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Forest pests in Central America

HANDBOOK

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PRESENTATION

There has been growing interest in tree production in Central America in recent years resulting from support to silvicultural research. This interest can be observed throughout communities where small plantations of mixed species have started to appear.

The LEÑA and MADELEÑA Projects, developed by CATIE in Central American countries from 1980 to 1991 and funded by ROCAP, have stimulated this interest and increased the number of species now being used.

In order to develop silviculture as a productive activity capable of competing with traditional production, many aspects needed consideration. A plant health study of the 14 priority species was considered fundamental to complement the efforts made in silviculture. The study covered the recognition of pests and diseases found in different stages of tree development from seed and nursery to mature forest.

This line of research is also fundamental for ensuring success in establishing forestry plantations. It is well known that as the population of one forestry species increases, so the risk of prejudicial pests or diseases also increases.

The regional level plant health evaluation was complemented by the preparation of a "Field Guide and Handbook for Forest Pests".

It is hoped that these two documents will be useful tools, both for those carrying out research in pests and diseases of tropical forest species and for educators and extensionists who must cater to the producers' needs.

Rodolfo Salazar
MADELEÑA Project Leader

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The consultants

PREFACE

Many organisms go unnoticed by man, unless they impinge on his activities or interests. In Central America, plant health problems have grown to an unprecedented level during the last few years along with the establishment of extensive, homogeneous forest plantations.

In some cases, a panic reaction has resulted in the application of drastic solutions such as widespread felling and the massive application of pesticides. Rarely has the organism's damage potential, risk of spreading or host range been thoroughly analyzed in order to come up with less radical or expensive measures. The situation could be summarized in two words: ignorance and desperation.

There are no simple measures for overcoming ignorance and coping with desperation but efforts must be made immediately to find remedies. Starting with an appropriate theoretical strategy, there must be observation, analysis, trials of new techniques and organization of findings to resolve field problems. To a great extent, this is what members of PIPROF (Programa Interinstitucional de Protección Forestal) have achieved in Costa Rica since 1984. They have been aware that there is little available information for combating plant health problems in nurseries, plantations and forests.

When the Madeleña Project first approached us regarding the consultancy, which included the preparation of a field guide and handbook, we were apprehensive in view of the complexity and scope of the work. However, we soon realized the need to fill the large gap that exists in information in the region. When we later visited the countries of the area, we were even more sure that there was an urgent need for published material in the field of forestry protection.

It is with great satisfaction that we present the Field Guide and Handbook which, in reality, together constitute a single work. The Field Guide concentrates on 18 trees considered priority species by MADELEÑA, and is designed for field use. It permits fast identification of damage agents and offers some general information on their biology and epidemiology. The Handbook contains theoretical information at greater depth, such as guidelines for plantation inspection and pest and disease management in general, making it, in practice, inseparable from the Guide. The authors feel that the information given in the Handbook will help provide better criteria for confronting any novel plant health problems not covered by the Guide.

It should be noted that there is a marked bias, especially in the Guide, to plant health problems found in Costa Rica. In part, this is due to Costa Rica being the seat of PIPROF, the organization which has been gathering information continually for six years. Only one week was *allowed for collecting samples from other countries in the region and, for operational reasons, identifiable forms of the material being reared or grown in the national laboratories was not always available.*

Lack of expertise and operational difficulties mentioned above have meant that the works may lack polish and depth. Both the Guide and Handbook should be regarded as preliminary texts which will, in later editions, include material omitted involuntarily as well as new knowledge acquired in the future. With this in mind, the authors would be grateful to receive any information or suggestions to improve and amplify the works. Amongst the more ambitious hopes is the establishment of a regional forestry protection network to facilitate the exchange of information and observations. It is hoped that these documents will act as catalysts for this important project.

We hope that the continued use of these two complementary texts will help overcome the ignorance of pests and diseases affecting nurseries, plantations and forests and help dispel the desperation which has so often led to ill-advised solutions.

The consultants

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DAMAGE-CAUSING AGENTS

CHAPTER I

AGENTS CAUSING DAMAGE

Both established trees in plantations and seedlings and stumps in nurseries are liable to be affected by a wide range of damage-causing agents. These include animals (insects, mites, mollusks, nematodes and vertebrates), fungi, bacteria, viruses, parasitic plants and abiotic factors.

Since intrinsic characteristics such as mode of action vary considerably, each must be considered in detail to avoid incorrect diagnosis and to combat problems effectively.

1. INSECTS

A. GENERAL CHARACTERISTICS

The insects are not only the most numerous animal group (with almost one million species) and the most diverse in habits and habitats, they are also one of the most economically important groups, especially as pests.

Some cause considerable losses in forestry and must be controlled. This control should be based on an adequate knowledge of the pest species' morphology, physiology, behavior and ecology. Some of these aspects will be discussed in this handbook.

a) General morphology

In general terms, adult insects can be distinguished from other invertebrates by the following characteristics: they possess six legs and four wings (although some may only have two or lack them altogether) and the body is covered by a fairly hard exoskeleton, which, like the antennae and legs, is made up of individual segments joined or jointed by membranes (Fig.1).

The morphology of the body and its appendages varies considerably according to the habits particular to each species. These differences are also seen in the immature forms: eggs, larvae, pupae and nymphs. Since the characteristics of the antennae are important for taxonomic purposes, a classification of these is given in Fig.2.

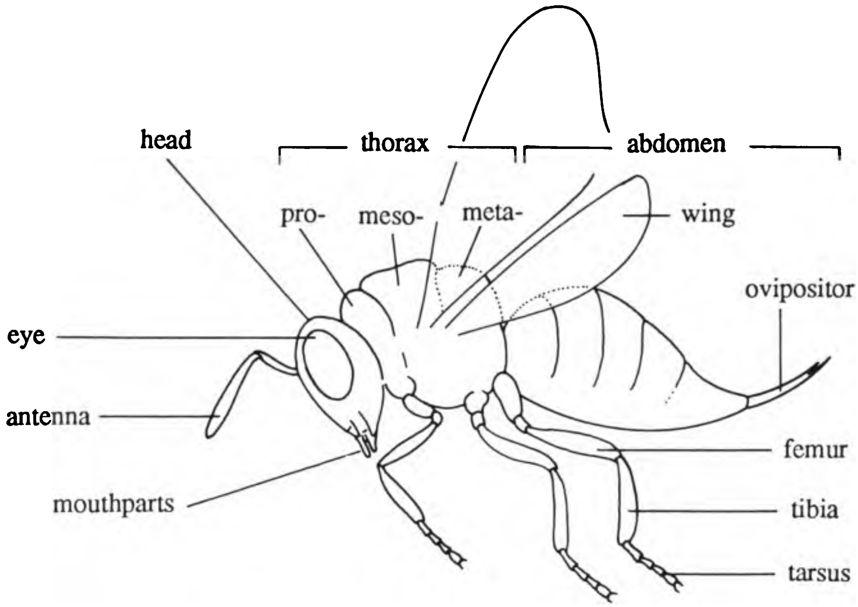


Figure 1. Insect body parts.

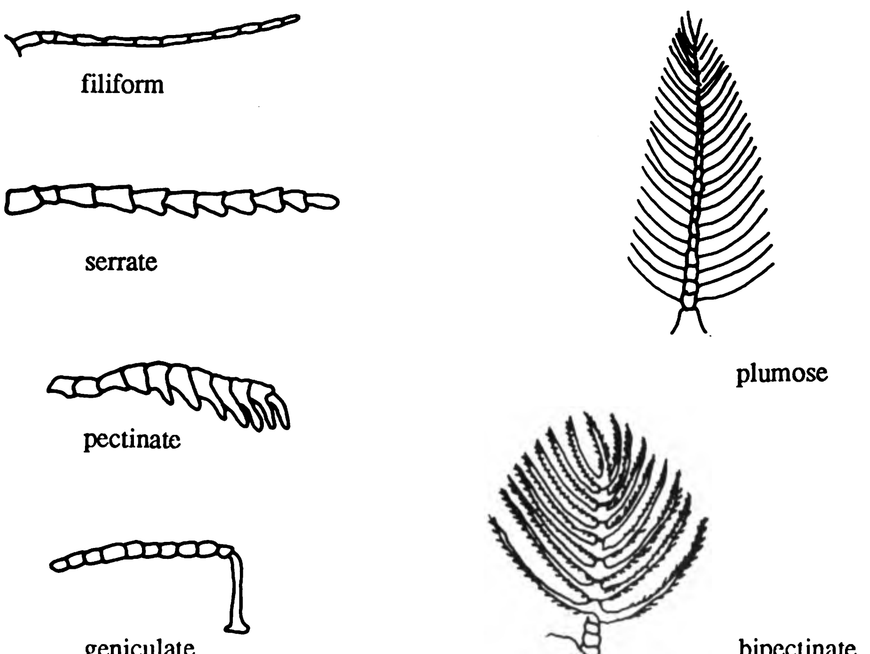


Figure 2. Different types of antennae.

b) Types of metamorphosis

Metamorphosis is the change that insects undergo during their development from egg to adult. There are two types of metamorphosis: gradual and complete. All insects which are pests of forest species undergo one of these types of metamorphosis.

In gradual metamorphosis, a nymph emerges from the egg and progressively increases in size until it becomes an adult (Fig.3). The adults differ from the nymphs in the possession of full wings and the ability to reproduce. In practical terms, nymphs and adults have similar mouthparts, feed on the same type of food and generally live in similar sites, sometimes gregariously. In other words, both can simultaneously damage plants.

Insects of importance to forest species which show gradual metamorphosis (also called hemimetabolic or paurometabolic, depending on author) belong to the orders Hemiptera, Homoptera, Isoptera, Thysanoptera and Saltatoria.

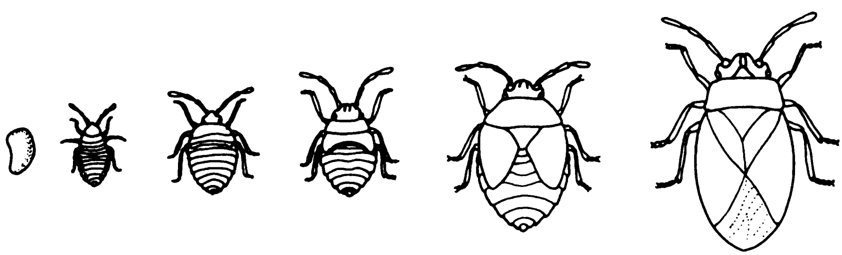


Figure 3. Gradual metamorphosis.

In complete or holometabolic metamorphosis there are four morphologically distinct stadia or stages: egg, larva, pupa and adult (Fig. 4). The active forms are the larva and adult, but these normally have different mouthparts, feed on different food and live in different places. Of those having importance in forestry, insects of the orders Lepidoptera, Coleoptera, Hymenoptera and Diptera show complete metamorphosis.

Nymphs and larvae molt or shed their skin during their growth. The period between molts is called an instar, so that an insect referred to as a fifth instar larva is a larva that has molted four times and is about to molt a fifth time.

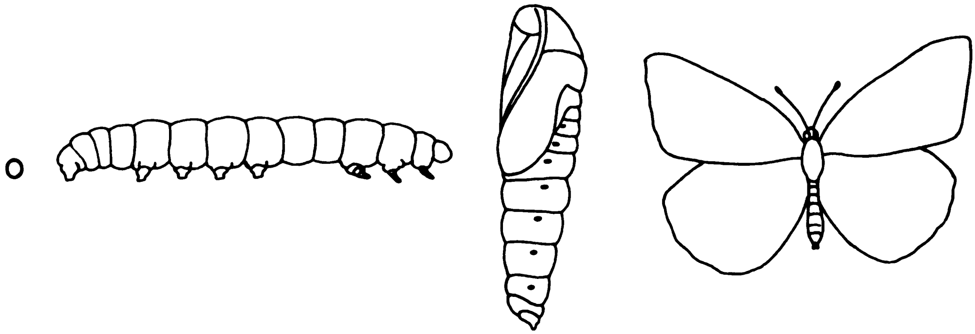


Figure 4. Complete metamorphosis.

c) Mouthpart types

A knowledge of the type of mouthpart an insect possesses is of great practical importance, not only to check that the insect really caused the damage but also because it determines the type of control to use (especially in the case of insecticides).

Although there is a great variety of insect mouthparts, those which are forest pests show one of four types.

The most common are **chewing** mouthparts. The most important structures are the mandibles and maxillae (Fig. 5) which the insect uses to cut and eat leaves, buds, shoots, seedlings and roots, mine leaves and bore into buds, seeds, bark and the wood of trees. Insects with this type of mouthpart include: bee and butterfly larvae, adult beetles, ants and some bees, nymphs and adults of termites, grasshoppers and crickets.

The **piercing-sucking** mouthparts are in the form of a needle or stylet (Fig. 6). These allow the insect to extract sap or liquid from soft tissues such as leaves, buds, shoots and young stems. They can be seen in bugs, cicadas, leafhoppers, aphids, jumping plantlice and scale insects.

