of many different types of trap; yellow water traps consistently catch more aphids and more Cabbage Root Fly adults; sticky traps coloured yellow, and even pheromone traps for Tortricoidea and Tephritidae, are often more effective than white ones. In a monitoring programme, it is of course necessary to make allowance for any enhanced trapping effect due to the colour of the trap. Conversely, many flying insects are repelled by blue colours and by reflective material. This has been exploited by using strips of aluminium foil, or metallicized plastic, between the rows and around the periphery of the crop, the result being that fewer flying aphids and other insects settle in the crop than would otherwise. Thus, reflective strips also result in crops having far less aphid-borne virus diseases. Another effective method is to surround the seed-beds by flooded furrows, as practised in S. China with vegetable crops. The ionizing radiations (X-rays, γ-rays) are sterilizing at lower dosages but lethal at higher. The use of these radiations in controlling stored product pests, particularly in grain, is being quite extensively studied in various countries.

3.4 Tutor Marked Assignment

1. Explain the mechanical method of insect pest management, giving examples
2. Explain how temperature and gases cn be used in insect pest control
3. Describe the use of electromagnetic energy as insect pest deterrents.

3.5 References/Further Reading

Oldroyd, H. (1968) Elements of Entomology, 312 pp. Weidenfeld & Nicolson: London.

Pury, J. M. S. de (1968) Crop Pests of East Africa, 227 pp. Oxford University Press: E. Africa.

Unit 4: Cultural control

Content **Pg.**

4.0 Introduction

These are regular farm operations, that do not require the use of specialized equipment or extra skills, designed to destroy pests or to prevent them causing economic damage. Often these are by far the best methods of control since they combine effectiveness with minimal extra labour and cost. Most of the cultural methods do not give high levels of pest control, and in the recent past, when reliance was placed almost entirely on chemical control (using organochlorines), these methods received little attention. However, with the recent interest in integrated pest management there is a revival of interest in the use of cultural methods for incorporation into management programmes. Often the present-day scheme is to use several different methods in conjunction, each method achieving a certain level of control, so that in concert the desired level is achieved with minimal ecological disruption etc.

4.1 Optimal Growing Conditions

A healthy plant growing vigorously has considerable natural tolerance to pests and diseases (as with a healthy animal), both physically and physiologically. Good plant vigour is a result of sound genetic stock and optimal growing conditions. Obviously the farmer attempts to provide such growing conditions so that the crop yield will be maximal. Many diseases are more severe, and the damage by pests more serious, if the plant is suffering from water-stress (drought), unfavourable temperature, imbalance of nutrients or nutrient deficiency, etc. This *predisposition* to pest attack and disease can be very serious when crops are grown on marginal land. This is one main reason, together with reduced yield, why the cultivation of marginal land is generally not very successful. This point is of particular interest at the present times, for various countries are endeavouring to increase their national agricultural yield, partly to produce more food crops to feed the ever-increasing population, and partly to increase the cash crops as a source of national revenue. But the great majority of countries are already utilizing all their high quality agricultural land and the only land available for agricultural development is marginal tracts with a very limited potential. In some countries this situation is exacerbated in that land has to be taken from agriculture in order to provide sites for new towns, airports, and the general ever-increasing sprawl of urbanization; such land is almost invariably choice agricultural land, and may be the finest such land in the country (that being the main reason for the historical siting of the town in that location).

4.2 Photosynthetic Efficiency

When aiming at a maximum level of sustained crop yield it is advantageous to understand the physiology of the crop plant in order that cultivation is practised in the most effective manner. This is also important in some countries where cultivation of marginal land is being undertaken, for only certain crops give adequate yields on poor land. Plants struggling in poor growing conditions are invariably more susceptible to damage by pests. Some plants are now known to have a more efficient photosynthetic activity than others. They are referred to as C4 plants – so named because of the chemical intermediary, the four-carbon oxaloacetic acid. The majority of plants, which could be called the 'normal' plants, are referred to as C3 plants; C4 plants generally have a high productivity in situations of high temperature and low humidity (and the concomitant low carbon dioxide concentration). They have a high level of stomatal resistance, which conserves water at high temperatures, but of course restricts carbon dioxide entry, but they are able to carry out photosynthesis very effectively under low carbon dioxide concentrations. As a group these plants are generally the most productive agriculturally. Examples of C4 plants include maize, sugarcane and other tropical Gramineae as well as many weed species in the Chenopodiaceae, Euphorbiaceae, etc. The more effectively functioning plants are generally those with the highest agricultural yields, and are also often more tolerant of insect attack and less susceptible to damage. The importance of shade has been somewhat misunderstood in the past; several crops have in the past been thought to require shade for best growth and production; in some cases because they are naturally occurring forest understory plants and to be regarded ecologically as skiophytes (i.e. shade-tolerant). A striking example is tea – for some obscure reason tea was thought to need shade, and many plantations bear mute testimony to this previous practice in the large number of dead trees to be seen standing throughout the plantation. Recent experiments in Indonesia have shown that cocoa grown as a heliophyte (i.e. fully exposed to sunlight) gives a greater yield than when grown as usual under the shade of a tree cover. In the wild this shrub is a skiophyte adapted for life as a rain forest under storey shrub; but this adaptation to a low light intensity does not necessarily imply that it prefers shaded conditions. And the practice of growing cocoa as a forest-edge crop, under the shade of the trees, frequently exacerbates the pest situation in that many of the more serious pests live on (or in) the forest trees and continually invade the crop plants from this vast natural reservoir. In parts of Africa the most serious pests to ripening cocoa are the local monkeys, and in the forest these animals are almost impossible to control economically. In Europe it has long been realized that strawberry plants grow and yield best when fully exposed to sunlight, even though they are found wild as woodland ground flora. To minimize pest damage to agricultural crops it might be advantageous to review cultivation methods to determine that each crop is really being grown under optimum conditions, and not just to continue cultivation practices on the grounds of historical precedent.

4.3 Avoidance

Empirical observations will reveal that certain areas (and fields) are constantly 'at risk' from particular pests and conversely others are pest-free. Clearly, if a crop can be grown in areas of the latter category it can be expected to remain free rom that particular pest. This practice is particularly effective against certain soil-borne diseases and nematodes, but less so against most insects because of their greater mobility. This is one of the advantages of shifting cultivation, so widely practised in parts of the tropics. Soil insects, such as root maggots (Anthomyiidae), wireworms, chafer grubs, rootworms (USA) and swift moth caterpillars, can to some extent be avoided by the planting of non-susceptible crops and the growing of the vulnerable crops at some distance away. Such practice is to be highly recommended, but is sometimes difficult to achieve as there may be strong agricultural, or other, reasons for growing the crops in those areas. Thus in the UK the East Anglian fenlands are ideal for growing carrots, celery and parsnip, but many of these areas have endemic Carrot Fly populations on the native hemlock and other Umbelliferae, and have long been areas highly 'at risk' from Carrot Fly. In this situation it is possible to minimize the risk from this pest by using other cultural methods such as crop rotation, etc., and of course chemical protection has to be used.

4.4 Time of Sowing

By sowing early (or sometimes late) it may be possible to avoid the egg-laying period of a pest, or else the vulnerable stage in plant growth may have passed by the time the insect numbers have reached pest proportions. Early sowing is regularly practised against Cotton Lygus (*Taylorilygus vosseleri*) and Sorghum Midge (*Contarinia sorghicola*) in Africa. In N. Thailand it has been shown that early transplanting of paddy rice reduced the level of Rice Gall Midge attack appreciably. Another important aspect of the time of sowing is that of simultaneous sowings of the same crop over a wider area, to avoid successive plantings which often permit the build-up of very large pest populations. In Europe the recent trend towards autumn-sowing cereals (winter wheat, winter barley) has reduced the risk of aphid damage to seedlings to a negligible level. At the same time this practice does increase the risk from Wheat Bulb Fly. Autumn-sown field beans are generally not at risk at all from Black Bean Aphid, whereas the spring-sown plants may be severely damaged. With Wheat Bulb Fly only the very early-sown spring wheat is at risk, so if spring wheat is sown later there is little risk from this pest; but if sowing is delayed too much then crop growth is impaired!

4.5 Deep Sowing (Planting)

Some seeds are less liable to damage and pest attack if rooted deep, but of course if planted too deep germination will be impaired. Many root crops are also less liable to attack by pests if they are deeper in the soil. This is true for sweet potato in that the deeper tubers always have fewer weevils (*Cylas* spp.) boring inside, and the deeper potatoes have fewer infestations of Tuber Moth larvae. Even if no special attempts at deeper planting of root crops are made, then care should be taken to ensure that no tubers are allowed to grow too close to the soil surface; earthing-up should be done when required. Exposed root crops may be damaged by pheasants, other birds, and by rodents and rabbits grazing.

4.6 Time of Harvesting

Prompt harvesting of maize and beans may prevent these crops from becoming infested by Maize Weevil (*Sitophilus zeamais*) and Bean Bruchid (*Acanthoscelides obtectus*) respectively. Both of these pests infest the field crops from neighbouring stores, but are generally not able to fly more than about half a mile; so an added precaution is to always grow these crops at least half a mile away from the nearest grain store. New varieties of crops which mature early may enable a crop to be harvested early, before pest damage is serious. This is one of the qualities that many plant breeders are constantly seeking in a very wide range of different crops. This approach requires detailed knowledge of the ecology and life history of the local serious pests so that crop development might be desynchronized in relation to pest population development.

4.7 Close Season

In E. Africa legislation has been passed to ensure that there is a close season for cotton growing in order to prevent population build-up of Pink Bollworm (*Pectinophora gossypiella*) which is oligophagous on Malvaceae. This legislation stresses that all cotton plants should be uprooted and destroyed (or burned) by a certain date and quite clearly no seed would be planted until the following rains arrive. However, it is clear that many farmers do not bother to destroy the old plants by the appointed date and so in some areas there is considerable survival of diapausing Pink Bollworm larvae this approach to pest control tends to be more applicable to the tropics where insect development and crop production may be more or less continuous. In temperate regions there is already established very firmly a close season for virtually all crops, namely winter!

4.8 Deep Ploughing

Many Lepidoptera (particularly Noctuidae, Hepialidae, Sphingidae and Geometridae), Coleoptera and Diptera pupate in the soil, and a large number of their larvae live there. The bulk of the soil insect population lie in the top 20 cm of the soil (most are in the top 10 cm). Deep ploughing will bring these insects to the surface, to be exposed to hot sunlight (insolation), desiccation and predators. In many tropical areas a farmer ploughing a field will be followed by a flock of cattle egrets, little egrets, crows or starlings, in a seaside locality there might be a flock of gulls; all these birds will feed on the exposed worms, slugs and insects. In temperate regions a plough is usually accompanied by a large flock of birds (gulls, crows, etc.), and although the birds are also eating earthworms their consumption of insect larvae and pupae (many or most of which are pests) must be prodigious, as often a hundred or more birds may follow a single tractor.

4.9 Fallow

Allowing a field to lie fallow almost invariably reduces pest and pathogen populations, but care must be taken to ensure that there are no volunteer crop plants or important secondary host weed species. Fallowing may be done as *bare fallowing* when the soil surface is left bare, or *flood fallowing* when the field is flooded with water for a while. Sometimes, as an alternative, a cover crop of legumes is grown as *green manure* which is then ploughed under.

4.10 Crop Rotation

In olden times a period of fallow was an essential part of all crop rotations, but nowadays economic pressures mean that fields can seldom be left fallow. Instead, basic crop rotation is usually practised for the obvious reasons that continuous cultivation of one crop depletes the minerals and trace elements in the soil quite rapidly, and also induces disease and pest build-up. However, some agricultural crops require rather specialized growing conditions, and these, combined with the practice of large scale cultivation, result in some areas growing crops such as sugarcane, wheat, pineapple, maize or potato, almost continuously. Obviously the orchard crops (apple, plum, pear, citrus, peach, olive, etc.) are also very long-term monocultures, as are vineyards. The alternation of completely different crops in a field has very obvious advantages from the pest and disease control aspects. But in a rotation it is necessary to remove a particular crop quite a distance away; having the same crop in an adjacent field is not really ‘rotation’ so far as active insects are concerned, although it might be adequate for soil nematodes and some soil-borne diseases. So, for effective pest control crop rotation has to separate crops both spatially and in time (temporally). Against monophagous and oligophagous pests crop rotation can be effective, especially with beetle larvae that may take a year or more to develop, but it is not effective against migratory pests or those with effective powers of dispersal. The alternation of cereals with non-cereals may be an important method of curtailing *Nematocerus* weevils in Africa. A common type of rotation is the alternation of a legume crop with cereals; this is effective against some pests, but others (e.g. *Colaspis*, *Diabrotica*) can utilize both host types. In Europe a combination of potato, wheat and rape is currently popular and successful.

4.11 Secondary Hosts

Most pests are not monophagous and so will live on other plants in addition to the crop. Sometimes, in point of fact, the crop itself is not the preferred host! For example, Turnip Aphid is often more abundant on *Cardamine* and charlock, etc., than on the *Brassica* plants. In many cases the pests build up their numbers on wild hosts and then invade the crop when the plants are at the appropriate stage of development. Many Cicadellidae and Delphacidae that are crop pests (on rice and other cereals) feed and breed on wild grasses in the vicinity of the paddy fields so that when the young rice is planted out there is a large bug population waiting to infest the young tender shoots of the rice. The destruction of alternative hosts (or the control of insects on them) may be an important part of an IPM programme. The alternative hosts are usually native plants (but may be introduced), and may be trees, shrubs, or herbaceous plants; they may be cultivated species, wild plants or weeds. Solanaceous weeds, for example, are important alternative hosts for pests of tomato, tobacco, eggplant and potato. In many cases the permanent pest population in an area is maintained not on crop plants but on wild plants belonging to the same family; there are many wild Cruciferae that support *Brassica* pests and the number of wild Leguminosae, Chenopodiaceae, Rosaceae, etc., is very large. In temperate situations a number of pests and diseases have an alternation of generations on quite different hosts, e.g. *Myzus persicae* on peach and potato. The removal of the alternative host can effectively reduce such pests to insignificance, but in the case cited, of course, the alternative host is itself a crop plant. Black Bean Aphid overwinters on spindle trees, and in some areas attempts have been made to remove these trees locally, but usually without much success. *Pemphigus bursarius* overwinters on poplar trees where it makes petiole galls in the spring; later generations migrate to lettuce where they encrust the roots. With monophagous pests it is important to remove any host plants between crops (if feasible for the species concerned). A monophagous insect would normally be confined to the species of a single genus for host, though it would be unusual for it to be restricted to a single species of one genus. Thus, for sugar beet pests it is not feasible to attempt to remove all wild species of Chenopodiaceae as they are too abundant. But, for the Brown Plant hopper of Rice (*Nilaparvata lugens*) which is restricted to rice (*Oryza* spp.) as a host plant, the alternative host plants are either wild rice or volunteer rice; by destruction of wild rice weeds, volunteer plants and crop residues, this pest can be partially controlled. The situation with regard to secondary/alternative hosts tends to be more important in the tropics where usually there are more wild plants in the immediate neighbourhood of the crop, especially where land is cultivated along the edges of tracts of native forest ('jungle').

4.12 Weeds

Most cultivation practices require destruction of weeds because of their competition with the crop plants, and their interference with different aspects of cultivation. But weeds can also be important from the viewpoint of pests and diseases; sometimes the weeds may be alternative hosts, as already mentioned. Weeds in a particular crop often belong to the same family as the crop plant because of the selective nature of many post-emergence herbicides. Some pests seem to prefer weeds as oviposition sites; for example, some cutworms (*Agrotis* spp.) and some beetles (Scarabaeidae) lay most of their eggs on, or in the immediate vicinity of, weeds in the crop. Weed removal at the appropriate time may result in many potential pests being destroyed. Some weeds are important as natural reservoirs (alternative hosts) of both pathogens and invertebrate pests.

4.13 Trap crops

The use of trap plants to reduce pest infestation of various crops is based upon the knowledge that many pests actually prefer feeding upon plants other than those on which they are the most serious pests. This preference may be exploited in two different ways: either the pests are just lured from the crop on to the trap plants where they stay and feed, or else, because of the greater concentration of pests on the trap plants, only the trap plants need be sprayed with pesticides. In the latter case, since the trap plants are either grown as a peripheral band or else inter-planted at about every fifth to tenth row, the saving of insecticide represented is considerable. This is a technique used mostly in warmer parts of the world where insect pest breeding is more or less continuous; in the cooler temperate regions, with the cold dormant winter period, it is of less applicability. The practice of intercropping is based upon the same premise, and this has long been a regular method of reducing levels of pest damage in Nigeria.

4.14 Intercropping

This practice obviously has various drawbacks for large-scale agriculture, but can be of particular application for the small farmers, who often use little insecticide. Intercropping can certainly reduce a pest population on a crop, and without doubt reduces the visual and olfactory stimuli that attract insects to a particular crop species. As a method of control it is most effective against exogenous pests, such as locusts, which enter the crop for only part of their life-cycle. Groundnuts are inter-cropped with maize, and nymphs of Locust were induced to leave the maize (particularly on hot days) for the lower foliage of the groundnuts where they were eaten by ducks. In Nigeria, on smallholdings, it has long been a regular practice to intercrop, often using plants with very strong odoriferous qualities in the hope that the odours released would confuse the host-seeking female insects, which it does appear to do. Onions and crucifers, for example, would be used to shield carrot crops. Often wild type plums are grown around the periphery of apple orchards where they act partly as a wind shield and also as a diversion for a number of different insect pests.

4.15 Crop sanitation

This is a rather general term, and usually is used to include the following different aspects of crop cultivation.

(a) Destruction of diseased or badly damaged plants – the roguing of such plants is an important agricultural practice, but of course requires hand labour. For agricultural crops this is sometimes not feasible, but some farmers do make the necessary effort; with horticultural crops such as fruit orchards, flowers and some vegetables, destruction (preferably by burning) of infected and infested branches etc., is an important aspect of any control programme, as it is easier to remove the foci of infection than to kill the organism with pesticides.

(b) Removal and destruction of rubbish – old crop remnants, fallen leaves, branches, dead trunks, also weeds, etc. Some pests use rubbish heaps for breeding purposes, for example scarab larvae are to be found in rotting vegetation and soil, especially in rubbish heaps. The tropical *Oryctes* beetles are good examples, as the larvae are found in rotting palm trunks and rubbish heaps.

(c) Removal and destruction of fallen fruits – for the control of many fruit flies and boring caterpillars this is important, as the insects will continue to develop in the fallen fruit and will pupate either there or in the soil. This is, in fact, still a successful method for reducing the numbers of Codling Moth and other fruit-boring caterpillars, as well as for many different fruit flies (Tephritidae). It is still one of the best methods of control for Coffee Berry Borer, where labour permits.

(d) Destruction of crop residues – this is often vitally important in order to kill the resting stages (pupae, etc.) of many pests after harvest. Many stalk borers (Pyralidae, Noctuidae) pupate in the lower parts of the cereal stems and as such will be left in the stubble even if the main parts of the stalks are removed. With some crops of maize, sorghum and millets most of the actual stem is left. The stems should be burnt immediately after harvest. The rotting residues of crops such as turnip, parsnip and *Brassica* generally, after being ploughed in attract ovipositing female Bean Seed Fly and other Muscoidea. For diseases, crop residue destruction may be even more important. Ploughing in of crop stubble may kill a small proportion of pupae but most will survive; burning is most effective. European corn borer traditionally overwinters in maize stubble, but most farmers are now aware of this and so the stubble is destroyed. The recommended method of destruction of all weeds, crop residues, rubbish, rogued plants, fallen fruits, etc., is by collection and burning; other methods may not kill the pests. Crop sanitation tends to be a term mostly used by plant pathologists rather than entomologists, as it aims mostly at the removal of sources (foci) of disease infection.

4.16 Crop plant resistance to pest attack

In most growing crops it may be observed that some individual plants either harbour far fewer pests than the others or else show relatively little sign of pest damage. These individuals usually represent a different genetic variety from the remainder of the crop, and this variety is said to show *resistance* to the insect pest. Also when different varieties of the same crop are grown side by side, differences in infestation level may be very marked. Resistance to pest attack is characterized by the resistant plants having a lower pest population density, or fewer damage symptoms, than the other plants which are termed *susceptible*. Conversely, there will be some plants that appear to be preferred by the pests and these especially susceptible plants will bear very large pest populations. Frequently these plants will actually be destroyed by the pests and so will not breed and pass on their disadvantageous genetic material.

The main use of resistant varieties of crop plants in agriculture has been against plant diseases (Russell, 1978), and in general a high level of success has been achieved. Plant-parasitic nematodes (eelworms) in some ways behave rather like soil pathogens, and the development of resistant varieties of potato and wheat have been very successful in combating Potato Cyst Eelworm and Cereal Root Eelworm. Against insect pests plant breeding for resistance has not had the same success, but in some instances good control has been achieved with enough success to encourage further work in this area. On the whole it can be said that many resistant varieties of crop plants have given quite good control of insect pests, albeit only partial, against a very wide range of insect species. Many varieties of crop plants showing good resistance to important pest species have not been fully exploited because their yield is less, or of inferior quality, than the usual susceptible varieties.

Varietal resistance to insect pests was broadly classified by Painter (1951) into three categories: non-preference, antibiosis, and tolerance; but Russell (1978) suggests the use of a fourth category: pest avoidance. Some workers restrict the use of the term varietal resistance to antibiosis, but this view is rather narrow and not practical. In fact it is often very difficult to distinguish between some cases of non-preference and antibiosis.

4.16.1 Types of resistance

(a) Pest avoidance

(b) Non-preference (= non-acceptance)

(c) Antibiosis
(d) Tolerance

The basis of these types of resistance is slight variations in genetic material; as defined by Russell (1978), 'Resistance is any inherited characteristic of a host plant which lessens the effect of parasitism.' The term *parasitism* is used in a broad sense to include the attack of insect pests, mites, vertebrates, nematodes, and pathogens (fungi, bacteria, viruses) on the host plant. The feeding of phytophagous insects on plants is not generally regarded as parasitism by most zoologists, but rather as ecological grazing. Genetically there are three main types of a resistance. *Monogenic* resistance is controlled by a single gene, usually a *major gene* which has a relatively large effect. This type of resistance (often biochemical, involving phytoalexins) is fairly easily incorporated into a breeding programme, and it usually gives a high level of resistance; unfortunately this resistance is just as easily 'broken' by new pest 'biotypes' (new races or strains). *Oligogenic* resistance is the term used when the character is controlled by several genes acting in concert. *Polygenic* resistance is the result of many genes, and is clearly more difficult to incorporate into a plant breeding programme. It may be either morphological or biochemical, and it is generally less susceptible to biotype resistance ('breaking'). Many of the genes will be *minor genes* which individually only have a small effect genetically. In epidemiological terms, resistance is classified as either *horizontal resistance* (alternatively, durable resistance), with a long-lasting effect and effective against all genetic variants of a particular pest, or *vertical resistance* (alternatively, transient resistance), effective for a short period and against certain variants only. There are a few other terms which are in use in plant breeding for pest resistance. *Field resistance* is the term used commonly to describe resistance which gives effective control of a pest under natural conditions in the field, but is difficult to characterize in laboratory tests; usually it is a complex kind of resistance giving only partial control. *Passive resistance* is when the resistance mechanism is already present before the pest attack, for example an especially thick cuticle, or hairy (pubescent) foliage. *Active resistance* is a resistance reaction of the host plant in response to attack by a parasite more usually applicable to attack by pathogens rather than pests (insects etc.); for example, the formation of phytoalexins or other antibiotics (antifungal compounds) by some host plants in response to attack by some pathogenic fungi. This reaction is not unlike the human production of antibodies in response to foreign matter in the blood or tissues. *Qualitative resistance* applies when the frequency distribution of resistance and susceptible plants in the crop population is discontinuous, and the plants are individually easily categorized as either resistant or susceptible. *Quantitative resistance* is the term used when a crop shows a continuous gradation between resistant plants and susceptible plants within the population, with no clear-cut distinction between the two types.