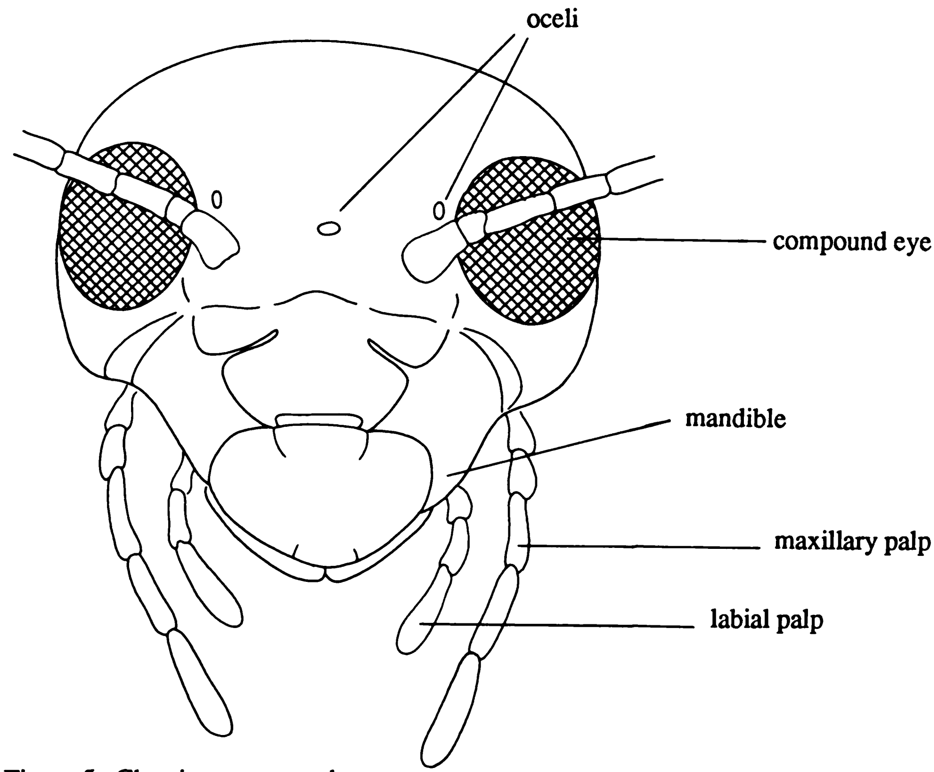


Figure 5. Chewing type mouthparts.

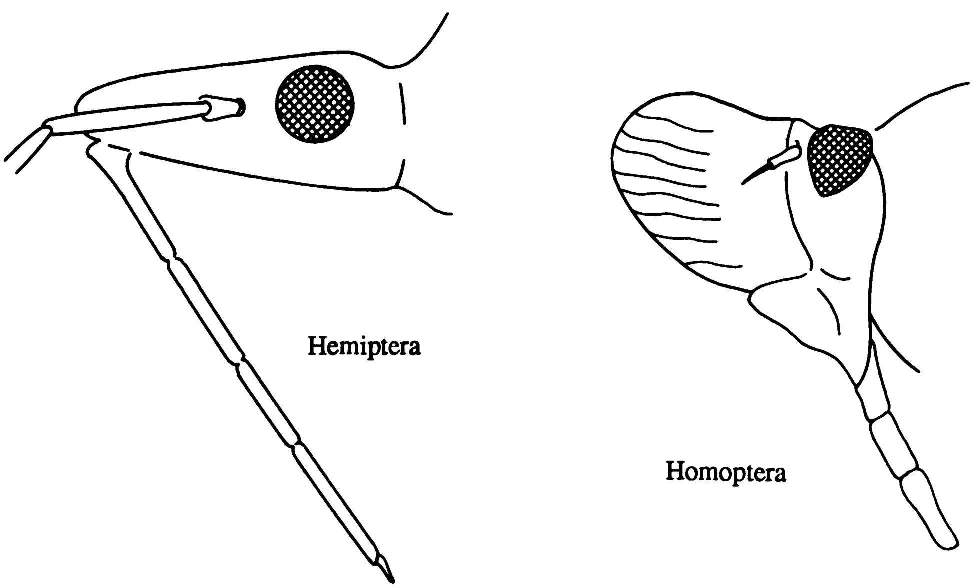


Figure 6. Piercing-sucking mouthparts.

The **rasping-sucking** type of mouthparts is a hybrid of the previous two. The mouthparts are cone shaped (Fig. 7) with asymmetric mandibles. These are only seen in the order Thysanoptera which includes the thrips. These insects rasp the lamina of the leaf and then suck the sap which flows from the ruptured tissue.

Finally, adult butterflies and moths have **siphoning-sucking** mouthparts (Fig. 8). These are adapted for extracting nectar from flowers and insects with these mouthparts cannot damage seedlings or trees.

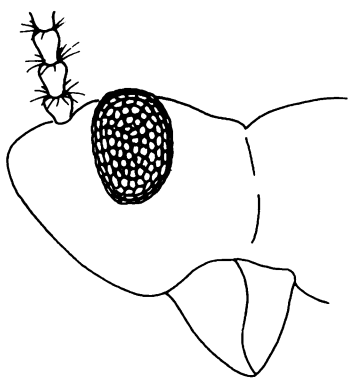


Figure 7. Rasping-sucking mouthparts.

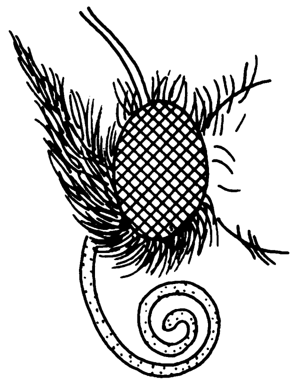


Figure 8. Siphoning-sucking mouthparts.

B. RECOGNIZING INSECTS OF FOREST IMPORTANCE

To assist in their study, insects are classified according to certain characteristics, mainly morphological, which subdivide them into a hierarchical grouping. Only four categories or taxa will be considered here: order, family, genus and species. An order is a group of families, a family is a group of genera and each genus is made up of several species. For example, in Central America there are three species of leaf-cutting ants called ***sexdens***, ***cephalotes*** and ***colombica***. All three belong to the genus ***Atta***. This genus, along with other ant genera, belongs to the family Formicidae. This family, along with wasps (Vespidae), bees (Apidae) and others, belongs to the order Hymenoptera. The use of names derived from Latin or Greek enables scientists to communicate with each other irrespective of their native language or any common name given to a particular insect in different countries.

In reality, there are about thirty insect orders, but only nine of them include pest species: Saltatoria, Diptera, Lepidoptera, Coleoptera, Thysanoptera, Hymenoptera, Isoptera, Hemiptera and Homoptera.

Insects are normally identified using dichotomous keys. These are lists of characteristics arranged in pairs so that alternatives are progressively eliminated until the required level of identification is reached. Some form of complex optical apparatus such as a stereoscopic microscope is often needed to use these keys. Since this is not always available, the following modified classification system is given to aid identification in the field with only a hand lens.

The following outlines a classification method for adults and larvae to order level. Families, genera and species of pest importance are dealt with in the Field Guide.

a) Recognition of adults.

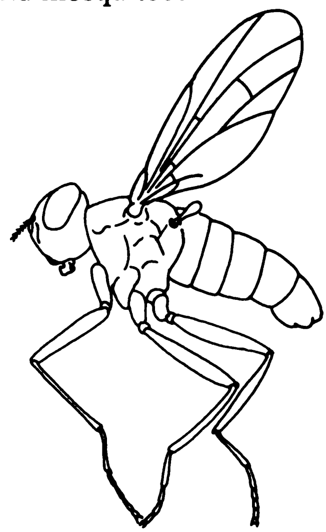
One simple method of classifying adults is based on the etymological origin of their name and the type of mouthparts they posess. The suffix -**ptera** is the plural of **pteron**, from the Latin, meaning wing. With the exception of the SALTATORIA, the names of all other orders include the suffix **ptera**. The prefix describes some characteristic of the wings. Of course, this system does not apply to apterous (wingless) forms such as scale insects, some aphids and some castes of ants and termites.

SALTATORIA (saltator = jump) Grasshoppers and crickets

Insects with a great jumping ability derived from adaptations of the femur and tibia of the hind legs

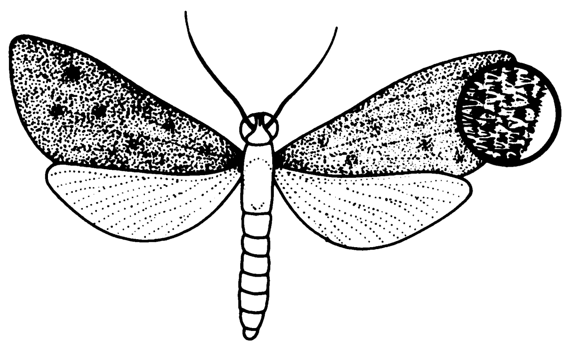
DIPTERA (di = two) Flies and mosquitoes

Insects with one pair of anterior wings only. The hind wings are reduced to halteres which are small knob-shaped structures used for balancing. The mouthparts are very variable.



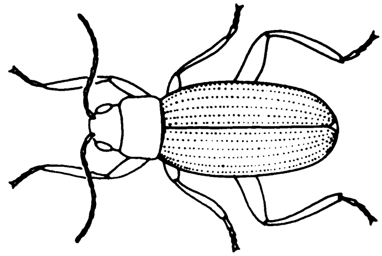
LEPIDOPTERA (lepido = scale) Butterflies and moths

The wings are nearly always covered in scales. The mouthparts are in the form of a spiral-shaped tube or proboscis.



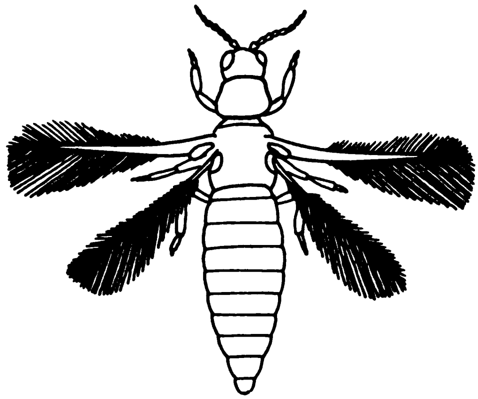
COLEOPTERA (coleo = hard) Beetles

The forewings are normally thick and hardened and cover the hind wings. The mouthparts are of the chewing type.



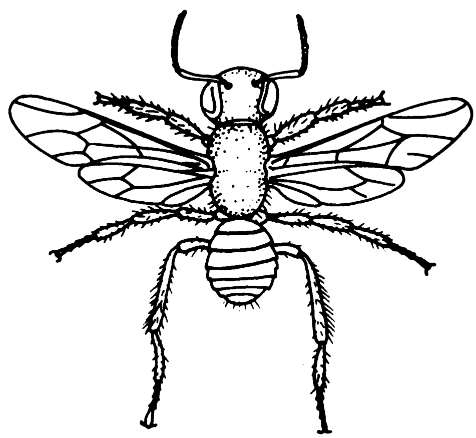
THYSANOPTERA (thysano = fringe) Thrips

The wings are narrow and fringed. The mouthparts are the rasping-sucking type and conical in shape. They are tiny insects, rarely measuring more than 5 mm long.



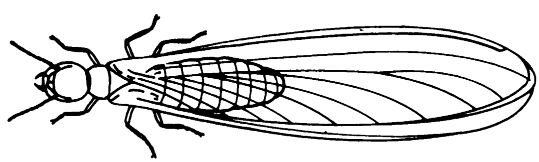
HYMENOPTERA (hymen = membrane) Ants, bees and wasps

The wings are membranous and usually transparent. The mouthparts are of the chewing type, with the exception of the honeybee and bumblebees.

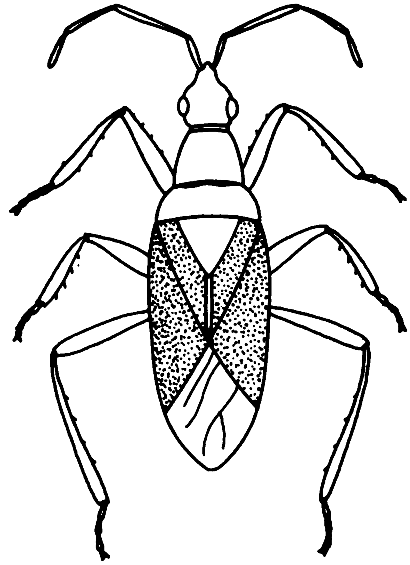


ISOPTERA (iso = equal) Termites

Both pairs of wings are the same morphologically. The mouthparts are the chewing type. They live in colonies of different castes, some of which lack wings.

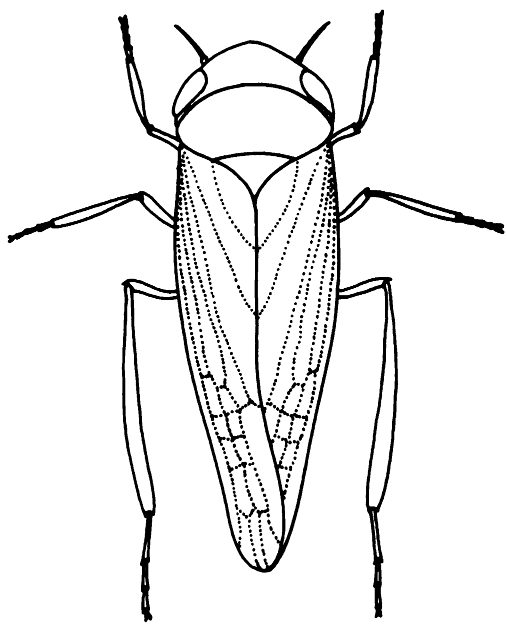


HEMIPTERA (hemi = half) Bugs



The fore wings are not homogeneous: the basal part is thick and solid while the terminal part is membranous. When the insect is at rest, the wings are held in a flat, horizontal position. The mouthparts are the piercing-sucking type and arise from the front of the head.

HOMOPTERA (homo = similar) Cicadas, hoppers, psyllids, whiteflies, aphids and scale insects.



Both pairs of wings are homogeneous. When the insect is at rest the wings are held rooflike over the body. The mouthparts are of the piercing-sucking type and arise from the back of the head. Some groups, such as the aphids, have apterous and winged forms. Female scale insects have a strange morphology which impedes recognition of the body parts.

b) Recognition of immature forms

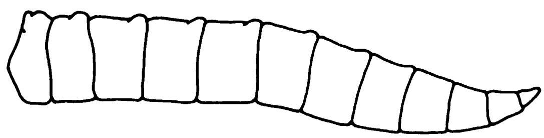
In this section only larvae and nymphs are considered since eggs and pupae are inactive in the field.

Generally speaking, the recognition of Saltatoria, Thysanoptera, Isoptera, Hemiptera and Homoptera nymphs is straightforward. With the exception of wings, the characteristics described for the adults will be very similar to those of the nymphs. In orders such as Isoptera, Thysanoptera and many Hemiptera and Homoptera, the nymphs stay close to the adults and can easily be identified by association.

Larvae of the remaining orders can be identified thus:

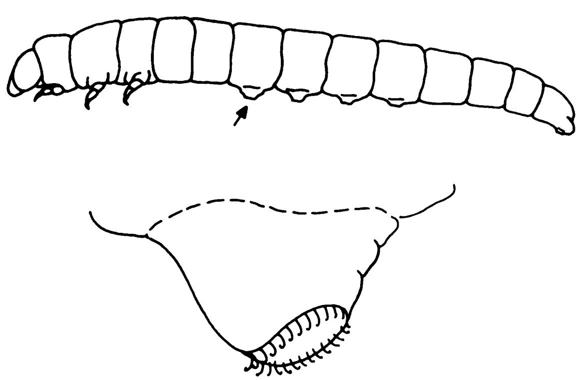
DIPTERA

Larvae without legs or prolegs. The head is very reduced, soft and little differentiated. The body is pointed anteriorly and blunt posteriorly.



LEPIDOPTERA

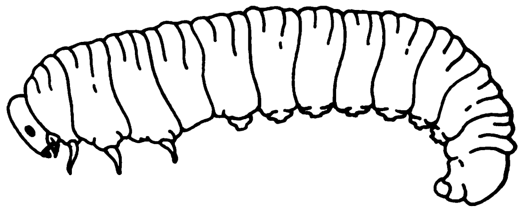
In addition to six thoracic legs, these larvae have up to five pairs of prolegs or false legs. The exceptions are the slug caterpillars (Limacodidae) which lack prolegs. These prolegs have tiny hooks called crochets, with the exception of the Castniidae, which have microspines and the Coleophoridae which lack crochets. The latter are recognizable by their cases.



prolegs

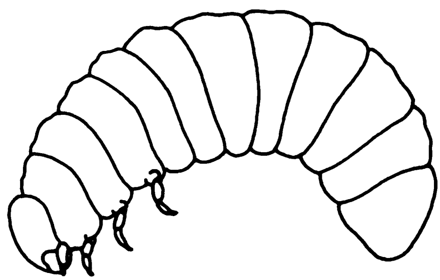
HYMENOPTERA

The larvae are varied. Some of the larger larvae which are of forest importance have more than five pairs of prolegs in addition to the six thoracic legs. These prolegs lack crochets.



COLEOPTERA

The larval morphology of this order is so varied that it is impossible to describe a typical larva. However, it is possible to identify them by process of elimination, since they lack prolegs and sometimes thoracic legs, and have a well differentiated head.



2. OTHER ANIMALS

A. MITES

Mites are similar to insects in that they have segmented appendages and their bodies are covered by an exoskeleton. However they lack wings and antennae and have eight legs (Fig. 9). Instead of mandibles and maxillae they have chelicerae which may be modified to form stylets for feeding.

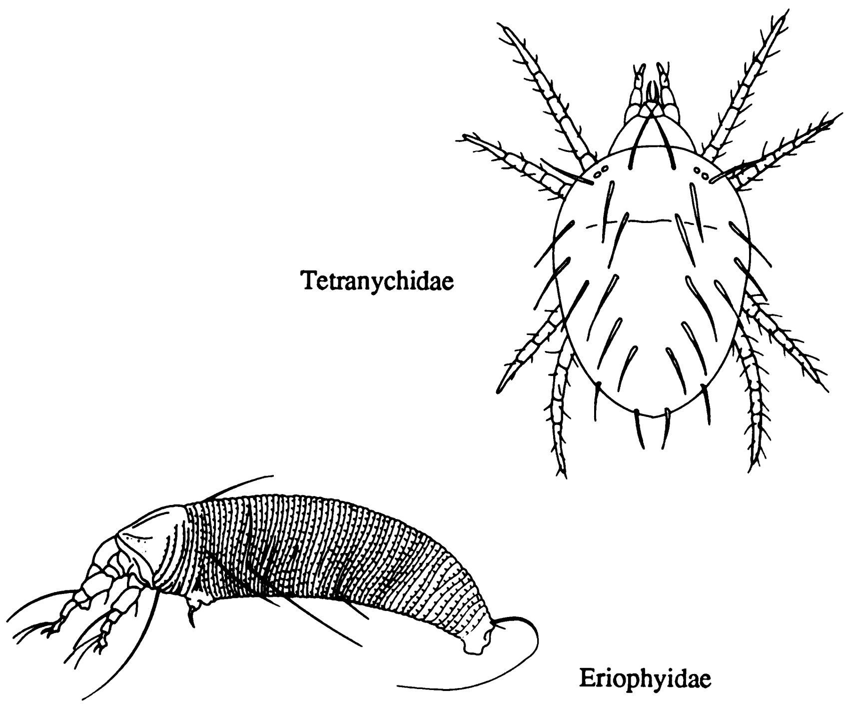


Figure 9. Mites.

Mites of agricultural or forestry importance are tiny arthropods, rarely measuring more than 1 mm long. Their life cycle is complex and includes the stages egg, six-legged larva, nymph (**protonymph, deutonymph** and **tritonymph**) and adult. Parthenogenesis is quite common.

Some species feed on leaves and fruits and also on the underground parts. They may be exposed or form galls. They rasp the tissues to obtain sap and their activity can result in a number of symptoms such as discoloration, yellowing, russeting and bronzing of the leaf, necrosis and leaf fall and deformation of leaves and fruit.

The families with greatest importance as agricultural pests are the Tetranychidae, Tenuipalpidae, Tarsonemidae and Eriophyidae. In the future these may also prove significant in forest species.

B. MOLLUSKS

The mollusks of importance to forest species are the slugs and snails. Damage is generally slight and mostly seen in nurseries.

Slugs and snails belong to the class Gastropoda, phylum Mollusca. They have a well differentiated head with two pairs of tentacles. The upper pair function as eyes while the lower pair are olfactory and tactile organs. Behind the head is a long body mass with a wide base or foot containing muscles and mucus glands which the animal uses for locomotion (Fig. 10). The mouth contains a type of rasp with tiny teeth called the radula. This is used for feeding on leaves, stems and fruits.

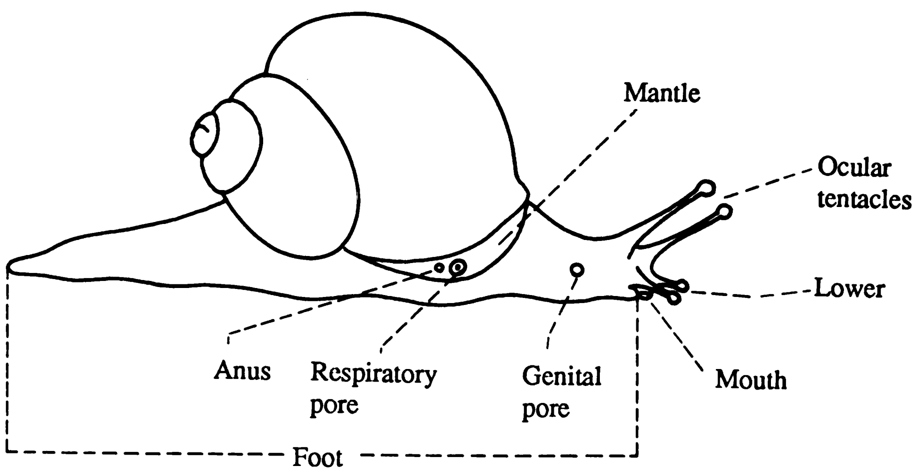


Figure 10. Snail.

Mollusks are hermaphrodite (each individual has male and female organs) and during copulation, each member of the pair inserts its penis into the other's vagina. Eggs are laid in groups in damp locations, either under the soil or on top of the soil, beneath litter etc.

Both slugs and snails live in dark, damp locations during the day. They emerge at night to feed sometimes eating entire seedlings or just the foliage. They can also eat fruits, consuming large portions or just leaving marks on the skins. Evidence of their presence is visible in the shiny, mucus trails they leave behind.

In Central America, slugs are represented by the families Limacidae and Veronicellidae. Limacidae have respiratory pores, clearly visible mantles and pointed posteriors. The genera ***Limax*** and ***Deroceras*** belong to this family. Members of the other family do not have a respiratory pore or visible mantle and are less sharply pointed posteriorly. The genera ***Sarasinula***, ***Belocaulus***, ***Diplosolenodes*** and ***Leydyula*** belong to the Veronicellidae.

C. VERTEBRATES

The vertebrate animals which have relevance to forest species include mammals, reptiles and birds.

Damage caused by reptiles is occasional, such as the removal of ***Gmelina arborea*** and ***Cordia alliodora*** stumps by ctenosaurs and Jesus Christ lizards. Some birds, such as parrots and parakeets (family Psittacidae) feed on fruits and seeds of forest species. Of the mammals, the most important group is the Rodent order and rabbits (order Lagomorpha). Others which can cause damage are the armadillos (***Dasypus novemcinctus***), peccaries (***Tayassu tajacu***), porcupines (***Coendou mexicanum***), howler monkeys (***Alouatta palliata***) and white-tailed deer (***Odocoileus virginianus***).

A description of the most notable characteristics of rodents and rabbits is given, since of all the vertebrates, these cause most damage to forestry species.

Rabbits and rodents have similarly structured teeth and jaws but there are some differences in the arrangement. Rabbits have several molar teeth in the lower jaw, separated from the others by a space or diastema. They have four incisors in the upper and two in the lower jaw (Fig 11). Rodents have two upper and two lower incisors.

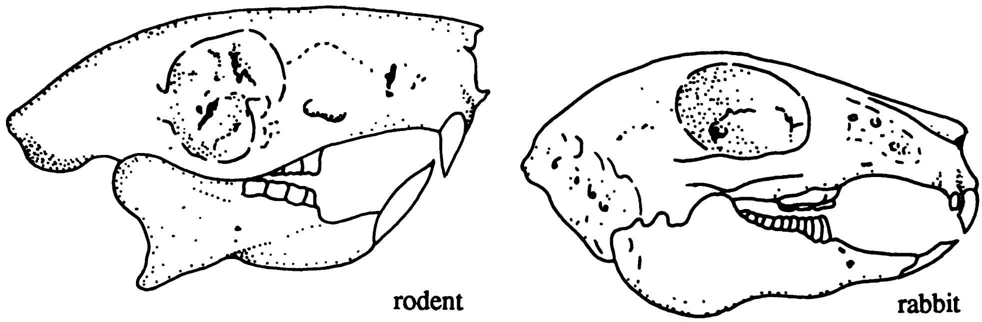


Figure 11. Mammal skulls.

Rabbit and rodent incisors grow continuously and must be worn down. They are covered with a layer of very hard enamel and continual use is also needed to keep them sharp. Frequently, rabbits and rodents such as squirrels, rats and pocket gophers destroy wood, cement and other hard materials in the act of sharpening their teeth.

Some rodents such as rats and pocket gophers cannot distinguish colors but have well developed senses of hearing, smell and taste.

Rodents and rabbits are generally very mobile and agile. They can run, jump, climb and even swim quickly. Their diet is very varied and they have a high reproduction potential. Some of these aspects are considered more fully in the Field Guide.

3. FUNGI

A. GENERAL CHARACTERISTICS

The fungi are a group of organisms whose origin has been debated for many years, especially in view of the varying habits and forms they exhibit. It is the largest group of disease-causing agents which affects plants of widely varying taxonomic groups.

There are approximately 100,000 species of fungi, of which about 8,000 are phytopathogenic and cause about 80,000 diseases.

The fungi constitute a fairly heterogeneous group; however, it is sometimes impossible to define the exact boundaries of the group. The most generalized definition of the fungi describes them as possessing a well defined nucleus, being unable to make their own food, reproducing sexually and asexually and being made up of a vegetative body of filaments which can compact to form reproductive or survival structures. These characteristics are common to the majority of fungi, but some species do not exhibit all those mentioned.

B. THE IMPORTANCE OF FUNGI

Fungi are important, not only for their beneficial role, but also for the damage they cause to silviculture, agriculture and human and animal health. In forestry, important economic losses due to fungal diseases are often reported from plantations, parks and saw mills. Damage includes reduction of growth, rotting, deformation, predisposing trees to toppling or attack from other pests and even causing tree death.

Although it is hard to quantify the extent of the damage or calculate economic losses, cases are known where some species of tree have had to be eliminated because of one pathogen, especially in the case of shade and ornamental trees.

In Costa Rica, fungal attacks have been reported to have caused almost 100% mortality in some plantations. In 1984, one pine plantation in Tilarán was so badly affected by Dothistroma Needle Blight (caused by ***Dothistroma pini***) that the project was lost. ***Pestalotia*** sp. is a pathogen which in recent years has affected many cypress plantations. In eucalypt nurseries there are great losses from ***Cylindrocladium*** or ***Colletotrichum*** attack. This indicates that phytopathogenic fungi can have great importance in the region.

C. BIOTIC RELATIONSHIPS

Some fungi and their host plants have an association which is mutually beneficial and is given the name symbiosis or mutualism. The best example of this is mycorrhiza. In this association, the fungus provides the host plants with certain nutritive elements and protects the roots from attack by pathogens and other factors. In exchange, the host provides favorable conditions for fungal growth. In forest species, the most well known example is the association between pines and fungi such as ***Phisolithos tinctorius*** and ***Telephora terrestris***.

Another form of association is saprophytism. Two ecological groups of saprophytes are distinguished according to their location in the soil ecosystem. One group inhabits the soil and the other the rhizosphere. The first group can grow freely in a suspension of soil, feeding on dead organic matter. The second group shows little ability to compete with other soil microorganisms and shows reduced growth, preferring to grow on decomposing organic matter, such as roots and leaves on the soil surface.