a. Pest Avoidance

This is when the plant escapes infestation by the plant not being at a susceptible stage when the pest population is at its peak. Some varieties of apple escape infestation by several different pest species in the spring by having buds which do not open until after the main emergence period of the pests, thus reducing the final amount of damage inflicted.

b. Non-preference (= Antixenosis)

The term 'non-acceptance' has been proposed as a more suitable alternative, but has never gained general acceptance. Insects are noticeably reluctant to colonize some individual plants, or some particular strain of host-plant, and these plants seem to be less attractive to the pest by virtue of their texture, colour, odour or taste. Non-preference usually is revealed when the bug or caterpillar either refuses to feed on the plant or takes only very small amounts of food, or when an ovipositing female insect refrains from laying eggs on the plant. In the Philippines *Chilo supressalis* females laid about 10–15 fewer egg masses on resistant rice varieties than on susceptible ones. Also at IRRI, the Brown Planthopper of Rice (*Nilaparvata lugens*) punctures the tissues of a certain rice variety but apparently feeds only little, probably because of the reduced amount of a particular amino acid (asparagine) in the sap of that variety. Two temperate examples of this type of resistance include Raspberry Aphid (*Amphorophora idaei*) which when placed on to leaves of resistant plants exhibit a reaction so strong that they will quickly walk off the plants completely. On sugarbeet aphids do not actually walk off the resistant plants, but they do feed for noticeably shorter periods of time and are quite restless whilst on resistant plants.

c. Antibiosis

In this case the plant resists insect attack, and has an adverse effect on the bionomics of the pest by causing the death of the insects or decreasing their rate of development or reproduction. The resistant plants are generally characterized by anatomical features such as thick cuticle, hairy stems and leaves, a thickened stem (cereals), a narrower diameter of the hollow pith in cereal stems, compactness of the panicle in sorghum, tightness of the husk in maize, and tightness of leaf sheaths in rice. Biochemical aspects usually involve the presence of various toxic or distasteful chemicals in the sap of the tissues of the plant which effectively repel feeding insects, sometimes to the extent that the odour is sufficient to completely deter them from feeding. Alternatively, there may be a chemical which normally functions as a feeding stimulant missing from the body of the resistant plant, or else at a sufficiently low concentration that it fails to stimulate the insect into feeding behaviour. Cotton Jassids (*Empoasca* spp.) have ceased to be important pests of cotton in Africa and India since the post-war development of pubescent strains which the bugs find quite unacceptable as host plants. In a similar manner, hairy-leaved varieties of wheat in N. America are attacked significantly less often by the Cereal Leaf Beetle (*Oulema melanopa*); the females lay fewer eggs on the leaves and, of the larvae that hatch, fewer survive. It is also recorded that pubescent foliage apparently deters oviposition by many species of Lepidoptera, but this situation is complicated in that some bollworms will apparently lay more eggs on the foliage of some pubescent varieties of cotton. The tightness of the husk in some maize varieties will deter feeding on the cobs by larvae of *Heliothis zea* (Corn Earworm) in the USA, and should also apply to field infestations of the drying grain by Maize Weevil (*Sitophilus zeamais*). Varieties of sorghum in Africa, with an open panicle, suffer far less damage by False Codling Moth (*Cryptophlebia leucotreta*) and other caterpillars. Wheat varieties with solid stems (i.e. very reduced pith) are noticeably resistant to Wheat Stem Sawfly (*Cephus cinctus*) in N. America in that growth and development of the larvae are retarded.

d. Tolerance

Tolerance is the term used when host plants suffer little actual damage in spite of supporting a sizeable insect pest population. This is characteristic of healthy vigorous plants, growing under optimal conditions that heal quickly and show compensatory growth. In fact most plants bear more foliage than they actually need, and can usually suffer a fair amount of defoliation with no discernible loss in crop yield. Tolerance is frequently a result of the greater vigour of a plant, and this may result from the more suitable growing conditions rather than from the particular genetic constitution of the plant. For example, sorghum growing vigorously will withstand considerable stalk borer damage with no loss of yield. Some varieties of crop plant (e.g. rice) may show both tolerance to a pest as well as antibiosis; this is true for several stalk borers. Sometimes pest attack on a tolerant variety can actually increase the crop yield; this occurs quite frequently with the tillering of cereals following shoot fly, stem borer, or cutworm destruction of the initial shoot in the young seedling. From a pest management point of view the use of a tolerant variety could in theory be a disadvantage in that it could support a larger population of the pest and so encourage a local population build-up rather than a decline. Many cases of clear-cut resistance to insect pests have been recorded, but they have not been investigated sufficiently for the mechanism of resistance to be evident. This is particularly the case in respect to the aphids *Myzus persicae* and *Aphis fabae* on sugar beet, and to Carrot Fly (*Psila rosea*) on carrots (Hill, 1974*b*; Ellis *et al*., 1980).

4.17 Breaking of Host Plant Resistance

In some agricultural situations there develop physiological races of the insect pest, known as *biotypes*, some of which are not susceptible to the host plant resistance. These are *resistance-breaking biotypes*. In nematology this type of variant is known as a *pathotype*, in virology it is a *strain* and, applied to fungi, it is a *race*. The development of resistance-breaking biotypes has been known for a long time in the Hessian fly, and several biotypes can attack wheat varieties that are quite resistant to other biotypes. The Brown Plant hopper of Rice (BPH) in S.E. Asia has recently become notorious in that for several reasons it has changed status from a minor to a serious major pest on rice. However, rice varieties resistant to this bug were developed at IRRI, and have been widely grown throughout the area; they have given such good control that sometimes insecticides have not been required. In some localities, however, resistance-breaking biotypes of BPH have developed to such an extent as to threaten local rice production. The present situation is that as fast as the research workers at IRRI produce resistant varieties of rice to BPH, the insects correspondingly produce new resistance-breaking biotypes. Detailed bio-systematic and ecological studies of the biotypes of *Nilaparvata lugens* have been initiated at IRRI. The breaking of host plant resistance is generally less common amongst insect pests than pathogens. This is thought to be because insects produce far fewer propagules than the fungi, bacteria and viruses, and thus far less genetic variation can be expressed.

Tutor Marked Assignment

Explain the following cultural control measures:

i. Optimal growing conditions
ii. Photosynthetic efficiency
iii. Avoidance
iv. Time of sowing
v. Deep sowing (planting)
vi. Time of harvesting
vii. Close season
viii. Deep ploughing
ix. Fallow
x. Crop rotation
xi. Secondary hosts
xii. Weeds
xiii. Trap crops
xiv. Intercropping
xv. Crop sanitation

References/Further Reading

Oldroyd, H. (1968) Elements of Entomology, 312 pp. Weidenfeld & Nicolson: London.

Pury, J. M. S. de (1968) Crop Pests of East Africa, 227 pp. Oxford University Press: E. Africa.

Unit 5: Biological control (Introduction)

Content **Pg.**

5.0 Introduction

In the broad sense (*sensu lato*) this can include all types of control involving the use of living organisms, so that, in addition to the use of predators, parasites, and disease causing pathogens (biological control – *sensu stricta*), one can include sterilization, genetic manipulation, use of pheromones, and the use of resistant varieties of crop plant. As already indicated in this book, the use of resistant crop varieties is being dealt with separately as it is an aspect of control of such importance, and plant breeding is a very specialized subject in its own rights. The main attraction of biological control is that it obviates the necessity (or at least reduces it) of using chemical poisons, and in its most successful cases gives long-term (permanent) control from one introduction. This method of control is most effective against pests of exotic crops which often do not have their full complement of natural enemies in the introduced locality. Then the most effective natural enemies usually come from their native locality, for the local predators/parasites/pathogens are usually in a state of delicate ecological balance in their own environment and cannot be expected to exercise much population control over the introduced pests. On rare occasions a local predator or parasite will successfully control an introduced pest, but this is rare!

5.1 Natural control

This is the existing population control already being exerted by the naturally occurring predators and parasites (and diseases) in the local agro-ecosystem, and it is vitally important in agriculture not to upset this relationship. Because it is not readily apparent, the extent of natural control in most cases is not appreciated. It is only after careless use of very toxic, broad-spectrum, persistent insecticides which typically kill more predators and parasites than the less sensitive crop pests, and which is then followed by a new, more severe pest outbreak, that the extent of the previously existing natural control may be appreciated. In summary, the importance of natural control of pests in most agro-ecosystems cannot be overemphasized.

5.2 Predators

The animals that prey and feed on insects are very varied, as are their effects on pest populations. The main groups of entomophagous predators are as follows:

Mammalia – (man), Insectivora, Rodentia Aves – Passeriformes (many families), many other groups, especially ducks, game birds, egrets and herons, hawks Reptilia – small snakes, lizards, geckos, chamaeleons Amphibia – most Anura (frogs and toads) Pisces – *Gambusia* etc. (control mosquito larvae) Arachnida – spiders, harvestmen, chelifers, scorpions, etc. Acarina – mostly family Phytoseiidae Insecta – Odonata (adults, and nymphs in water), Mantidae, Neuroptera, Heteroptera (some Miridae, Anthocoridae, Reduviidae, Pentatomidae), Diptera (Some Cecidomyiidae (larvae), Syrphidae (larvae), Asilidae, Therevidae, Conopidae, etc.), Hymenoptera (Vespidae, Scoliidae, Formicidae), Coleoptera (Cincindelidae, Carabidae, Staphylinidae, Histeridae, Lampyridae, Hydrophilidae, Cleridae, Meloidae and Coccinellidae) A few predators are quite prey-specific; for example, the larvae of Meloidae feeding on the egg-pods of Acrididae in soil, and Scoliidae feeding on scarab larvae in soil and in rubbish dumps. But most predators are not particularly confined to any specific prey. Some of the predators live in rather specialized habitats; for example, all the fish are aquatic, as are some insect larvae (e.g. Odonata), and so only prey on aquatic insects (such as mosquito larvae); some live in soil or leaf litter so their prey is restricted to certain types of insects.

5.3 Pathogens

Control by pathogens is sometimes referred to as *microbial control*. There are three main groups concerned: bacteria, fungi and viruses, and some other groups of entomophagous micro-organisms which are rather obscure and little studied. There are several types of *Bacillus*, which are specific to caterpillars or beetle larvae, responsible for natural epizootics, and several species are now commercially formulated and very important in pest control projects. Fungi are responsible for producing antibiotics and apparently about 300 antibiotics do show some promise as pesticides; these act directly as killing agents or inhibitors of growth or reproduction. Viruses are quite commonly found attacking insects in wild populations of caterpillars and beetle larvae, as well as some temperate sawfly larvae. They have long been used as biological insecticides, by finding dead larvae in the field and making an aqueous suspension of their macerated bodies. But now a few commercial preparations are available. Some of these new biological insecticides using insect pathogens are, however, only easily available in the USA as yet, although others are commercially available in Europe and parts of Asia.