On occasion, saprophytes can cause infections. This type of organism is called a **facultative saprophyte**. This is a very important condition from the phytopathological point of view, where an organism which does not normally cause infection turns into a pathogen and invades healthy tissue. Infection occurs when root exudates stimulate growth of the fungus and its invasion of the seedling or when other factors weaken adult trees and make them susceptible to attack. This situation often occurs in natural forest occasionally giving rise to trees which appear to have died for no apparent reason.

From the plant pathology viewpoint, the most important association is parasitism, where only one organism benefits. Parasitic fungi can be divided into two groups according to whether they live in the soil or rhizosphere. Members of the first group often have a wide variety of hosts, prefer to attack young or soft tissues and, evolutionarily speaking, are poorly developed. Some phytoparasites may become saprophytes when conditions are unfavorable, and are called facultative parasites. This behavior is important as a means of survival when there is no available host or when environmental conditions are unfavorable. ***Pythium*** spp., ***Fusarium*** spp., and ***Rhizoctonia*** sp., which cause damping off or root rot in many forestry species and are widely distributed in the soil, are good examples of these kind of microorganisms.

Parasites inhabiting the rhizosphere include those which have a smaller number of hosts. They are characterized by their ability to attack hosts in more advanced developmental stages, with mature tissues. Apart from in the host's roots, growth in the soil is much reduced.

Armillaria spp., ***Fomes*** spp., ***Ceratocystis*** spp. and ***Phellinus*** spp. are all fungi which cause rotting of the roots and trunk of adult forestry species trees. These parasites are also adapted to aerobic conditions and can survive for a time as saprophytes when the leaves fall or the host is eradicated.

Other pathogens, such as the rusts, have to complete their life cycle in living tissue. They are the most evolved and show high host specificity. They are known as **obligate parasites**.

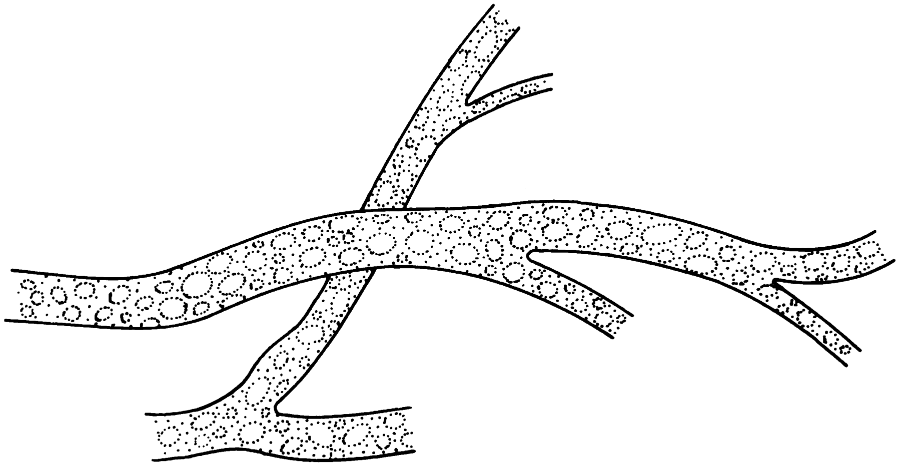
D. MORPHOLOGY

The somatic or vegetative form of the fungi consists of a group of thin, transparent, branching threads or filaments which grow terminally. Growth is radial on flat surfaces and spherical in a liquid medium. Each filament is called a hypha and a group of hyphae forms a mycelium. The mycelium is coenocytic when the filament is continuous (without divisions) and septate when there are divisions or septa (Fig. 12). Any hyphal fragment can give rise to a mycelium which, in turn, can initiate a new infection, move to the internal cells of the host and extract the nutrients necessary for its development.

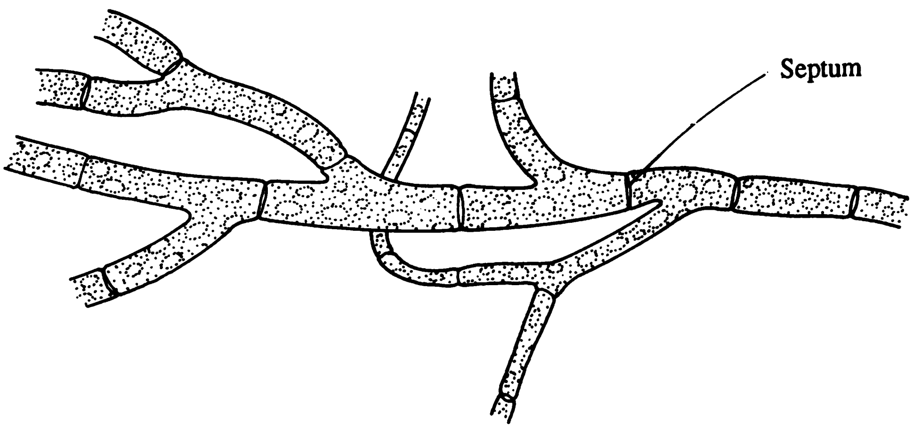
During the process of infection, the hyphae grow **between** the host cells, destroying the cell wall and feeding on the substances released from the ruptured cells. There is also growth **within** the cells where the fungus feeds through hyphal extensions (haustoria) in the interior of the cell (Fig. 13).

The mycelium forms structures such as sclerotia, rhizomorphs or micro and macroscopic fruiting bodies (such as mushrooms and toadstools) by compaction.

Sclerotia are hard structures in different shapes and sizes, produced by some fungi as a means of survival during adverse conditions. **Rhizomorphs** are thick strands of mycelium whose hyphae have compacted to become morphologically organized units (similar to roots). They are normally found below the bark growing like ribbons over the surface of the pith.



Coenocytic mycelium



Septate mycelium

Figure 12. Types of mycelia produced by fungi.

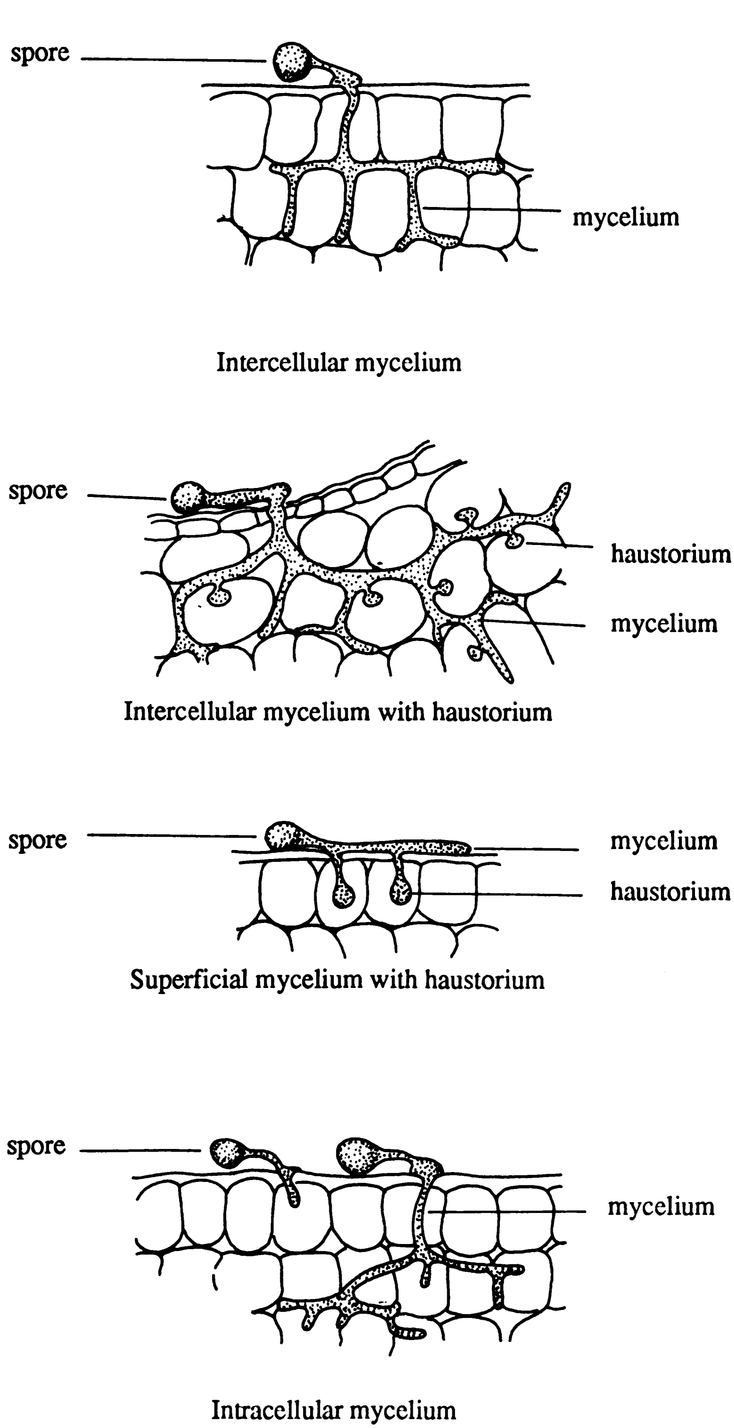


Figure 13. Methods of mycelial penetration and advance in host tissues.

E. REPRODUCTION

Fungi reproduce sexually and asexually. Asexual reproduction is more common and consists of the production of new individuals genetically identical to the organism from which they arose. Methods of asexual reproduction include: 1) the division of the mycelium into fragments which can grow and form new individuals; 2) the division of somatic cells into two new identical cells; 3) gemation of cells or spores and 4) the production of spores in specialized structures or by modification of mycelial cells. These asexual spores are called **conidia.**

Asexual reproduction speeds up propagation of the species since it produces a greater number of individuals in less time. The asexual cycle can be repeated several times in one season whereas sexual reproduction only occurs once a year or when conditions are favorable.

In the case of soil fungi, the most important means of reproduction is fragmentation. For this reason it is extremely important to remove the focus of infection from nurseries and avoid mixing contaminated soil in the germination or seedling beds.

F. HABITAT

It is estimated that the first 20 cm of soil contains the greatest concentration of fungi and that one gram of dry soil can contain up to a million spores or propagules. However, the population of any microorganism depends on the parent material, tree species and soil cover. For this reason, any changes in the surroundings implies a change for the fungal population.

Like any organism, fungi are influenced by their environment. This can include micro-environments which may favor or limit their growth. Some of the environmental factors which most affect fungi are humidity, temperature and chemical and physical soil conditions.

Water is an absolute necessity for fungi. Free water directly affects mycelial growth, nutrient availability and the accumulation of toxic substances. Relative humidity affects the size of the hypha, the level of branching, sporulation capacity and even the type of reproduction. Water availability varies according to soil type; clay soils retain more water than sandy soils.

Temperature is another important factor. Most fungi grow well between 20 and 30°C. Temperatures below 2°C and above 40°C inhibit growth. In the tropical climate of the region's countries it is not hard to find the optimum values, notwithstanding daily fluctuation between daytime and nighttime temperatures. In the case of non-specialized pathogens, the effect of temperature is most felt by the host. Conditions which are less favorable to the host make it more susceptible to attack.

Physical and chemical conditions in the habitat also influence fungal development. Sandy soils are less favorable than clay which tend to saturate and have a high water and organic matter content. Soil pH also influences the physiology of the fungus. ***In vitro*** studies have shown the optimum pH for most species to be between 5.0 and 6.5. Many fungi show a fairly wide tolerance of pH, but there is little growth at pH levels above 9 and below 3.

Sometimes fertilizer application can affect fungal growth by modifying the soil environment and changing the plant's growth. Nitrogen, for example, has a different mobility in the soil and alters the pH of the rhizosphere. Excessive nitrogen fertilization can predispose the plant to attack by many pathogens.

In general terms, the fungal population is determined by the surface vegetation, competition for food, interactions with antagonistic organisms, physico-chemical soil properties and soil and air microclimates.

G. SURVIVAL

The survival of pathogens is closely linked to the host's life cycle and prevailing environmental conditions. It has been seen that leaf and root pathogens of annual plants have short life cycles and incubation periods, since their substrate is short lived. On the other hand, tree pathogens, whose hosts live longer, have longer life cycles and incubation periods, sometimes lasting years.

Fungi which parasitize perennial hosts are at an advantage since, once the host is established, their survival is assured. Pathogens of lumber species, especially those affecting the trunk, stay within the invaded tissue. Examples of this are ***Clytocybe*** sp. and gall formers such as ***Cronartium ribicola***, which produces pine rust. ***Sphaeroteca pannosa*** and other fungi causing powdery mildew in eucalypts survive in the shoots of the host.

Parasites of annual plants cannot survive in the same way. Some take advantage of the host's seeds to stay alive until the next generation. Others produce thick-walled spores capable of remaining dormant over long periods, even in unfavorable conditions, until they can infect a new host.

Fungi which produce fruiting bodies use these to survive. Basidiocarps, including mushrooms and toadstools, are structures which can keep spores for some time. Organisms such as ***Rhizoctonia solani***, ***Sclerotium rolfsii*** or ***Botrytis cinerea*** can form sclerotia to survive adverse conditions. Sclerotia are structures formed by the compaction of mycelia. These condense to form hard bodies of varying shape and size. Humidity stimulates sclerotium germination producing a new mycelium. Other resistant structures made by some fungi are rhizomorphs. These are made of aggregates of small threads of mycelium in which each hypha loses its individuality and behaves as part of a unit.

Not all fungi can produce spores or resistant structures. Some, especially those that affect roots, stay as mycelia in plant residue. The success of this method depends on the pathogen's ability to find other sources of food and its aggressiveness with other microorganisms, some of which may be antagonistic.

H. DISPERSAL

Once the fungus has produced spores, these must be spread, either to the same or neighboring hosts. The efficiency of spread depends on the means used by the fungus and the density of hosts surrounding the source of inoculum (spores).