5.4 Sterilization

This usually refers to the sterilization of males by Xrays or γ-rays and is called the *sterile-male technique*; control of a pest by this technique is termed *autocide*. Sterilization can be effected by exposure to various chemicals and this practice is called *chemo-sterilization*. The rationale behind this method is that male sterilization is effective in species where females only mate once and are unable to distinguish or discriminate against sterilized males. The classical case was in about 1940 on the island of Curaçao against Screw-worm (*Callitroga*) on goats: the male flies were sterilized by exposure to γ-rays, and dropped from planes at a rate of 400/square mile/week. The whole pest population was eradicated in 12 months. The life-cycle took only about four weeks to complete, and the females only mated once in their lifetime. Generally, autocide is most effective when applied to restricted populations (islands, etc.), but can be effective on parts of the continents. The Screw-worm eradication campaign was extended to the southern part of the USA where the pest is very harmful to cattle. In Texas 99.9% control was achieved in only three years. Male sterilization trials were effective against Mediterranean Fruit Fly (*Ceratitis capitata*) on part of the island of Hawaii in 1959 and 1960, but immigration from untreated parts of the island prevented control from being long-lived. Chemosterilization has now advanced from a theoretical technique to a practical one, a variety of chemicals have been demonstrated to interrupt the reproductive cycles of a large number of insect species, see Curtis (1985).

5.5 Genetic Manipulation

In reality this method is an extension of the previous one, in that the electromagnetic radiations (X-rays, γ-rays) induce *dominant lethal mutations* in the germ cells of the insects. These mutations in insect sperm have been used successfully in several eradication programmes. Lethal mutations are not lethal to the treated cell, they are lethal to its descendant in that the zygote fails to develop to maturity. These mutations arise as a result of chromosome breakages in the treated cells.

5.6 Potential uses for Pheromones in Pest Control

The two obvious ways in which pheromones may be used in a pest control programme are firstly, in pest population surveys or for population monitoring (for emergence warnings, and spray warnings), and secondly for direct behavioural modification control. It is clear now from the work that has been done in recent years that pheromone traps are extremely useful in monitoring projects and this use is likely to be increased in the future. But to date there has not yet been a good example of pheromone use actually achieving a significant level of population control in a pest management programme; though, as already mentioned there have been behaviour disruption trials on several different crops with very encouraging results.

5.7 Insect Population Monitoring

The presence or absence of a particular insect species in an area can be established through the use of attractant pheromones, so that control measures may then be exercised, if necessary, with precise timing. Previously field population monitoring relied largely on either light-trapping, which requires a source of electricity, or the finding of eggs on the crop plants. The finding of the first eggs on a particular crop is a very tedious and time consuming process requiring a great deal of labour and is not particularly efficient. The examination of a few pheromone traps for the presence of male insects is relatively very easy, and much more efficient. Alternatively, the pheromone traps can be used to monitor the effectiveness of a pest control programme, even though not directly employed in the programme themselves.

Emergence of male Codling Moth in apple orchards in the spring in Europe and N. America, and Pea Moth, is now regularly monitored by the use of small paper (waterproof) pheromone traps with a sticky interior. Pink Bollworm, and other bollworms, on cotton crops in many parts of the tropics are likewise monitored with the use of these sticky pheromone traps, with considerable success. Various species of fruit flies (*Dacus* spp.) are monitored, sometimes using sticky pheromone traps and sometimes in traps with insecticides inside, in citrus and peach orchards to determine whether or not insecticide spraying is required, and if so just when. As more and more sex pheromones are being synthesized, and more chemical attractants are being discovered, it seems likely that the use of these chemicals in monitoring programmes will increase and will play a constant role in many pest management programmes.

Tutor Marked Assignment

Discuss the following;

i. Natural control
ii. Predators
iii. Pathogens
iv. Sterilization
v. Genetic manipulation
vi. Potential uses for pheromones in pest control
vii. Insect population monitoring

References/Further Reading

Oldroyd, H. (1968) Elements of Entomology, 312 pp. Weidenfeld & Nicolson: London.

Pury, J. M. S. de (1968) Crop Pests of East Africa, 227 pp. Oxford University Press: E. Africa.

Unit 6: Chemical methods

Content **Pg.**

6.0 Pesticides

Insecticides and their methods of application will be dealt with more fully in. Only rarely does chemical application kill all the pests, and the few which survive usually soon give serious problems by the development of resistance. Chemical control is essentially repetitive in nature and has to be applied anew with each pest outbreak. However, this method is very quick in action and, for the majority of pest outbreaks, chemical control remains the method by which the surest and most predictable results are obtained. The different modes of action of insecticides are briefly listed below.

(a) Repellants – designed to keep the insects away; usually employed against mosquitoes and other medical pests.

(b) Anti-feedants – certain chemicals block part of the feeding response in some phytophagous insects, and they can be used for plant protection.

(c) Fumigants – volatile substances that vaporize and the toxic gases kill pests within enclosed containers (food stores), greenhouses, or in soil.

(d) Smokes – finely divided insecticidal powders mixed with a combustible material; the insecticide is dispersed as 'smoke'; only of use in greenhouses and other enclosed spaces.

(e) Stomach poisons – have to be ingested to be toxic; either sprayed on to foliage (for foliage eaters) or mixed with a bait to encourage ingestion.

(f) Contact poisons – usually absorbed directly through the cuticle:

(i) ephemeral – short-lived; usually a foliar application.
(ii) residual – persistent (long-lived); soil or foliage application.

(g) Systemic poisons – watered into the soil, sprayed on to the plant, or applied to the trunk; absorbed and translocated by the plant and effective against sapsuckers especially. They may be applied as sprays or granules, to either soil or foliage.

Pesticide application still remains the major weapon in the pest war, for obvious reasons, but we now find that often, sometimes usually, there are three definite post application effects.

(a) Normal resurgence of treated pest – this always occurs as the target species initially suppressed by the insecticidal treatment shows a rapid population recovery after the decline of the treatment effect.

(b) Resurgence of the target species due to either development of a resistant biotype (as with the Brown Plant hopper of Rice) and/or destruction of natural enemies.

(c) Outbreak of a secondary pest or pests, due to the alteration of the agro-ecosystem, usually by the destruction of natural enemies.

6.1 Tutor Marked Assignment

1. Discuss chemical insecticides based on their mode of action.
2. What are the post application effects of synthetic insecticides? Explain any two.

6.2 References/Further Reading

Oldroyd, H. (1968) Elements of Entomology, 312 pp. Weidenfeld & Nicolson: London.

Pury, J. M. S. de (1968) Crop Pests of East Africa, 227 pp. Oxford University Press: E. Africa.

Unit 7: Integrated pest management (IPM)

In 1967 the FAO panel of experts on integrated pest control defined *integrated control* as ‘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 population at levels below those causing economic injury’. This definition incorporates the concept of pest management as defined by the Entomological Society of America, now expressed as IPM (Glass, 1975). The concept of (I)PM is now well established. One of the earliest definitions was by Rabb & Guthrie (1970); they commented that originally integrated control generally referred to the modification of insecticidal control in order to protect and enhance the activities of beneficial insects (predators and parasites). Subsequently, however, integrated control interpretations have become more comprehensive until now; some definitions of integrated control embody most of the essentials of pest management. Rabb preferred the term pest management because it connotes a broader ecological basis and a wider variety of opinions in devising solutions to pest problems. Pest management can be defined as the reduction of pest problems by actions selected after the life-systems of the pests are understood and the ecological as well as economic consequences of these actions have been predicted, as accurately as possible, to be in the best interests of mankind. In developing a pest management programme, priority is given to understanding the role of intrinsic and extrinsic factors in causing seasonal and annual changes in pest populations. Such an understanding implies a conceptual model of the pests’ life-system functioning as a part of the ecosystem involved. Ideally such a model would be mathematical, but a word or pictorial model may be useful in predicting effects of environmental manipulations. Five of the most characteristic features of the population management approach to pest problems are as follows.

(a) The *orientation* is to the entire pest population, or a relatively large portion of it, rather than to localized infestations. The population to be managed is not contiguous to an individual farm, county, state or country, but is more often international; hence a high degree of co-operation, both nationally and internationally, is a prerequisite for success.

(b) The *immediate objective* is to lower the population density of the pest so that the frequency of fluctuations, both spatially and temporally, above the economic threshold is reduced and eliminated.

(c) The *method*, or combination of methods, is chosen to supplement the effects of natural control agents where possible and is designed to give the maximum long term reliability of protection, the minimum expenditure of effort and money, and the least objectionable effects on the ecosystem.

(d) The *significance* is that alleviation of the problem is general and long-term rather than localized and temporary and that harmful side-effects are minimized or eliminated.

(e) The *philosophy* is to manage the pest population rather than attempt to eradicate it. The real significance of the concept is seen in relation to serious pest problems which defy solution through the more traditional approaches.

Tutor Marked Assignment

1. Discuss the four components of deploying an effective integrated pest management program.

References/Further Reading

Oldroyd, H. (1968) Elements of Entomology, 312 pp. Weidenfeld & Nicolson: London.

Pury, J. M. S. de (1968) Crop Pests of East Africa, 227 pp. Oxford University Press: E. Africa.

MODULE 3 PLANT DISEASE MANAGEMENT

UNIT 1: Introduction to Plant Diseases

Content **Pg.**

1.0 Introduction

Plant pathology or phytopathology is the science dealing with plant diseases and their control. Plant pathologists study plant diseases caused by fungi, bacteria, viruses, nematodes, and parasitic plants. They also study plant disorders caused by nutrient imbalances, air pollution, and other unfavourable growing conditions.

1.1 History of Plant Diseases

Plant diseases have had profound effects on mankind through the centuries as evidenced by Biblical references to the blasting and mildew of plants. The Greek philosopher Theophrastus (370-286 B.C.) was the first to describe maladies of trees, cereals, and legumes that we currently classify as leaf scorch, rots, scab, and cereal rust. The Romans were also aware of rust diseases of their grain crops. They celebrated the holiday of Robigalia when sacrifices of reddish colored dogs and cattle were made in an attempt to appease the rust god Robigo. With the invention of the microscope in the 17th century, fungi and bacteria associated with plants were investigated. In 1665, Robert Hooke published the first illustration of rust on a rose leaf. Advances in the study of diseases were hampered by the widely held belief in the theory of spontaneous generation. This theory, held by most people in the mid-18th century, considered pathogenic or disease causing microorganisms as products of disease rather than causes of disease. Epidemics of late blight of potato devastated Ireland in 1845 and 1846. These epidemics dramatized the effect of plant diseases on mankind. Tragically, these epidemics caused famine and death for over a million people. Between 1845 and 1860, death and migration accounted for the loss of nearly one-third of Ireland’s population. In 1861, a German botanist, Anton De Bary, proved that a fungus (*Phytophthora infestans*) was the causal agent of late blight of potato. This was a milestone in the study of plant diseases since it showed that a fungus was indeed the cause of a plant disease rather than an organism simply associated with the disease. Two years later, Louis Pasteur proposed his germ theory of disease that finally disproved the theory of spontaneous generation and changed the way modern science investigated the diseases of all living organisms.

A few examples of plant disease epidemics that have resulted in devastating plant losses in the United States include: chestnut blight, introduced in 1904, virtually eliminated chestnut trees from North America; citrus canker, introduced in 1910, and a closely related bacterium called citrus bacterial spot discovered in 1984, resulted in the destruction of millions of citrus trees; white pine blister rust, introduced in 1912, caused large economic losses in the timber industry; and Dutch elm disease, introduced in 1930, continues to destroy large numbers of elm trees from the East Coast to the Pacific Northwest.

1.2 Disease Concepts

1.2.1 What Is a Disease?

There are many ways to define what a plant disease is. However, simply put, plant diseases involve profound changes within the host that cause a disruption of normal plant function. A good working definition of a healthy plant is one that can carry out its physiological functions to the best of its genetic ability. Diseases are among the most important factors that can significantly diminish growth and yield, or reduce the usefulness of a plant or plant product. Healthy or normal plants develop and function to the maximum of their genetic potential. However, when plants are adversely affected by continuous irritation by a disease-causing agent, which interferes with normal development and functioning, plants are considered to be diseased. This broad definition excludes injury or damage such as mechanical injury (e.g., lawn mower or weed-eater injury to trees); deer, rodent, and bird damage; hail damage; and lightning injury. In addition to reduction in growth, yield, and economic or aesthetic value of a plant or plant product, diseases may lead to the death of the whole plant or destruction of the entire crop under conditions favourable for the disease. Diseases may interfere with absorption and translocation of water and nutrients from the soil to the various parts of the plant, may reduce the photosynthetic efficiency of the plant parts, may interrupt the translocation of photosynthetic products through the plant, or may interfere with the reproduction and storage of food reserves in the plant. Diseases in plants are caused by either living (biotic, parasitic, or infectious) agents called pathogens, or non-living (abiotic, nonparasitic, or non-infectious) environmental factors. Plant diseases may also be grouped by the causal agent involved (fungal diseases, bacterial diseases, viral diseases, nematode diseases, etc.), the plant part affected (root diseases, seedling diseases, leaf diseases, stem diseases, flower diseases, fruit diseases, tuber diseases, etc.), or the types of symptoms (damping-off, wilts, leaf spots, cankers, blights, galls, root knots, mosaics, storage rots, etc.).

1.2.2 Symptoms of Diseases

Symptoms are the visible reactions of a plant to a disease and may suggest a causal agent. A sampling of disease symptoms might include wilting, necrosis, abnormal coloration, defoliation, fruit drop, abnormal cellular growth, or stunting of the infected plant. However, it is important to remember that different disease agents can cause similar symptoms on the same host. An equally important point to remember is that insect feeding can also cause disease-like symptoms on plants.

1.2.3 Signs of Diseases

Signs are the visible parts of the pathogen or its products seen on the host that can be used to identify the pathogen. Examples of common disease signs include: the white coating of mycelium visible on powdery mildew-infected leaves, mushroom growth on a tree limb, droplets of bacterial ooze running down a fruit tree twig, nematode cysts on plant roots, or dark fungal fruiting bodies visible in leaf lesions.

1.2.4 Causal Agents of Disease

A pathogen is any organism that can cause a disease. Pathogens cause infectious diseases that can spread from an infected plant to a healthy plant. Pathogens that cause infectious diseases include bacteria, fungi, viruses, nematodes, and parasitic plants. Plant disease can also be caused by non-infectious or non-living factors. Causes of disease by non-living factors include unfavourable growing conditions, mineral deficiencies, and air pollution. Pathogens that cannot be cultured apart from their host are classified as obligate parasites. Pathogens that can be cultured apart from their hosts on artificial media are called non-obligate parasites. In general, obligate parasites only attack very specific host plants, whereas non-obligate parasites typically have a wider range of plants they can infect. Some pathogens are restricted to a single plant species, while others infect a single plant genus. Still others attack a large number of hosts from many plant genera. There are also several levels of parasitism that pathogens can have with their hosts. When a pathogen is capable of infecting a plant, the plant is considered susceptible to that pathogen. If a pathogen cannot infect a plant, then the plant is considered immune to that pathogen. Plants can vary in their response to pathogens from high resistance (very little disease development), to partial resistance (moderate disease development), or high susceptibility (severe disease development). Pathogens can vary in their degree of virulence on a susceptible plant ranging from highly virulent (causing severe disease symptoms) to weakly virulent (causing less disease).

1.2.5 Inoculum and Pathogen Dissemination

Inoculum is any part of the pathogen that can cause infection. Examples of inoculum include fungal spores, bacterial cells, virus particles, or nematode eggs. Inoculum that survives the winter and causes the original or primary infection in the spring is called primary inoculum. Secondary inoculum causes additional infections throughout the growing season. Inoculum is sometimes present at the site where a plant is grown and can also be introduced from an outside source. Inoculum already present at a plant site includes soil pathogens or pathogens that overwinter on perennial weeds. Introduced inoculum includes infected plant material such as infected seeds, wind-blown fungal spores, and inoculum transmitted by insects. Inoculum can be disseminated passively by wind, rain, and man. Inoculum can also be disseminated actively by insects and nematodes or fungal zoospores swimming through water in the soil toward plant roots. Only a fraction of any pathogen’s inoculum will ever land on a susceptible host. The vast majority of inoculum lands on material that cannot be infected. Most pathogens produce a tremendous surplus of inoculum.

1.2.6 Pathogen Survival

Pathogens in temperate climates must have a way of overwintering when their host plants are dormant or absent. In perennial plants, pathogens can survive in infected plant parts such as roots, bulbs, stems, and bud scales. Annual plants, however, die at the end of the growing season and pathogens must survive in insects, seeds, or as resistant spores.

1.2.7 Factors Affecting Disease Occurrence

Diseases in plants are an exception rather than a rule. Three factors, called the disease triangle (Fig. 1), must coincide for a plant to become diseased: the host, the pathogen, and the environment. The interaction between these three factors with time determines the occurrence and severity of a disease.

For the disease to occur, the following conditions must be met:

1 The host plant must be of a susceptible species or cultivar at the right stage of development (susceptible host).

2. The pathogen must be of a virulent race or strain and must be present in sufficient numbers (inoculum potential). The presence of appropriate vectors or other agents of dispersal is also necessary.

3. The environmental (atmospheric and soil) conditions such as temperature, humidity, rainfall, wind, moisture, light, soil type, texture and pH, density of planting, aeration, and nutritional status (mineral deficiency or excess) must be favorable for disease development.

1.3 Diseases Caused by Living (Biotic, Parasitic, or Infectious) Agents

1.3.1 Fungi

Commonly known as molds, fungi (singular = fungus) are mostly microscopic organisms that have bodies (mycelium) composed of multi-cellular, thread-like, branched filaments (hyphae) and reproductive structures called spores. Since they do not possess chlorophyll, fungi depend on either dead organic matter or living plants for their growth and reproduction. Some fungi produce vitamins and antibiotics that are useful to us. A few fungi, like some types of mushrooms and morels, are edible. On the other hand, some fungi thrive on living plants, drawing their nutrition from them and sometimes producing toxins that cause disease and death of the plants they infect. These are called plant pathogenic fungi. A majority of diseases in plants are caused by fungi. Some examples commonly encountered in home gardens and landscape trees are: brown rot of cherries, apple scab, black spot of rose, snapdragon rust, corn smut, powdery mildew of rose, peach leaf curl, sycamore anthracnose, early blight of potato, Verticillium wilt of tomato, damping-off, and root rot of vegetables.

1.3.2 Bacteria and Phytoplasmas

Bacteria (singular = bacterium) and phytoplasmas (formerly known as mycoplasmas or mycoplasma-like organisms) are microscopic, single-celled organisms that cause some of the most destructive diseases in plants. Some bacteria, like those that induce nodulation in leguminous plants, are beneficial to plants because they fix nitrogen from the air into the root nodules in a form that the host plant can utilize for its growth. Phytoplasmas are a type of bacteria that lack distinct cell walls. Under favorable conditions, bacteria reproduce very rapidly and can cause serious damage in a short period of time. Bacterial pathogens are spread by wind-splashed rain, insects, contaminated seed, or implements. Bacterial diseases are relatively difficult to control because there are very few chemicals that are effective against them. Some commonly encountered bacterial diseases are: crown gall of rose, grape, apple, cherry, and other ornamental plants; fire blight of apple and pear; soft rot of potato; ring rot of potato; and aster yellows phytoplasma on carrots, tomatoes, onions, lettuce, etc.

1.3.3 Viruses

Viruses are infectious agents so small they must be observed through an electron microscope. Particles of these viruses may be in the form of rods, spheres, or threads. They are composed mainly of a nucleic acid core surrounded by a protein coat. Viruses can multiply only in a living host cell and can often spread systemically throughout the infected plant. Viruses can be transmitted from infected to healthy plants mechanically, through grafts and by contaminated propagating material. Viruses can also be transmitted by certain organisms, referred to as vectors. In addition to insects (primarily aphids, white flies, leafhoppers, and beetles), virus vectors include mites, nematodes, and fungi in the soil. Viral diseases are not controlled by pesticide chemicals. Examples of viral diseases are: curly top of tomato, bean, cucurbits, etc.; potato leaf roll; bean common mosaic; and rose mosaic.

1.3.4 Nematodes

Nematodes are microscopic roundworms that live in soil as well as water, and survive as eggs or cysts. Most of them are saprophytes, but some infect living plants and cause diseases. Most plant parasitic nematodes feed on the underground parts of the plants (roots, tubers, bulbs, etc.) causing lesions or root knots. However, a few nematodes also affect the buds, leaves, flowers, and stems of plants. Nematodes spread through contaminated planting material (tubers, seedlings, etc.), manure, soil, water, machinery, and implements. Some nematodes are vectors of plant viruses. Some examples of plant parasitic nematodes are: root knot nematodes of tomato, potato, beans, and many other plants; root lesion nematodes of corn and potatoes, cyst nematode of sugarbeets; stubby root nematode of corn; stem and bulb nematodes of onion; and foliar nematode of chrysanthemum. E. Parasitic Higher (Flowering) Plants Several flower- and seed-producing plants live as parasites on other plants (host plants), deriving their nutrition from them and adversely affecting the host plant's growth and yield. Dodder (also know as strangleweed and devil's hair), for example, parasitizes several garden plants such as potatoes and carrots. It produces orange or yellow vine strands that entwine the stems and other plant parts from which it draws its nutrition through tube-like structures it introduces into the host tissue. Dodder produces abundant seeds that ensure its propagation and spread. Another example of a parasitic plant is dwarf mistletoes on pines.

1.4 Diseases Caused by Abiotic (Non-living, Nonparasitic, or Non-infectious) Agents

A variety of environmental and cultural factors can cause diseases in plants. Since these diseases occur in the absence of pathogens, they do not spread from a diseased plant to a healthy plant.

1.4.1 High or Low Temperatures

When plants or plant parts are exposed to high temperatures for prolonged periods, symptoms of scorching or scalding may develop. Some examples are: sunburn or scorching of leaves and sunscald of fruits (e.g., apples, tomatoes, peppers, and melons). Similarly, low temperatures, like frost or freeze, can damage the exposed or sensitive organs (buds, flowers, young fruits, etc.) or may kill the entire plant. Examples include: southwest-side damage to trunks of apple trees; frost damage to blossoms and young apple fruits; russet ring (caused by frost) on apple and pear fruits; winter injury to trees; and frost damage to tomatoes, beans, potatoes, etc.

1.4.2 High or Low Soil Moisture

Too much moisture due to excessive watering, poor drainage, ponding, or flooding may cause plants to turn yellow and be stunted. Potted indoor plants, for example, may show poor development or root rots. Seedlings are vulnerable to damping-off caused by soilborne pathogens under these conditions.

In some indoor or greenhouse plants (e.g., geraniums, begonias) growing under warm, humid atmospheric conditions and excessive soil moisture, a condition known as edema (small, wart-like rusty, corky bumps) can develop on the underside of the leaves, and on the stems. At the other extreme, low moisture or drought conditions can lead to poor development, wilting, and death of plants.

1.4.3 High or Low Light Intensity

High light intensity is usually not a problem but low light conditions, especially for indoor plants, can lead to etiolation (spindly or lanky plant growth with chlorotic yellow foliage).

1.4.4 Lack of Aeration or Low Oxygen Supply

Low aeration can deprive plant roots of adequate oxygen and can adversely affect their development or even kill the plant. Inadequate oxygen supply during the storage of potato tubers can lead to the development of a condition called blackheart, the browning and death of internal tuber tissue.

1.4.5 Air Pollution

Certain chemicals, such as ozone, sulfur dioxide, and nitrogen dioxide are released into the air from factories, power plants, and automobile exhausts. These chemicals can accumulate in the atmosphere in sufficient concentration to cause damage to plants. Ozone damage appears in the form of mottling, chlorosis, spots, and bleaching of young leaves. This is common in certain regions of the country where there is a high ozone concentration in smog. For example, ozone damage is frequently found on the leaves of beans, petunias, and grapes. Some of the air pollutants responsible for acid rain cause damage to vegetation in certain regions. In Idaho, however, plant damage due to air pollution is not common.