The production of large numbers of spores is not, in itself, a guarantee that infection will occur. In natural forests, where the species composition is varied, the inoculum frequently fails to find a susceptible host and the disease does not establish itself at epidemic levels. By contrast, in homogenous plantations, where the pathogen finds ample susceptible tissue close by, the majority of the spores become efficient inocula and the disease quickly spreads through the population.

In natural conditions there are several spore dispersal mechanisms. The most noteworthy are air, water, insects, the soil and man.

I. MAIN TAXONOMIC GROUPS

This Handbook has adopted the classification proposed by ALEXOPOULOS and MIMS (1979) which is relatively recent and places the fungi in a separate kingdom, the Myceteae. Moreover, groups which have been left together in spite of marked differences, are classified in other taxa according to more logical criteria. Only classes or orders of forest pathology interest are mentioned.

Division : MASTIGOMYCOTA
Subdivision : Diplomastigomycotina
Class : Oomycetes

Division :	AMASTIGOMYCOTA
Subdivision :	Zygomycotina
Class :	Zygomycetes
Subdivision :	Ascomycotina
Class :	Ascomycetes
Subdivision :	Basidiomycotina
Class :	Basidiomycetes
Order :	Agaricales
	Aphyllophorales
	Uredinales
Subdivision :	Deuteromycotina
Class :	Deuteromycetes
Order :	Melanconiales
	Sphaeropsidales
	Moniliales
	Agonomycetales

To simplify the descriptions, only classes and a few exceptional orders will be mentioned.

a) Class Oomycetes

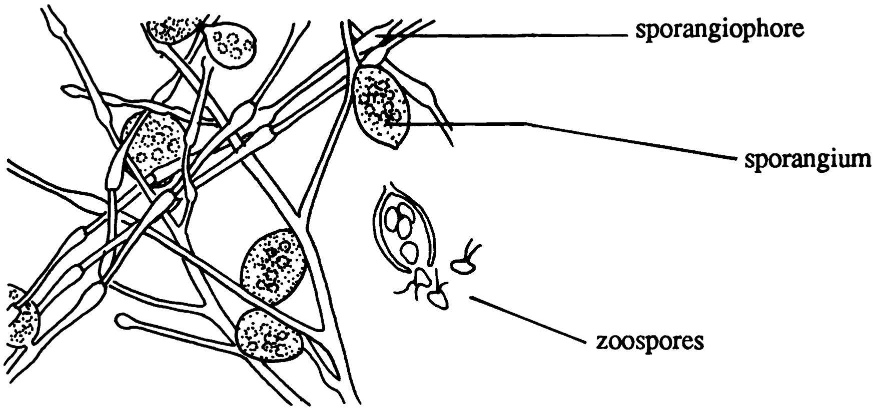
The characteristics of the Oomycetes (**oon** = egg, **mykes** = fungus) are as follows: the mycelium is filamentous and branching without divisions, growing abundantly on the substrate; they produce sporangia and flagellate spores.

Most species are aquatic, parasitizing algae, animals and other aquatic life forms. Some species have evolved to be able to parasitize higher plants. They use the wind to disperse spores and sporangia.

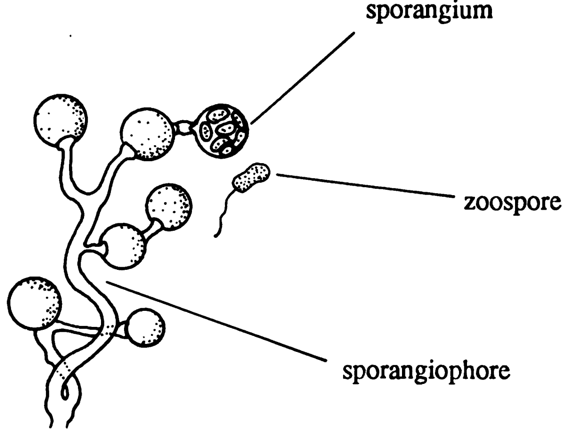
The characteristic structures of this class are the sporangiophore and sporangium (Fig. 14). These are used to identify specimens to genus level.

These fungi reproduce sexually by means of heterogametangia: the antheridium (which acts as the male gametangium or donor) and the oogonium (the female gametangium or receptor). These unite to form an oospore, which is the sexual spore. This is thick-walled and can survive in the soil or in plant remains while conditions are unfavorable. Asexual reproduction is carried out by sporangia. These may germinate directly, putting out a germ tube, or indirectly by the liberation of zoospores. Indirect germination needs temperatures below 12°C and enough free water to surround the sporangium (Fig. 15).

Of the Oomycetes, the most important genera are ***Phytophthora*** and ***Pythium***, both of which cause root rot in seed beds and nurseries.



Phytophthora spp.



Pythium spp.

Figure 14. Reproductive organs in two genera of the class Oomycetes.

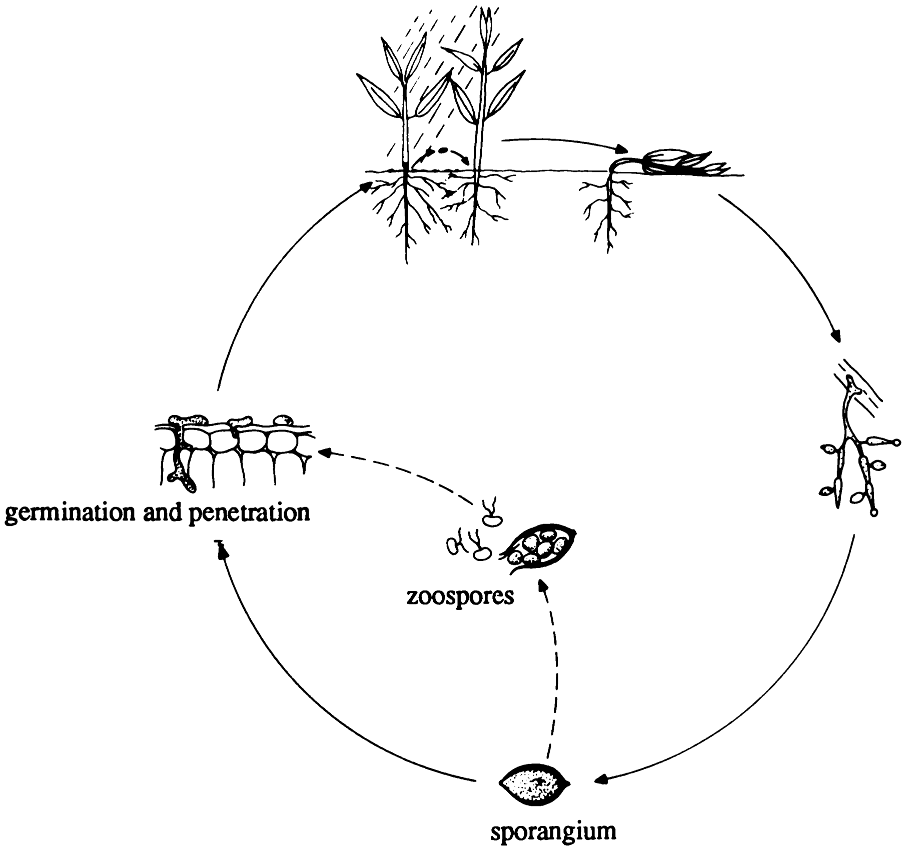


Figure 15. Asexual life cycle of ***Phytophthora*** spp.

b) Class Zygomycetes

The Zygomycetes (zygos = joining or pairing) are a natural group of fungi whose main characteristic is the production of a sexual spore called the zygospore. This is thick walled and develops inside the zygosporangium, which is formed from the union of different mycelia. Asexual reproduction takes place through sporangiospores.

Within this group there are different levels of biological relationships such as facultative saprophytes and weak plant parasites.

From the phytopathological point of view, the genera ***Rhizopus*** and ***Mucor*** are among the most important. In the field of forestry, these fungi cause decomposition of poorly stored seed. They also may be found masking germination trials. They completely cover the seeds with a greyish mycelium and many sporangia.

The life cycle of ***Rhizopus*** sp. shows sexual and asexual phases (Fig.16). The sexual cycle starts with the union of two compatible hyphae which form a fusion septum. This enlarges and gives rise to the zygosporangium and the zygospore, which is the sexual spore. This has a thick wall, allowing it to survive from one season to the next in plant residues or decomposing plant material. Asexual reproduction starts with the rupture of the sporangium and the release of spores. These are dispersed by the wind and germinate to repeat the cycle.

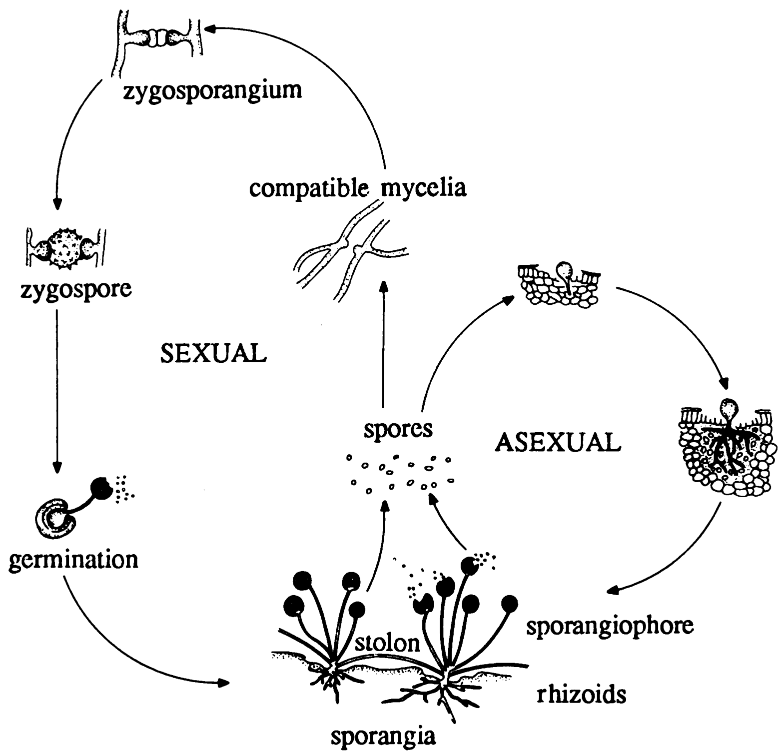


Figure 16. Life cycle of ***Rhizopus*** sp.

c) Class Ascomycetes

Beginning with the Ascomycetes (**askos** = bags), the structure of the fungi increases in complexity giving rise to a large and varied group known as the higher fungi. The Ascomycetes include saprophytic or parasitic species occupying aquatic or terrestrial habitats.

This class is characterized by the production of eight sexual spores known as ascospores. These are produced in asci which form inside specialized fruiting bodies called ascocarps.

The mycelium is made up of well developed, partitioned hyphae which may be thick or thin and branching. There are two types of reproduction: sexual or perfect phase and asexual or imperfect phase.

In relation to its life cycle, sexual reproduction is more important since it produces asci and ascospores. Two gametangia, the antheridium and the ascogonium, containing one or several nuclei, unite to form a fruiting body with a large number of tiny sacs. These contain the ascospores that are characteristic of this class.

These fruiting bodies or ascocarps are the basic structures for Ascomycetes identification. The most common forms (Fig. 17) are: a) cleistothecium, completely closed; b) perithecium, pear-shaped with a small opening at the top and c) apothecium, cup-shaped and open. There are other variations such as those which lack specialized ascocarps, the asci being produced in the internal openings of ascostromata. Others produce them freely on the epidermis of the host.

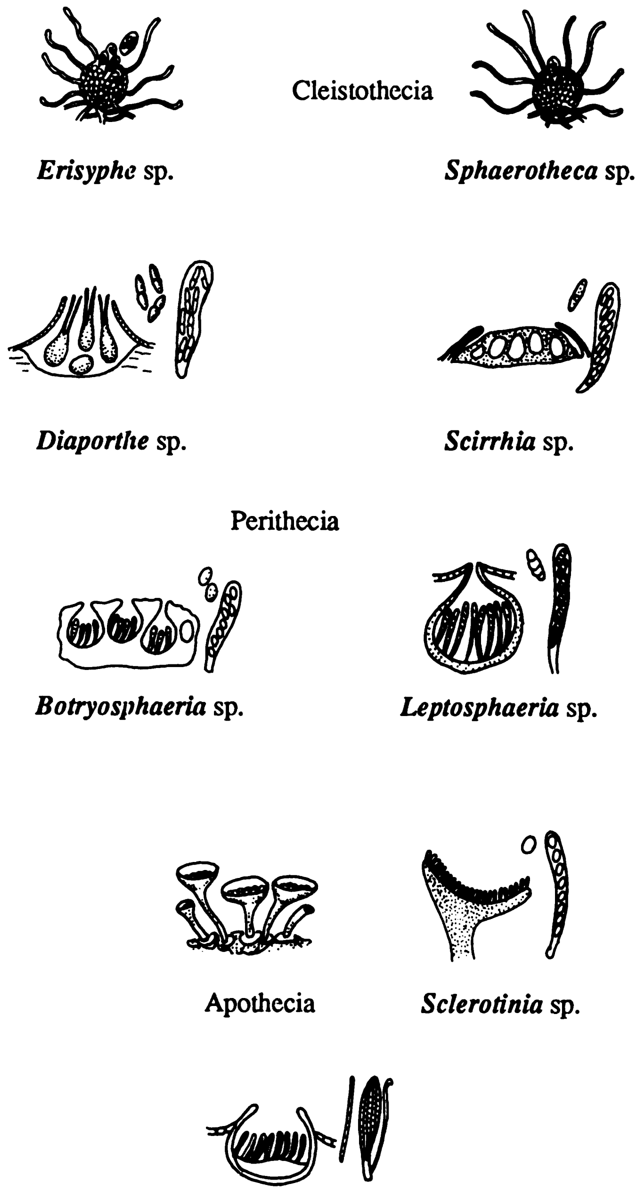


Figure 17. Types of fruiting bodies in Ascomycetes class.

d) Class Basidiomycetes

The Basidiomycetes (**basidium** = small base) vary from the microscopic rusts and smuts to the large "parasols" of the mushrooms and toadstools. They include saprophytes with a wide range of hosts and highly specific, obligate parasites, which can affect nursery plants, destroy foliage and degrade wood. Some Basidiomycetes are important pathogens of shade trees and species of forestry interest.