1.4.6 Nutrient Deficiencies

Plants require several major (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur) and minor (iron, boron, copper, zinc, etc.) elements for normal growth. Deficiency or lack of any of these essential nutrients results in disease symptoms in the plant. Specific symptoms depend on the plant species and the deficient nutrient. If not corrected, a prolonged acute deficiency of essential nutrients can lead to death of the plant. Common examples of nutrient deficiencies are: nitrogen deficiency in beans, iron deficiency in peaches, zinc deficiency in apple trees, and calcium deficiency in apple fruit (bitter pit). In the home garden, the common blossom-end rot of tomato fruit is caused, in part, by calcium deficiency.

1.4.7 Mineral Toxicity

Presence of excessive available amounts of certain minerals in the soil can lead to mineral toxicity to the plants. The extent of injury depends on the mineral, its concentration, and the species of the plant. Excessive amounts of sodium salts in the soil can lead to high pH and to alkali injury (e.g., alkali injury to apple). Plants growing in acidic soils can be injured by aluminum or manganese toxicity.

1.4.8 Unfavourable Soil pH

Although many plants can grow in a rather wide range of soil pH, plants growing in soils with unfavourable pH usually show poor growth and mineral deficiency or toxicity symptoms. For example, iron deficiency symptoms are very common in plants growing in high pH soils. Under conditions of high soil pH, iron in the soil becomes unavailable to the plant, thus inducing interveinal chlorosis and yellowing of leaves. The plant may die if the condition remains uncorrected for a prolonged time.

1.4.9 Pesticide Toxicity

Some pesticides, if improperly used, can cause serious damage to plants. For example, if wettable sulfur is sprayed (for powdery-mildew control) on a very hot day (above 90□F), it will result in injury to the plant phytotoxicity). However, the most common type of chemical injury to plants is due to soil residues or spray drift of herbicides. Examples of pesticide toxicity are: 2,4-D damage to beans and tomatoes, dicamba (Banvel) damage to vegetables and trees, and glyphosate (Roundup) damage to fruit trees. Some herbicides used as soil sterilants may leave the soil unsuitable for any plant growth for several years.

1.4.10 Improper Cultural Practices

Any cultural practice done in the wrong way or at the wrong time can result in significant damage to plants. Injury can result from improper mounts of chemical fertilizer or pesticide or improper chemical mixes in the spray tank. Root pruning can result from excessively deep cultivation; distorted and twisted roots can result from pot-bound conditions of a plant. African violet leaves sprinkled with very cold water develop rings and ring-like patterns that resemble symptoms caused by some viruses.

1.5 Diagnosing Plant Disease Problems

1.5.1 Why Is Diagnosis Important?

Whether in an effort to save existing plants or to prevent problems from recurring, it is important to know “What went wrong?” Diagnosis is the process of gathering information about a plant problem and determining the cause. Once the cause has been determined, it is then possible to recommend a solution or remedy. Diagnosing plant problems can involve considerable detective work. Sometimes there is insufficient information and other times, the primary cause of a problem is hidden by more obvious, but less-important, problems. Success in diagnosing plant problems depends on how much we know about the host plant, about the plant problems in general, and the quality of information obtained from the client. For example, 10 tomato plants all similarly damaged are brought to you. All have yellow leaves, stunted growth, and very few feeder roots. You learn from questioning the grower that he applied one-half of a 20- pound bag of 10-10-10 fertilizer to a tomato plot that measures 60 square feet. The grower put 10 pounds of fertilizer on 60 square feet, which translates to a rate of 166 pounds per 1,000 square feet. This is almost 10 times the normal rate of 20 pounds per 1,000 square feet of a 10-10-10 fertilizer. The grower’s fertilization rate is enough to kill fine feeder roots. The diagnosis is damage to the roots caused by over fertilization.

1.5.2 Basic Steps in Reaching a Diagnosis

1. Identify the plant—The better your plant identification skills the faster you will be able to diagnose a problem. Most references on plant pests and diseases are organized by plant, so knowing the plant is the essential first step in using many reference books.

2. What is normal? Your familiarity with the normal appearance and cultural requirements of the plant will enable you to differentiate normal changes from symptoms of a problem.

3. What is the problem? To make a disease diagnosis, you need to know: the pattern of distribution of the diseased plants or plant parts, the plant species or cultivar involved, the site where the plant is growing (field, orchard, garden, greenhouse, inside the house, etc.), and previous crop history of the site. For example, uniform damage to many species in an area, to all plants on one side of the field or garden, or to all shoots on one side of the tree indicates that the cause may be an abiotic factor. Also, if the damage is well demarcated in a garden or in a plant, it may suggest that some abiotic factor is involved. On the other hand, if there is evidence of progressive spread of the disease from an initial focus to other plants of the same cultivar or species or to different parts of the plant, it may indicate that an infectious agent is involved.

4. Examine the plant and note symptoms and signs —For a presumptive diagnosis of diseases in plants, look for the symptoms and signs of the disease. The characteristic internal or external alterations of a plant in response to a disease-causing agent are called symptoms (leaf spot, necrosis, blight, canker, wilt, lesion, gall, witches' broom, rot, chlorosis, mosaic, etc.). Sometimes, the pathogen that causes the disease produces its own characteristic growth or structures on the diseased plant that are of diagnostic value. These are referred to as signs of the disease (mold, mildew, sclerotia, mushrooms, conks, etc.)

5. Tentative diagnosis—Based on your knowledge of the plant and information from reference books, formulate a tentative diagnosis. This will help you focus your examination of the plant and assist in collecting relevant information.

6. Double-check the diagnosis—Once you have arrived at a diagnosis, unless it is an obvious diagnosis, double-check it. Ask other master gardeners or extension educators for their opinions. Read through the reference books about your diagnosis to make certain everything matches. Additional laboratory work may be needed to confirm your diagnosis.

7. Types of plant disease diagnosis—Verbal descriptions by a telephone call or evaluation of a sample provide the most common diagnostic opportunities. However, a site visit provides more complete information. To make a telephone diagnosis, you must completely rely on information provided by the caller in order to make your diagnosis. There will be common, familiar problems, such as powdery mildew of apples, when a little information easily leads to a correct diagnosis. In other cases, it will be very difficult to make a diagnosis over the telephone and it may be necessary to evaluate a sample.

Much of your diagnositic work will be done with plant samples. Usually, the sample will provide the clues necessary to solve the problem. But when the sample only confirms the identification of the plant, you must concentrate on acquiring information to reach a diagnosis. Your job will be to learn about the plant's cultural and environmental conditions, the care the plant has received, and whether the sample is representative of the problem affecting the plant. A site visit provides the greatest opportunity to gather information, but a successful plant diagnosis also depends on a combination of factors: your knowledge of the plant involved, your understanding of the plant's basic cultural requirements, and your recognition of the potential problems that might affect it. It also depends on your ability to gather information, both through observation of the plant and discussion with the client.

1.6 Conditions for Disease Development

1.6.1 Disease Triangle

Disease development is dependent upon three conditions: a susceptible host plant, a favourable environment, and a viable pathogen. All three of these factors must be present for disease to occur. Figure 1 presents this concept as a 'disease triangle.' Each side of the triangle represents one of these factors: host plant, environment, or pathogen. When all three sides of the triangle are complete, disease occurs. If one of the conditions is not present (one side of the triangle is missing), then disease does not occur. By altering the susceptibility of host plants, the surrounding environment, and/or the viability of pathogens, the disease triangle can be broken and disease development prevented.

1.6.1.1 Host plant genetic makeup determines its susceptibility to disease. This susceptibility depends upon various physical and biochemical factors within the plant. A plant's stature, growth habit, cuticle thickness (a protective outer layer on plant tissues), and shape of stomata (small openings that allow water, oxygen, and carbon dioxide in and out of plant tissues) are a few physical factors that influence disease development. Plants may also produce biochemical compounds that limit or prevent colonization or infection. Growth stage and ability to deter pathogens can also impact plant susceptibility to disease. For example, young leaves are often more susceptible to infection than mature leaves.

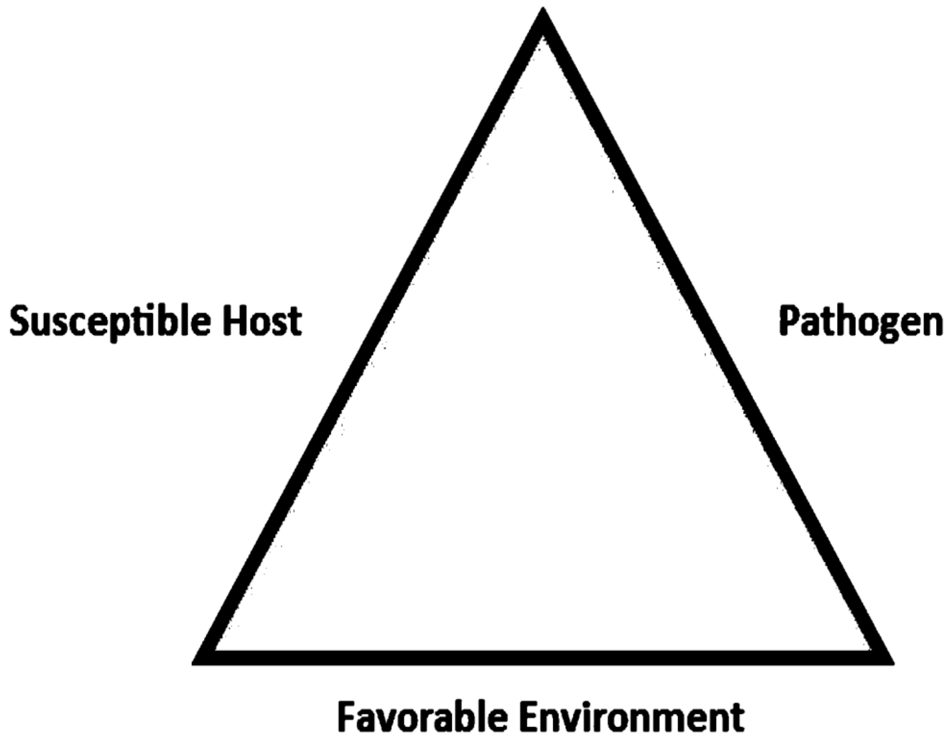


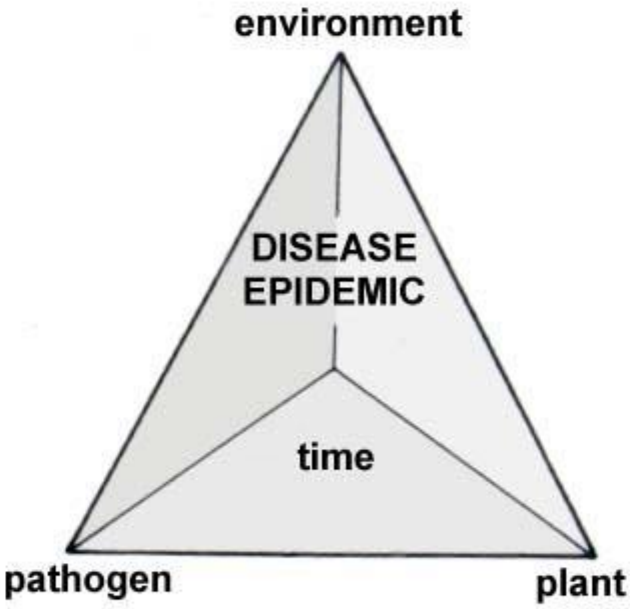
Figure 1: Disease Triangle—Plant disease results when there is a susceptible host, viable pathogen, and favourable environment.

1.6.1.2 Environment plays an important role in disease development. Pathogens generally require specific environmental conditions for infection and spread. Most plant pathogens require high humidity and moderate temperatures. Other pathogens, such as bacteria and water molds, require surface water for spread. In some disease cycles, environmental conditions influence the development of symptoms. For example, extreme temperatures or drought can cause plant stress; this loss of vigor can increase host susceptibility to both infection and disease development. Other environmental factors affecting disease can include those resulting from planting and maintenance practices. For example, high density plantings can a have higher relative humidity, while overhead watering increases leaf surface moisture needed by pathogens to infect plant leaves.