These fungi are characterized by the production of a round basidium which carries four sexual spores called basidiospores. The mycelium is made up of filamentous hyphae. The Basidiomycetes are generally considered the most highly evolved of the fungi due to their macroscopic fruiting bodies and the specificity exhibited by the rusts.

The three orders of greatest phytopathological interest which will be considered here are the Agaricales, Aphyllophorales and Uredinales.

Order Agaricales. This is a large group including the mushrooms and toadstools. They have fleshy, sometimes leathery fruiting bodies containing basidiospores.

These fungi have a wide geographic distribution and distinctive characteristics. Many are soil-dwelling saprophytes that live on decomposing organic matter, but can also destroy roots and wood. Others are commercially exploited as food while quite a few are poisonous or hallucinogenic.

Mycorrhizae also belong to this group. These are symbiotic relationships between the hyphae of certain fungi and plant roots. Both organisms benefit from the association. The fungus improves its host's absorption of minerals, protects it from root pathogens and provides growth hormones. The fungus receives carbohydrates and other growth factors. Micorrhizae may be endo- or ectomycorrhizae depending on their location in or on the host roots.

Sexual reproduction is more complex in this class than those previously mentioned. Most species exhibit sexual organs on separate thalli. Two compatible nuclei unite by hyphal fusion and move to the edge of the basidium. Here they form the papillae which, after absorbing the nuclei, become the four basidiospores typical of the class. The basidiospores are located between the gills of the basidiocarp.

The fruiting body or basidiocarp, when mature, consists of the cap (pileus), scales, gills (lamellae), ring (annulus), stalk or stipe and the cup (volva) (Fig. 18).

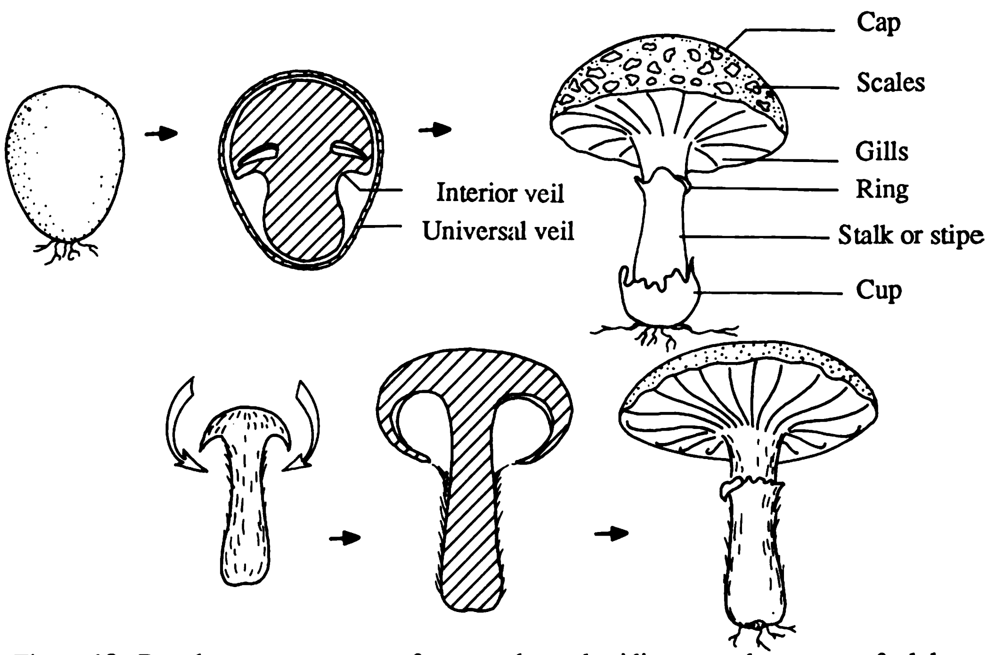


Figure 18. Development sequence of a parasol type basidiocarp and structure of adult.

Order Aphyllophorales. This order was originally classified as the Polyporales. Members of the order produce different types of basidiocarps, the most common being the bracket fungi found on dead or dying trees. These are hard, often leathery or corky and occur in many colors, shapes and sizes. The fruiting bodies are compact mycelial masses with thousands of pores containing the basidia and the basidiospores (Fig. 19).

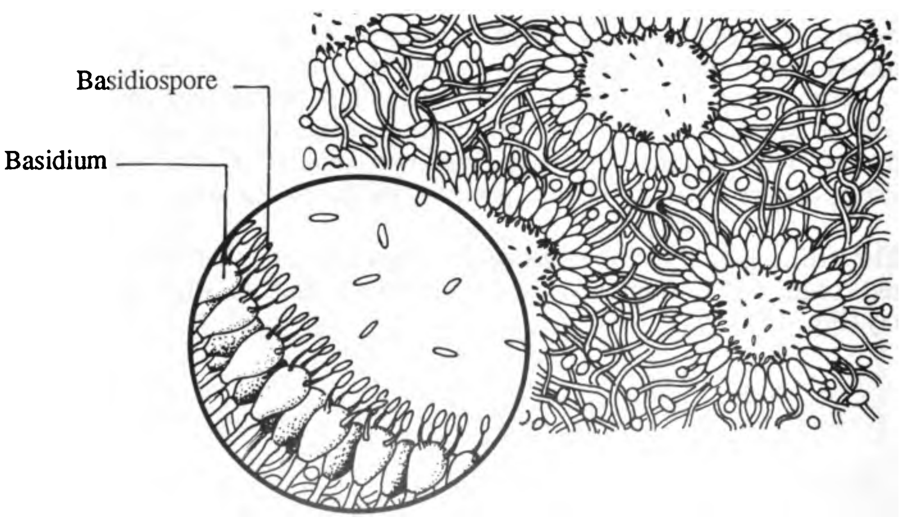


Figure 19. Transverse section of bracket fungus basidiocarp.

This order includes soil organisms and wood pathogens. Some are parasites of shade trees and cause rotting of the roots and pith. However, most are saprophytes which have an important function in degrading wood and plant residues.

Order Uredinales. This order includes the rusts. There are about 4,000 species of rusts which cause considerable losses both to food crops and forestry species. They attack leaves, stems, flower parts and fruits. The affected organs show pimples or powdery spots in colors varying from white to brick red. In some cases they produce galls on the affected tissue. They are highly specialized fungi only attacking the host specific to the genus. They are also obligate parasites.

Their life cycle is complex and includes five states, each of which produces a different kind of spore. Not all species pass through all five states, some only go through two or three. Those that complete the full cycle need two hosts: the main host and an alternative host. The main host may not always be a tree of economic interest, sometimes it is the alternative host. Similarly there may be occasions when both hosts are of interest to man.

The five states in the life cycle of rusts are:

State 0: Spermacia and receptive hyphae found in a structure called a pycnium (spermogonium).

State I: Aecium. Produced on the underside of the leaf.

State II: Uredium. Produces uredospores. This state can reinfect the main host and is most important for spreading the disease (Fig. 20).

State III: Telium. Produces teliospores, which are thick-walled and used for classification

State IV: Basidium. The characteristic state of the class which produces basidiospores.

Rusts completing all states in their life cycles are called macrocyclic, those omitting state II are demicyclic and those missing states I and II are microcyclic.

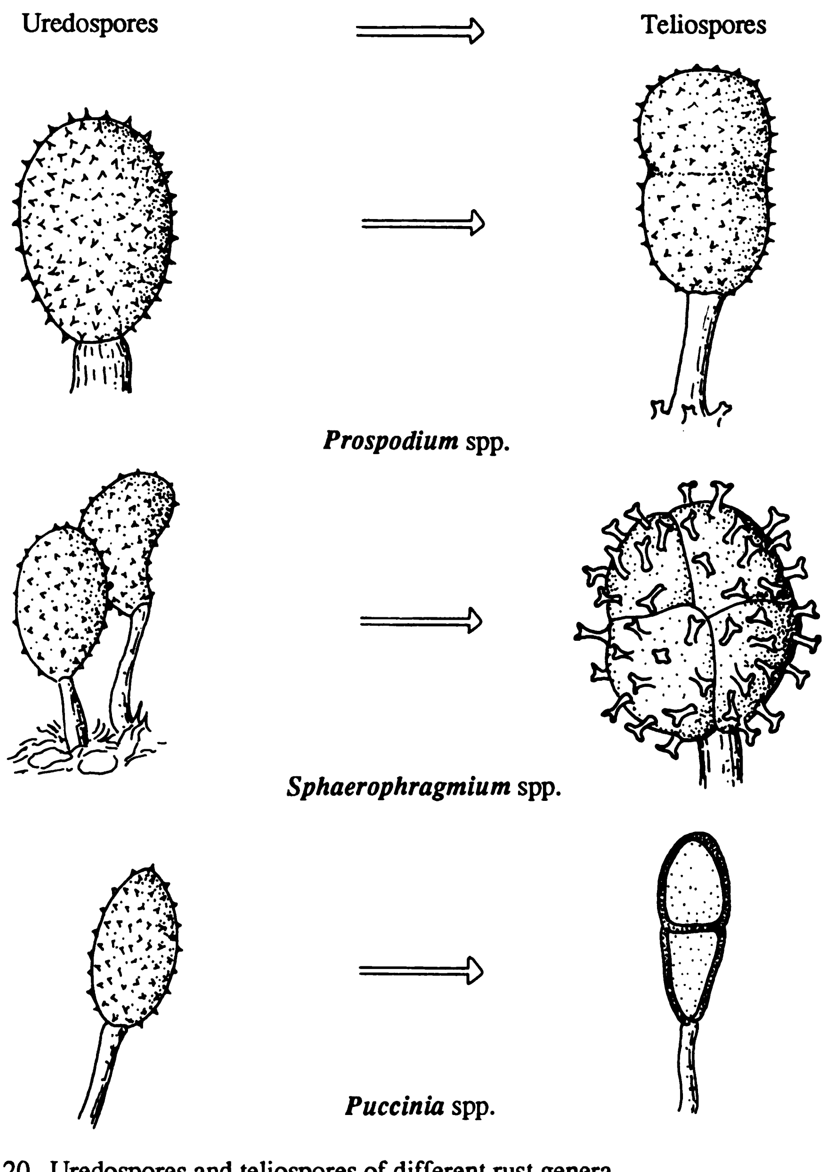


Figure 20. Uredospores and teliospores of different rust genera.

e) Class Deuteromycetes

This class comprises some 15,000 species which reproduce asexually. Sexual reproduction has either never been seen, has never existed in this class or has been lost through evolution. For this reason they are known as the "Fungi Imperfecti".

On occasions, a sexual stage has been found for some genera (either under laboratory conditions or in the field). In the majority of cases this sexual stage has corresponded to the class Ascomycetes or, very rarely, to the Basidiomycetes.

These fungi have septate mycelia and produce asexual spores called conidia. These are formed at the apical or lateral extreme of the sporogenic cell located in the conidiophore. Both the conidia and conidiophore vary greatly in size, shape, color, degree of branching and mode of production. For this reason they are used for identifying genera of Deuteromycetes (Fig. 21).

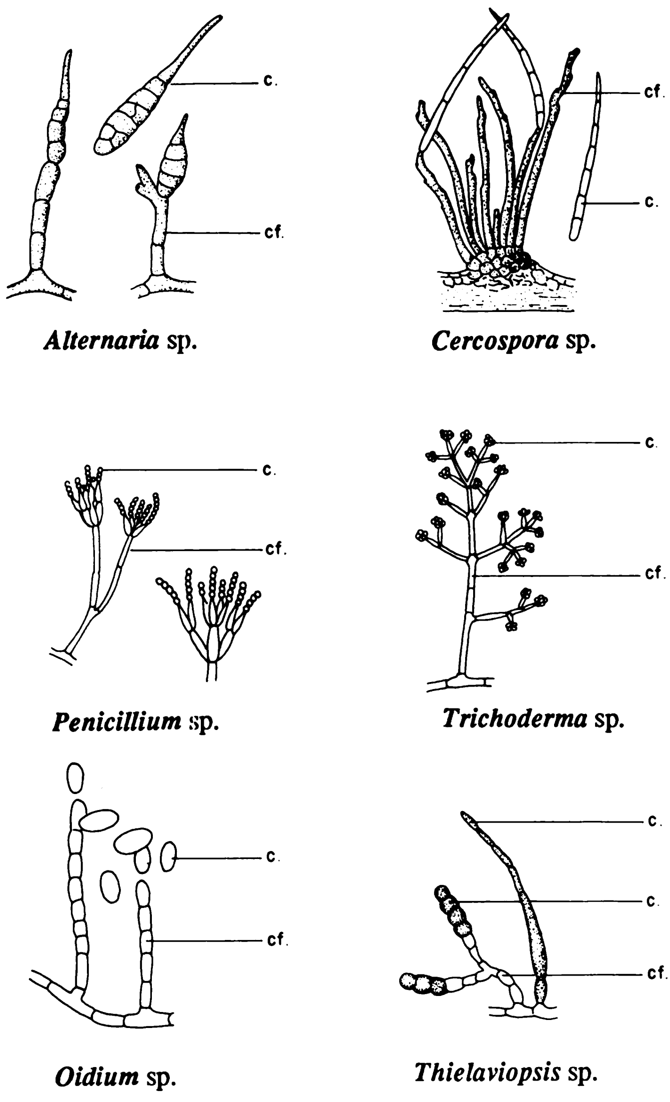


Figure 21. Conidia (c.) and conidiophores (cf.) of Deuteromycetes.

The majority of Deuteromycetes are terrestrial although a few are aquatic. They may be saprophytes or parasites of plants, animals or humans. They multiply through mycelial fragments and conidia.

There are four orders in the class:

Order Melanconiales. This order is characterized by the production of conidia in acervuli. These are ball-shaped structures located under the cuticle or epidermis of the host. They rupture when the conidia are mature (Fig. 22).

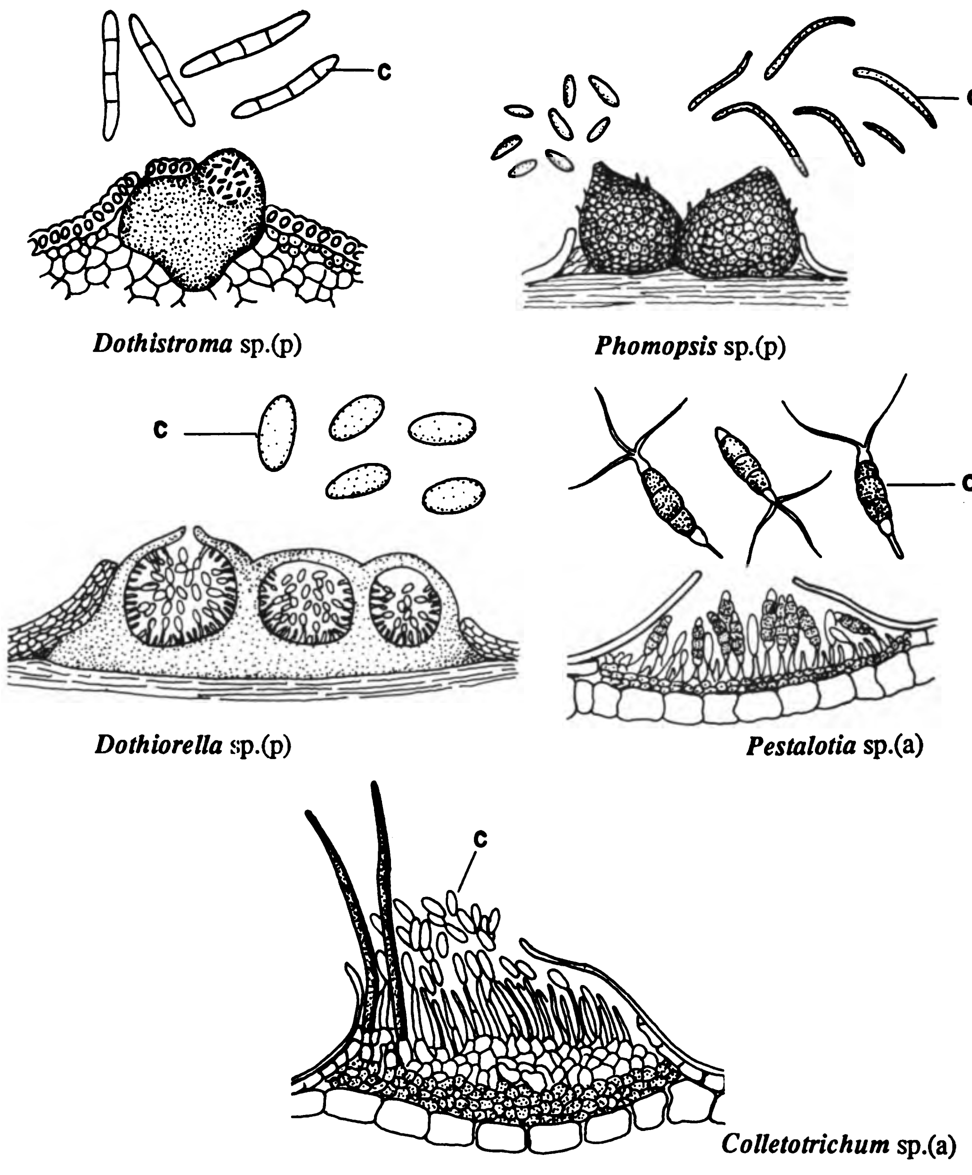


Figure 22. Pycnidia (p), conidia (c) and acervuli (a).

The most common genus is ***Colletotrichum*** which causes a complex of symptoms known as anthracnose. Twenty species and innumerable physiological races have been identified. The sexual phase corresponds to ***Glomerella cingulata***.

Order Sphaeropsidales. The conidia develop in pycnidia which are the distinctive structures of this order and differ from genus to genus (Fig. 22). They may be superficial or embedded in the host tissue, pale or dark, round, elongated or cup-shaped, produced singly or in groups.

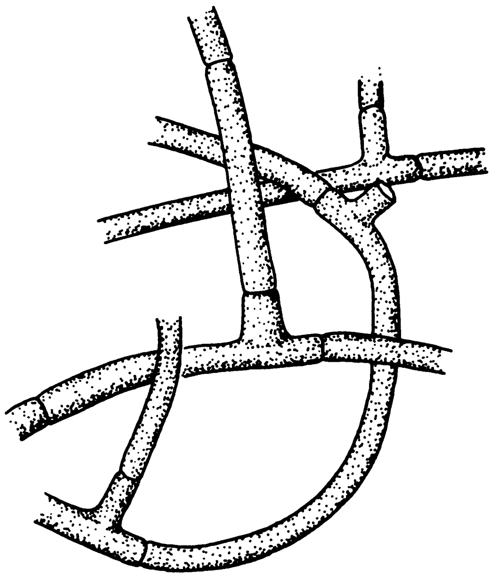
Order Moniliales. This is the largest order containing some 7,000 species which include saprophytes, laboratory contaminants, plant and human pathogens and fungi of industrial interest. Conidia are produced on free conidiophores which do not have a fruiting body. They are produced directly onto the substrate and emerge to be spread by the wind.

The conidiophores vary in shape and can be simple, branching, unicellular or multicellular. The conidia may be produced at the apex or laterally, singly or in groups and may be uni- or multicellular (Figs. 21 and 22).

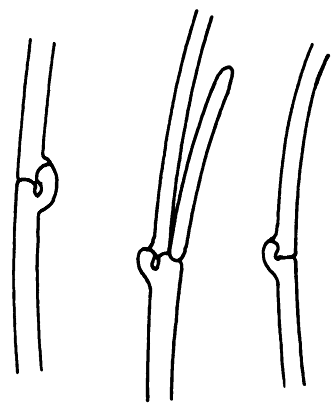
The majority of pathogens in this order attack foliage and other aerial plant parts. Some affect seed viability during storage and a few are root pathogens in nurseries.

Order Agonomycetales. This order was formerly known as the Mycelia Sterilia. It only includes two genera of phytopathogenic interest: ***Rhizoctonia*** and ***Sclerotium***. These are typical soil-dwelling pathogens and do not produce spores. Reproduction occurs through fragmentation of the mycelium. They survive in plant residues or in seeds as mycelia or sclerotia.

Rhizoctonia sp. produces microsclerotia whilst ***Sclerotium*** sp. produces larger sclerotia about the size of a pin head. Both are brown. Identification is based on the shape of the mycelia. ***Rhizoctonia*** sp. branches at right angles, has septa equidistant from the branching point and constriction of the cell wall where septa occur. In ***Sclerotium*** sp. there are small bulges in the mycelium where the septa occur (Fig. 23).



Rhizoctonia sp.



Sclerotium sp.

Figure 23. Characteristics of mycelia in ***Rhizoctonia*** sp. and ***Sclerotium*** sp.

4. BACTERIA

A. GENERAL CHARACTERISTICS

Forest diseases caused by bacteria are far fewer in number than those caused by fungi. However bacterial diseases can produce epiphytes of economic importance.

There are about 1,600 known species of bacteria of which about 200 are phytopathogenic. Apart from their direct effects, bacteria are important for their secondary effects. For example, there is evidence that bacteria may have a significant role in pith death and the staining and degradation of wood. They may interact with other pathogens to form complexes and synergisms. This can be positive, as in the case of bacteria isolated from elm trees which, ***in vitro***, inhibited the growth of ***Ceratocystis ulmi***.

Most bacteria are strictly saprophytic and as such participate in fermentation and degradation which may benefit man. Furthermore they can be isolated and cultivated in the laboratory on artificial medium.

B. MORPHOLOGY

They are simple, unicellular, flagellate microorganisms without a nucleus. The genetic material is found in a circular chromosome. There is an internal cell membrane, a rigid cell wall which gives the bacterium its oval shape and a mucilaginous outer coat. There are no vacuoles or cytoplasmic streaming.

Bacterial cells exhibit varying shapes: round, elliptical, spiral or rod-shaped. Most phytopathogenic bacteria are rod-shaped or bacilli (Fig. 24).

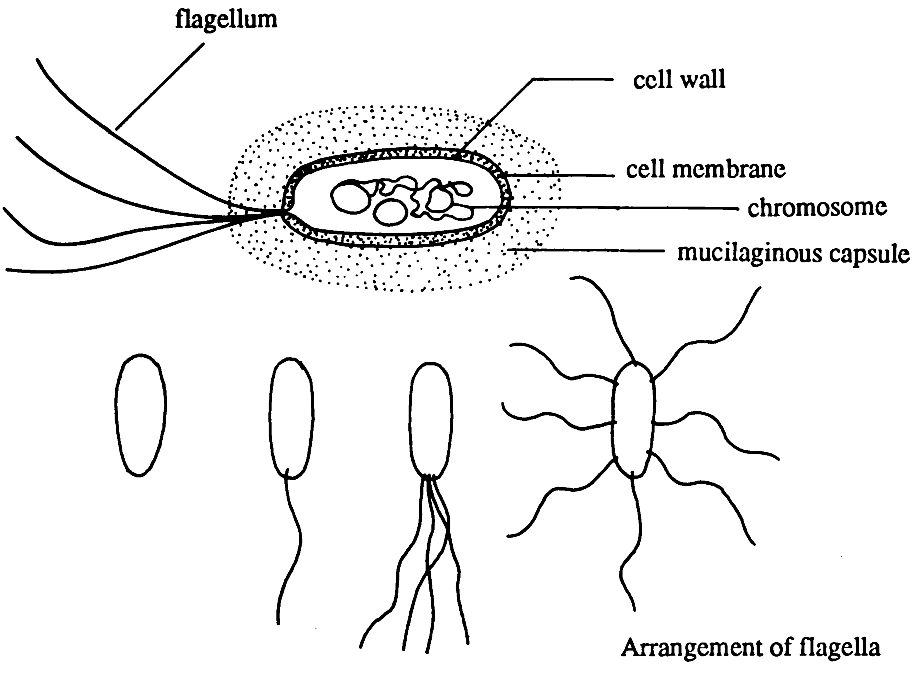


Figure 24. Diagram of bacillus type bacterium and variations in the number and arrangement of the flagella.

C. REPRODUCTION

Phytopathogenic bacteria reproduce asexually by means of binary fission. An invagination occurs in the plasma membrane and the cell divides transversely into two identical cells. This is a relatively rapid process so that large populations of bacteria can be produced in just a few hours. Under natural conditions, there are checks to growth such as lack of nutrients or the accumulation of metabolic wastes and toxins which retard or inhibit reproduction.

In its strictest sense, sexual reproduction does not take place. However new genotypes do appear through a process of recombination of genetic material. Sections of chromosome from one cell are incorporated into the chromosome of another. This gives rise to cells that are genetically different and capable of surviving in adverse conditions.

D. HABITAT

Most phytopathogenic bacteria develop preferentially as plant parasites and partially as saprophytes. No matter what environment they inhabit, they always require free water or damp conditions to multiply.

Humidity is the main factor affecting the development of bacteria. They need free water to move within the host or in the soil, using their flagella to `swim' from place to place. Rainwater is essential for spreading the pathogen from host to host. Splashes produced by the raindrops help to carry the bacteria for short distances.

Other edaphic factors affect bacteria. In general, low pH inhibits development and sandy soils, which do not retain sufficient moisture, limit the establishment of bacterial colonies. Also, soil microfauna compete constantly with bacteria.

E. DISPERSAL AND SURVIVAL

Bacteria are spread mainly by water, insects, tools, soil movement, animals and man. Raindrop splashes and run off can spread bacteria horizontally from plant to plant or vertically from the soil to aerial parts. Insects are efficient vectors since they land on infected tissue, bacteria stick to their bodies and then they move to another plant they spread the inoculum. Where the insect pierces the plant, the effect is even greater since the bacteria are introduced directly into the tissues. Tools can spread disease when they are used for pruning. Soil can spread bacteria in the clods that stick to farm machinery and tools. Over large distances, man is instrumental in the transport of soil or bags from nurseries.

Bacteria use several forms of survival. Some survive in intimate association with the host, others in different locations, some without a host. Some survive in soil or in decomposing organic matter. Whatever the survival site, it is of special importance since it represents the source of inoculum for infecting new hosts.

The following is a description of some of the more common ways of survival.

Seeds: About 50 species of bacteria are transmitted by seeds. This is a very efficient medium since they may be stored under conditions which do not affect bacterial viability and may then be transported large distances by man.

Soil: It is generally assumed that bacteria which attack foliage are poorly adapted to survival in the soil. However, decomposing residues of affected plants provide an excellent survival medium and several studies indicate that leaf pathogens can be isolated from post-harvest plant remains or the rhizosphere.

Latency in tissues: This method is infrequent and only demonstrated in the case of ***Erwinia amylovora***, which is found in apparently healthy shoots and stems.

Epiphytes: Epiphytic or resident bacteria are those which are capable of living and multiplying on the surface of plants, whether these are susceptible or not.

5. NEMATODES

A. GENERAL CHARACTERISTICS

The study of phytoparasitic nematodes started with researchers interested in saprophytic soil organisms. It is now known that there are almost 200 species which are plant parasites.

Nematodes are invertebrate unsegmented worms exhibiting bilateral symmetry and found in soils with a high moisture content.