1.6.1.3 Pathogens: A plant disease is any physiological or structural abnormality that is caused by a living organism. Organisms that cause disease are referred to as 'pathogens,' and affected plants are referred to as 'hosts.' Many organisms rely on other species for sources of nutrients or as a means of survival, but are not always harmful to the host. For example, saprophytic organisms obtain nutrients from dead organic material and are a vital part of many ecosystems. Plant pathogens, on the other hand, utilize hosts for nutrients and/or reproduction at the hosts' expense. Disease causing organisms include fungi, oomycetes (fungus-like organisms called water molds), bacteria, viruses, nematodes, phytoplasmas, and parasitic seed plants. Once a pathogen infects a host, symptoms often develop. Symptoms are the outward changes in the physical appearance of plants. Symptoms take time to develop, and thus, disease development may be delayed for several days, weeks, months, or even years after initial infection occurs. Examples of symptoms include wilt, leaf spots, cankers, rots, and decline. Physical evidence of pathogens (called 'signs') may also be observed on diseased tissue. Examples of signs include fungal fruiting bodies, bacterial ooze, nematode cysts, and fungal mycelia. Both symptoms and signs are utilized in making disease diagnoses.

1.6.2 Disease Pyramid

The disease pyramid describes how disease can eventually destroy a plant. It is comprised of the presents of the pathogen that causes the disease, the plant or host, the environmental conditions that sets up the pathogen to go after the plant and time. It requires all four at the same time to have a disease. So in the case of avocado root rot, it's necessary to have *Phytophthora cinnamomi* there with a susceptible avocado root, in warm, moist conditions for a period of time for the disease to express itself. For a young tree, the disease may show up within a year but for older trees it may take several years to see the disease symptoms. For avocado crown rot, it may take several years for *Phytophthora citricola* to appear. In the case of Huanglongbing, not only is the pathogen required, but also the vector for spreading it, the Asian Citrus Psyllid. Not only time is important, but timing of sampling and point of sampling are important. In the case of avocado root rot, the best sample if from a recently infected root in the hot dry season. If the wrong leaf or root is sampled for the Huanglongbing bacteria, the assay will show a negative response, even though it is in the plant. And then too, even if a disease is finally diagnosed, it doesn't mean the tree is going to die. If Phytophthora is caught soon enough, it can be treated with phosphites, but the environment needs to be changed at the same time. Meaning, the irrigation needs to be adjusted so that the treatment will work. If the irrigation is changed, the trunk canker will disappear.



Tutor Marked Assignment

1. What Is a Disease?
2. Differentiate between Symptoms and signs of Diseases.
3. What are the causative agents of a disease?
4. Define Inoculum and explain its function in Pathogen Dissemination.
5. How do pathogens survive?
6. What are the factors that affect disease occurrence?
7. Discus the following as they affect plant diseases.

i. Temperature
ii. Soil Moisture
iii. Light Intensity
iv. Oxygen Supply
v. Nutrient Deficiencies
vi. Unfavorable Soil pH
vii. Pesticide Toxicity

8. Why Is Plant Disease Diagnosis Important?
9. What are the Basic Steps in Reaching a Diagnosis?
10. Explain the Disease Triangle in the establishment of a disease.
11. Discuss the Disease Pyramid

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UNIT 2: Disease Management

Content **Pg.**

2.0 Introduction

The goal of plant disease management is to reduce the economic and aesthetic damage caused by plant diseases. Traditionally, this has been called plant disease control, but current social and environmental values deem "control" as being absolute and the term too rigid. More multifaceted approaches to disease management, and integrated disease management, have resulted from this shift in attitude, however. Single, often severe, measures, such as pesticide applications, soil fumigation or burning are no longer in common use. Further, disease management procedures are frequently determined by disease forecasting or disease modeling rather than on either a calendar or prescription basis. Disease management might be viewed as proactive whereas disease control is reactive, although it is often difficult to distinguish between the two concepts, especially in the application of specific measures.

This topic is a general overview of some of the many methods, measures, strategies and tactics used in the control or management of plant diseases. Specific management programs for specific diseases are not intended since these will often vary depending on circumstances of the crop, its location, disease severity, regulations and other factors. Plant disease management practices rely on anticipating occurrence of disease and attacking vulnerable points in the disease cycle (i.e., weak links in the infection chain). Therefore, correct diagnosis of a disease is necessary to identify the pathogen, which is the real target of any disease management program. A thorough understanding of the disease cycle, including climatic and other environmental factors that influence the cycle, and cultural requirements of the host plant, are essential to effective management of any disease.

The many strategies, tactics and techniques used in disease management can be grouped under one or more very broad principles of action. Differences between these principles often are not clear. The simplest system consists of two principles, prevention (prophylaxis in some early writings) and therapy (treatment or cure). The first principle (prevention) includes disease management tactics applied before infection (i.e., the plant is protected from disease), the second principle (therapy or curative action) functions with any measure applied after the plant is infected (i.e., the plant is treated for the disease). An example of the first principle is enforcement of quarantines to prevent introduction of a disease agent (pathogen) into a region where it does not occur. The second principle is illustrated by heat or chemical treatment of vegetative material such as bulbs, corms, and woody cuttings to eliminate fungi, bacteria, nematodes or viruses that are established within the plant material. Chemotherapy is the application of chemicals to an infected or diseased plant that stops (i.e., eradicates) the infection. Although many attempts have been made to utilize chemotherapy, few have been successful. In a few diseases of ornamental or other high value trees, chemotherapy has served as a holding action that must be repeated at intervals of one to several years. For example, antibiotics have been infused into plants to reduce severity of phytoplasma diseases of palms (lethal yellowing) and pears (pear decline) and fungicides have been injected into elms to reduce severity of Dutch elm disease (caused by *Ophiostoma ulmi*) but in all cases the chemotherapeutant must be reapplied periodically.

There exist four general disease control principles: exclusion, eradication, protection and resistance.

2.0.4 Exclusion

This principle is defined as any measure that prevents the introduction of a disease-causing agent (pathogen) into a region or farm. The basic strategy assumes that most pathogens can travel only short distances without the aid of some other agent such as humans or other vector, and that natural barriers like oceans, deserts, and mountains create obstacles to their natural spread. In many cases pathogens are moved with their host plants or even on non-host material such as soil, packing material or shipping containers. Unfortunately, exclusion measures usually only delay the entry of a pathogen, although exclusion may provide time to plan how to manage the pathogen when it ultimately arrives. Karnal bunt (caused by *Tilletia indica*) of wheat is an example of a pathogen originally from India that was anticipated. Measures were established to prevent its introduction, but it finally found its way into the United States.

An important and practical strategy for excluding pathogens is to produce pathogen-free seed or planting stock through certification programs for seeds and vegetatively propagated plant materials such as potatoes, grapes, tree fruits, etc. These programs utilize technologies that include isolation of production areas, field inspections, and removal of suspect plants to produce and maintain pathogen-free stocks. Planting stock that is freed of pathogens can be increased by tissue culture and micro-propagation techniques as well as be maintained in protective enclosures such as screen houses to exclude pathogens and their vectors. Exclusion may be accomplished by something as simple as cleaning farming equipment (Figure 2) to remove contaminated debris and soil that can harbor pathogens such as Verticillium, nematodes or other soil borne organisms and prevent their introduction into non-infested fields.

2.0.5 Eradication

This principle aims at eliminating a pathogen after it is introduced into an area but before it has become well established or widely spread. It can be applied to individual plants, seed lots, fields or regions but generally is not effective over large geographic areas. Two large attempts at pathogen eradication in the United States were the golden nematode (*Globodera*

rostochiensis) program and the citrus canker (caused by *Xanthomonas axonopodis* pv. *citri* and pv. *aurantifolii*) program. However, neither of these attempts was a lasting success.
Eradication of the golden nematode involved removing infested soil, fumigating soil in infested fields and eventually abandoning infested potato fields for housing developments and other uses. Citrus canker eradication involved widespread removal and burning of diseased trees and, in some cases, destruction of entire citrus groves and nurseries. The disease appeared to be contained and the pathogen eradicated, but the disease has reappeared and new attempts at eradication are ongoing.

Eradication can also be on a more modest scale such as the removal of apple or pear branches infected by the fire blight bacterium (*Erwinia amylovora*) or pruning to remove blister rust cankers (caused by *Cronartium ribicola*) on white pine branches. Or, it can be the sorting and removal of diseased flower bulbs, corms or rhizomes. Hot water seed-treatment of cereal seeds to kill smut mycelium in the seed and heat treatment to eliminate viruses from fruit tree budwood for grafting are other examples of pathogen eradication.
Two programs that are actually forms of protection and not pathogen eradication are barberry eradication for reducing stem rust (caused by *Puccinia graminis*) of wheat eradication for preventing white pine blister rust. The strategy is that removing these alternate hosts breaks the disease cycles and prevents infection of the economically more valuable host. These two examples are mentioned here because they are frequently cited as eradication measures. However, stem rust can readily spread from wheat to wheat in many regions by the uredinial stage although elimination of the aecial host, barberry, may deter or diminish the development of pathogenic races of the rust. The white pine blister rust fungus is perennial in the pine host and eradication of the alternate host only protects non-infected trees but does not necessarily eliminate the pathogen from the area. Eradication may also be accomplished by destroying weeds that are reservoirs of various pathogens or their insect vectors.

Soil fumigation has been a widely used eradication strategy. This technology involves introducing gas-forming chemicals such as carbon disulfide, methyl bromide, or chloropicrin into soil to kill target pathogens. However, undesirable side effects such as killing beneficial organisms, contamination of groundwater, and toxicity of these chemicals have resulted in less reliance on this approach for disease management.

Crop rotation is a frequently used strategy to reduce the quantity of a pathogen, usually soil-borne organisms, in a cropping area. Take-all of wheat (caused by *Gaeumannomyces graminis*) and soybean cyst nematode (*Heterodera glycines*) are two examples of soil borne diseases that are easily managed by short rotations of 1 and 2 years, respectively, out of susceptible crops, which may include susceptible weed hosts such as grasses in the case of take-all.

Burning is an effective means of eradicating pathogens and is often required by law to dispose of diseased elm trees affected by Dutch elm disease (DED), citrus trees infected by citrus canker or of bean fields infected by halo blight bacteria (*Pseudomonas syringae* pv.

phaseolicola). However, burning agricultural fields is controversial because the smoke creates human health and safety and environmental concerns.

2.0.6 Protection

This principle depends on establishing a barrier between the pathogen and the host plant or the susceptible part of the host plant. It is usually thought of as a chemical barrier, e.g., a fungicide, bactericide or nematicide, but it can also be a physical, spatial, or temporal barrier. The specific strategies employed assume that pathogens are present and that infection will occur without the intervention of protective measures. For example, bananas are covered with plastic sleeves as soon as the fruit are set to protect the fruit from various pests including fruit decay fungi. Protection often involves some cultural practice that modifies the environment, such as tillage, drainage, irrigation, or altering soil pH. It may also involve changing date or depth of seeding, plant spacing, pruning and thinning, or other practices that allow plants to escape infection or reduce severity of disease. Raising planting beds to assure good soil water drainage is an example of cultural management of plant diseases such as root and stem rots.

Fungicides have been used for more than a hundred years and new fungicides continue to be developed. Bordeaux mixture, a basic copper sulfate fungicide, was the first widely used fungicide and is still used today in various forms. The earliest fungicides were simple elements like sulfur or metallic compounds of copper or mercury, and these are generally classed as inorganic fungicides. In the early to mid-1900s organic fungicides such as thiram, captan, and the bisdithiocarbamates were developed. These are broad-spectrum, contact or protectant fungicides that control a wide range of fungal diseases. Starting in the 1960s the "systemic" fungicides were developed. Most of these are not truly systemic in plants but have some limited mobility, usually translaminar, and often give some post-infection benefits. Some of the "systemic" fungicides move upward in the plant's vascular system, but currently only one (fosetyl-Al) has ambimobile distribution (both upward and downward) that would constitute a truly systemic fungicide. Some fungicides have narrow ranges of activity and are used primarily for control of specific groups of diseases such as downy mildews, rusts, smuts or powdery mildews while others are active against a wider range of diseases.

One liability of these recent narrow-range fungicides is that they often have single-site modes of action, (that is, their site-specific activity is controlled by one or a few genes), and thus are especially prone to development of fungicide resistance in the pathogen. Several management strategies have been developed to combat fungicide resistance. These include using mixtures of single-site and multi-site fungicides, alternating applications of fungicides with different modes of action, applying fungicides only when needed instead of on either a calendar or prescription basis, and applying the recommended dosage and not attempting to cut costs by reducing the recommended amount of fungicide applied. Many cultural practices can be modified to manage the occurrence, intensity or severity of plant diseases. These include selection of suitable growing sites for the crop, adequate tillage to bury pathogen-infested plant residues, rotation to non-susceptible crops, selecting pathogen-free planting stocks, orientation of plantings to improve exposure to sun and air currents, pruning and thinning to eliminate sources of infection and improve aeration in and around susceptible plants, water management on both plants and in soil, adequate nutrition, proper cultivation to improve root growth and avoid plant injury, and sanitation procedures to eliminate sources of inoculum. Biological control involves the use of one living organism to control another, and this management technology has received much attention in recent times. However, the number of biological agents registered for use is relatively small, success has been limited, and application has been largely restricted to intensively managed, high value crops such as greenhouse plants. Two examples of effective biological control are the use of the fungus *Peniophora gigantea* to inoculate tree stumps to prevent infection of adjacent trees by the wood decay fungus *Heterobasidion annosum*, and the application of the nonpathogenic (i.e., non-tumor-producing) bacterium *Agrobacterium radiobacter* to fruit trees before planting to prevent infection by the crown gall bacterium (*Agrobacterium tumefaciens*)

2.0.7 Resistance

Use of disease-resistant plants is the ideal method to manage plant diseases, if plants of satisfactory quality and adapted to the growing region with adequate levels of durable resistance are available. The use of disease-resistant plants eliminates the need for additional efforts to reduce disease losses unless other diseases are additionally present. Resistant plants are usually derived by standard breeding procedures of selection and/or hybridization. A few disease-resistant lines have been obtained by inducing mutations with x-rays or chemicals. There is also interest in chemicals called “plant activators” that induce plant defense responses called systemic acquired resistance (SAR) and induced resistance. Recently, resistant plants have been developed through the use of genetic engineering (e.g., resistance to the Papaya ring spot virus).

Selection of resistant plants involves subjecting plants to high levels of disease pressure and using the surviving plants as sources of disease resistance. Plants that survive this pressure often have genetic resistance that can be utilized directly by propagation or as sources of resistance to develop resistant plants that also have the requisite qualities for that crop. Hybridization is a tactic where a plant having the desired agronomic or horticultural qualities, but is susceptible to a disease, is crossed with a plant that is resistant but which may or may not have the other desirable characteristics such as size, yield, flavor, aesthetics, etc.

Disease escape occurs when susceptible plants do not become diseased for some reason. This may be due to some anatomical or physical character, such as the occurrence of leaf hairs, thick cuticle, or modified stomata, or they may be environmental, in which conditions are not conducive to disease development. Although disease escape based on some anatomical feature is useful occasionally, escape more often complicates the process of developing disease resistant plants.

Development of disease-resistant plants has been relatively successful with annual and biennial plants, but less so with perennials, primarily because of the longer time required to develop and test the progeny. Woody perennials, such as ornamental, forest, and orchard trees, has been especially difficult for plant breeders to develop useful disease resistance. For example, chestnut blight and Dutch elm disease have devastated two valued native trees. In both cases there have been extensive attempts to develop resistant trees, usually by creating hybrids with exotic chestnut or elm trees, and some resistant selections have resulted.

Unfortunately, these generally lack the desirable qualities, such as nut flavor or tree forms characteristic of the native trees. Development of resistance has been most successful against the more specialized pathogens such as rust fungi, smut fungi, powdery mildew fungi, and viruses, but less so against general pathogens such as many blight, canker, root rot and leaf spotting pathogens.

A major problem with genetically resistant plants is that host-differentiated pathogenic races can be selected, so that many breeding programs become continuous processes to develop disease resistant plant lines. Disease resistance conferred by a single major gene is sometimes called specific or qualitative resistance and is race-specific. This type of resistance is often unstable, and emergence of a pathogenic race that can attack that genotype can completely overcome this type of resistance. Quantitative resistance or general resistance derives from many different genes for resistance with additive effects to provide more stable (or durable) resistance to pathogens.

There are several strategies to minimize this race development and resistance failure. These include methods of gene deployment, where different genetic plant types are interspersed on a regional basis to avoid a genetic monoculture, or planting mixtures of cultivars having different genetic compositions to ensure that some component of the crop will be resistant to the disease. A recent and controversial technique in developing disease resistant plants is the insertion of genes from other organisms into plants to impart some characteristic. For example, genes from the bacterium *Bacillus thuringiensis* have been inserted into plants to protect against insect attacks. Plants with these inserted genes are called genetically-modified organisms (GMOs), and have caused concern that unanticipated, and perhaps detrimental, characteristics, such as unforeseen allergens, may also be transferred to the new plants. However, unforeseen and undesirable qualities also can be transmitted by conventional plant breeding techniques. The potato cultivar Lenape was developed in part because of its resistance to Potato virus A and resistance to late blight tuber infection. After it was released it was discovered that the tubers contained very high levels of solanine, a toxic alkaloid. The wheat cultivar Paha had resistance to stripe rust (caused by *Puccinia striiformis*) but also was very susceptible to flag smut (caused by *Urocystis agropyri*). Both of these plant cultivars, developed by conventional breeding methods, were quickly taken out of production. There is much interest in the genetic engineering of disease-resistant plants and some success has been obtained with several virus diseases, the best known of which is papaya ring spot. This approach to plant disease management will likely expand, especially for widely grown crops such as wheat, corn, soybeans, rice, and the like, as social, legal, and economic obstacles are overcome.

2.1 Integrated Disease Management

Integrated Disease Management (IDM) is a concept derived from the successful Integrated Pest Management (IPM) systems developed by entomologists for insect and mite control. In most cases IDM consists of scouting with timely application of a combination of strategies and tactics. These may include site selection and preparation, utilizing resistant cultivars, altering planting practices, modifying the environment by drainage, irrigation, pruning, thinning, shading, etc., and applying pesticides, if necessary. But in addition to these traditional measures, monitoring environmental factors (temperature, moisture, soil pH, nutrients, etc.), disease forecasting, and establishing economic thresholds are important to the management scheme. These measures should be applied in a coordinated integrated and harmonized manner to maximize the benefits of each component. For example, balancing fertilizer applications with irrigation practices helps promote healthy vigorous plants. However, this is not always easy to accomplish, and "disease management" may be reduced to single measures exactly the same as the ones previously called "disease control." Whatever the measures used, they must be compatible with the cultural practices essential for the crop being managed.

Plant Disease Terms

Anthracnose—Black or brown dead areas on leaves, stems, or fruits (anthracnose of sycamore, maple).

Blackleg—Darkening at the base of a stem (blackleg of potato).

Blight—Rapid death of leaves and other plant parts (fire blight of apple, early blight of tomato).

Brown rot—Soft rot of fruit covered by gray to brown mold (brown rot of cherries, peaches, nectarines).

Canker—Sunken, discolored, dead areas on twigs and branches, usually starting from an injury or wound (Cytospora canker of trees, common canker of rose, fire blight cankers).

Chlorosis—Yellowing or whitening of normally green tissue (iron chlorosis of trees).

Crown gall—Excessive, undifferentiated growth that may girdle roots, stems, or branches (crown gall of grapes, rose, apple, cherry).

Curly top/leaf curl/leaf roll—Rolling and curling of leaves and growing point (curly top of sugarbeet, tomato, bean, etc.; peach leaf curl; potato leaf roll).

Damping-off—Stem rot near the soil surface leading to either failed seed emergence or falling over after emergence.

Epidemic—A widespread and severe outbreak of a disease.

Etiolation—Long internodes and pale green color of plants growing under insufficient light or in complete darkness.

Fumigation—The application of a toxic gas or volatile substance to disinfect soil or a container such as a grain bin.

Fungicide—A compound toxic to fungi.

Host plant—A plant that is invaded by a parasite.

Host range—The various plants that may be attacked by a parasite.

Inoculum—The pathogen or its parts that can cause infection.

Integrated control—An approach that attempts to use all available methods for control of a pest or disease.

Isolation—The separation of a pathogen from its host by culturing on a nutrient medium or on an indicator plant.

Lesion—A localized area of discolored or dead tissue (early blight lesions on potato leaf).

Life cycle—The successive stages of growth and development of an organism.

Microscopic—Organisms so small that they can be seen only with the aid of a microscope.

Mosaic—Intermittent yellowish and green mottling of leaves (bean common mosaic, rose mosaic).

Necrosis—Death of tissue (necrotic area in black spot of rose).

Organism—A living being.

Parasite—An organism that lives in or on another organism (host) and derives its food from the latter.

Pathogen—A disease-causing agent.

Plant disease—Any lasting change in a plant's normal structure or function that deviates from its healthy state.

Plant pathology—The study of diseases in plants, what causes them, what factors influence their development and spread, and how to prevent or control them.

Powdery mildew—Fine, white to gray, powdery coating on leaves, stems, and flowers (powdery mildew of rose, grapes, lilac, and apple).

Resistance—The ability of a host plant to prevent or reduce disease development by retarding multiplication of the pathogen within the host.

Root and stem rots—Soft and disintegrated roots and lower portions of the stem, sometimes results
in death of plant (root rot of pea, damping- off of seedlings, collar rot of apple).

Root knots—Swelling and deformation of roots (tomato root knot).

Rust—Raised pustules on leaves, stems, and fruits; contain yellow-orange or rust-colored spore masses (snapdragon rust, geranium rust).

Sanitation—The removal and disposal of infected plant parts; decontamination of tools, equipment,
hands, etc.

Saprophyte—An organism that can subsist on non-living matter.

Scab—Slightly raised, rough areas on fruits, tubers, leaves, or stems (common scab of potato, apple scab).

Shot-hole—Roughly circular holes in leaves resulting from the dropping out of the central dead areas of spots (Coryneum leaf spot of peach).

Sign—The part of a pathogen seen on a host plant (moldy growth, spores, etc.).

Smut—Black masses of spores in galls that may form on stems, ears, etc. (common smut of corn).

Spore—The reproductive unit of a fungus, similar to the seed of a plant.

Susceptibility—The condition of a plant in which it is prone to the damaging effects of a pathogen or other factor.

Symptom—The altered external or internal appearance of a diseased plant (spot, gall, soft rot, etc.).

Systemic—Spreading internally throughout the plant.

Vascular pathogen—A disease-causing organism that invades mainly the conductive tissues (xylem or phloem) of the plant.

Vector—A living organism that is able to transmit or spread a pathogen.

Virulent—Capable of causing severe disease.

Wilt—Drooping and drying plant parts due to interference with the plant's ability to take up water and nutrients (Verticillium wilts, Fusarium wilts).

Tutor Marked Assignment

1. Explain the following principles of disease management.
   i. Exclusion
   ii. Eradication
   iii. Protection
   iv. Resistance

2. Define the following terms
   i. Canker
   ii. Chlorosis
   iii. Crown gall
   iv. Anthracnose
   v. Blight
   vi. Etiolation
   vii. Inoculum
   viii. Lesion
   ix. Mosaic
   x. Necrosis

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