The body is semitransparent and covered with a hyaline cuticle which is normally striated. They measure 0.5 to 2.0 mm in length. They are cylindrical with pointed ends. The digestive system is a tube running from end to end and divided into buccal cavity, esophagus, intestine and anus. The genitals of the male open into the anus whilst those of the female (the vulva) are found at a point between the middle and posterior end. The basic characteristic of nematodes is the possession of a stylet. This is a lancet- shaped structure used to pierce tissues and extract nutrients. In general, the males and females are similar except that the males are slightly smaller and sometimes have a bursa or expansion of the cuticle covering part of the reproductive organs (Fig. 25). In some genera (such as ***Meloidogyne*** spp. and ***Heterodera*** spp.) there is sexual dimorphism.

B. HABITAT

Nematodes which parasitize plants are inhabitants of damp soils and can maintain themselves feeding on roots. Very few live in the aerial tissues of the plant. Temperature, humidity and aeration all affect their survival. The greatest concentration of individuals is found in the first 15 cm of soil, associated with plant roots (rhizosphere).

The optimum temperature for nematodes is between 15 and 30° C. Temperatures below 10 or above 35°C are lethal for them. Soil temperature in forested areas does not seem to be a limiting factor since temperature fluctuations are less, compared to agricultural soils which are sometimes ploughed and bare.

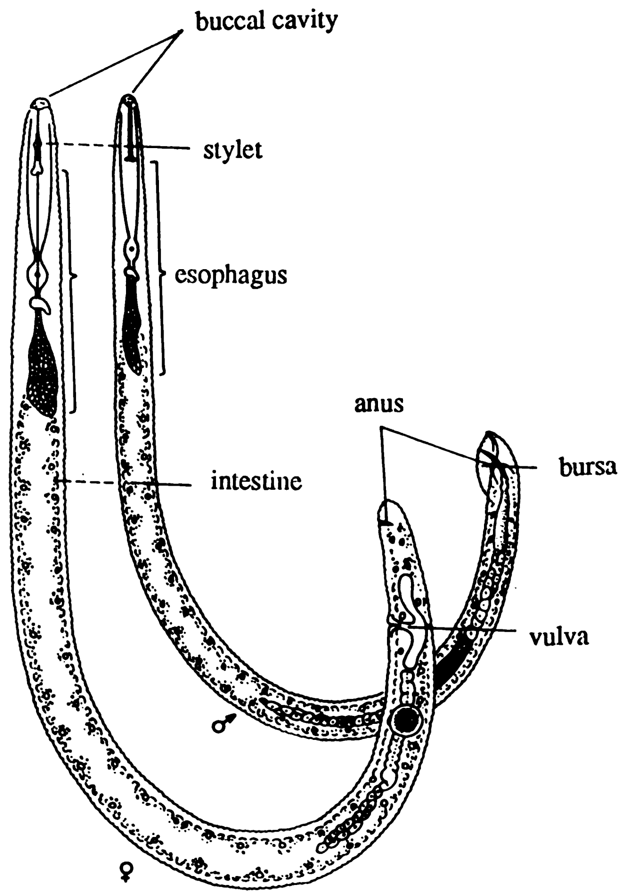


Figure 25. Male and female nematodes.

Nematodes need water for nearly all their activities and they are nearly always restricted to habitats with a saturated atmosphere. Each species has an optimum humidity for survival but it is possible that movement is easier where the soil is covered with a film of water. These conditions are found at levels slightly below the field capacity.

Soil aeration varies in each soil type and greatly influences nematode movement. Sandy soils have reduced aeration and here the organism's activity is reduced.

The biological condition of the soil is also fundamental for the nematodes. Alterations in the rhizosphere, especially those caused by organic and inorganic exudates, favor the accumulation of microorganisms including nematodes. This produces an environment of intense competition, association and antagonism. Root exudates have been shown to stimulate the eclosion of some nematode eggs as well as attract juveniles.

C. PARASITISM

Nematodes are classified by feeding habit, movement and the type of damage caused. Nematodes feeding on the root surface behave like ectoparasites, while those entering the root tissue are endoparasites. Nematodes which stay in the area of the infection site are called sedentary whilst those that move inwards or to other roots are called migratory (Fig.26).

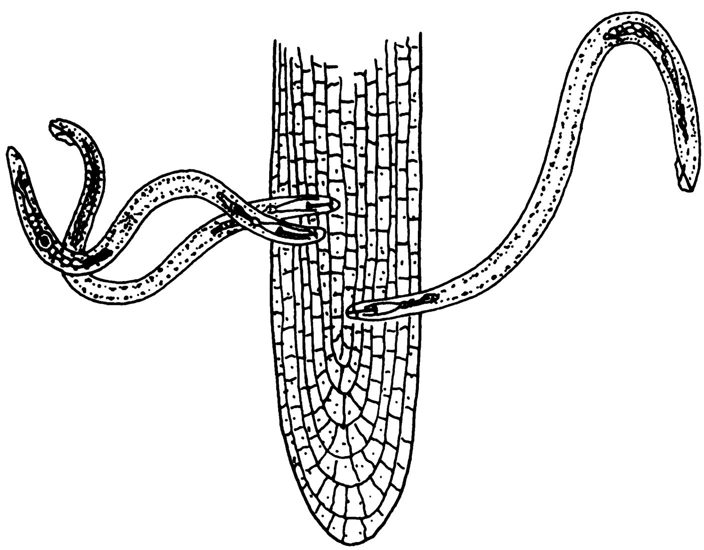


Figure 26. Longitudinal section of root attacked by nematodes.

Phytoparasitic nematodes repeatedly pierce the root with the stylet in search of water and nutrients. Although the activity of one nematode is insignificant to the root system of a tree, there may be thousands or even millions of these tiny organisms feeding in this way and causing damage to the roots and rootlets.

Nematode attack causes wounds and absorption difficulties. The liberation of toxins may induce gall formation and even the death of the plant. The root system of the attacked individual has a spongy appearance and fails to develop, affecting the entire growth of the plant.

The importance of nematodes is not limited to the mechanical damage to the roots. This damage predisposes the plant to infection by soil-dwelling fungi and bacteria. It has also been shown that nematodes carry viruses in the buccal cavity and can transmit these.

D. LIFE CYCLE

Phytoparasitic nematodes have a relatively short life cycle which is completed in 26 weeks. The female lays eggs covered in a cuticle containing tiny nematodes which can move after a few days. As the nematode grows it molts and changes its cuticle several times. The juveniles can feed as soon as they can move but are not sexually mature until after the fourth molt.

E. DISPERSAL AND SURVIVAL

Although able to move, nematodes move relatively little, perhaps no more than a meter a year. If the soil pores are covered with a film of water they move faster than when they are saturated. The most efficient means of movement over large distances is as a soil contaminant transported on tools, machinery and bags from nurseries. At the local level, dispersal occurs through irrigation, drainage, the movement of people and animals or high winds carrying dust.

Once installed in the soil the nematodes can survive in the roots of the host. In the absence of a host they can survive in weeds or shrubs.

6. VIRUSES

A. GENERAL CHARACTERISTICS

Because of their submicroscopic size, the characterization of viruses has been subject to great variation in the light of findings from the most recent research.

One definition of a virus is that of a particle in which a group of nucleic acids is covered with a protein coat. This particle can only multiply within the living cell of a host, using its metabolic system. That is to say that viruses are submicroscopic particles made up of nucleic acid and protein, which behave like obligate parasites and are unable to multiply except through the metabolic processes of the susceptible cell.

B. MORPHOLOGY

Although viruses have many shapes and sizes, the majority have been described as elongate, spherical or bacillus shaped.

The elongate forms are rigid or flexible filaments depending on size. Those between 400 and 1,300 nanometers long are flexible whilst those smaller are rigid (Fig. 27). The nucleic acid inside forms a spiral covered by protein subunits.

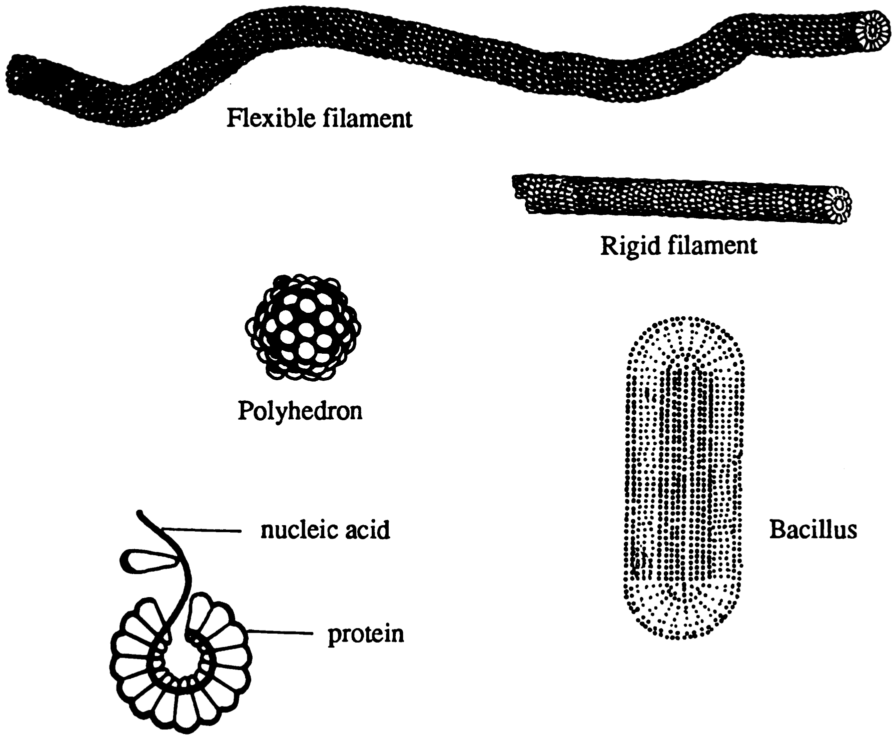


Figure 27. Phytopathogenic viral particles and their components.

C. TRANSMISSION

As an obligate parasite, the virus can spend a long time inside its host without causing its death. However, like any other parasite, to survive it must spread to new hosts.

Under natural conditions, viruses are transmitted mainly by insects, but they can also be transmitted through foliage contact between plants, through seeds, cuttings, mites, directly through the soil or through nematodes or fungi.

Of the main insect vectors, aphids (Aphididae), leaf hoppers (Cicadellidae), whiteflies (Aleyrodidae), scale insects (Coccidae) and some mites are most important. Aphids are some of the commonest insects and also the most efficient virus transmitters since they constantly visit plants sucking the sap.

Viruses transmitted by insects are divided into two groups according to how long the vector stays virulent without having to feed from another diseased plant. These two groups are the **persistent** and **non-persistent,** also known as those carried in the stylet and those which circulate, respectively.

Non-persistent viruses, which are carried in the stylet, cause mosaic viruses in plants. The aphid acquires the virus from infected plants when it makes rapid probes into the tissue with its stylet (generally less than 30 seconds) to determine the availability of nutrients. An important aspect of this mechanism is that transmission must be immediate since the virus particle in the stylet quickly loses activity. Prolonged acquisition times also have a negative effect on transmission efficiency.

Persistent or circulating viruses have been found in aphids, leafhoppers, whiteflies, chrysomelids and thrips. The insect vector acquires the virus as it feeds for periods of at least between 10 and 60 minutes. After the acquisition period there is an incubation period of at least 12 hours. This is essential for the insect to become virulent. Another group of persistent viruses, called the propagative viruses, are mainly transmitted by leaf hoppers and, to a lesser extent, aphids. These viruses circulate and are able to multiply in the body of the vector. In some cases, virulent leaf hoppers which have not fed from infected plants may be found, and it is thought that they have acquired the virus from their parents.

D. FOREST VIROSIS

There are few cases of viral diseases in forest plantations in the Tropics. This is an area of study which needs more attention from specialists in order to determine the presence of causal agents in plantations. It is very possible that being perennial species in which the virus multiplies slowly, many viroses have gone unnoticed or been masked by host tolerance.

7. PARASITIC PLANTS

All of the parasitic plants, known as "mistletoes", belong to the family Loranthaceae. Although capable of photosynthesis to produce carbohydrates using the chlorophyll in their leaves and stems, they also take minerals and water from the tree which they parasitize. They have haustoria instead of roots. These are root-like and penetrate the bark of the branches and trunk in search of the transport tissue where they absorb nutrients and water.

There are many effects produced by parasitic plants. They stimulate the production of adventitious buds, giving rise to the growths known as "witches' broom". This condition reduces the growth and vigor of the tree and makes it prone to insect or pathogen attack. Also, in the parts where the mistletoe implants, there is often deformation or bulging and the wood turns spongy and abnormally grained, making it unusable. Trees often suffer breaks at these points. In seedlings and saplings, and even in mature trees, parasitic plants can even cause death.

There are two types of parasitic plant: the dwarf and the leafy or true mistletoes.

All the dwarf mistletoes (Fig. 28) belong to the genus ***Arceuthobium*** and are specific to conifers. Their stems are from 1.5 to 10 cm long, yellow, olive green or greenish brown colored with scale-like leaves of the same color. The stems are disperse or in branchlets and the sexes are separate. Male flowers die after flowering and female flowers die after seed dispersal.

The fruits are oval shaped berries containing sticky seeds. These disperse by themselves either by pressure or explosion and can spread up to 15 m. They stick easily to whatever surface they land on. The seed produces a germinal tube which, when it reaches a shoot or leaf base, produces a haustorium. This penetrates the vascular tissue where it forms longitudinal filaments to assist in absorption.

The true mistletoes (Fig. 29) belong to several genera, such as ***Phoradendron***, ***Struthanthus***, ***Psittacanthus***, ***Oryctanthus***, ***Phthirusa***, ***Antidaphne***, ***Cladocolea***, ***Gaiadendron*** and ***Dendrophthora***. With the exception of a few species in the latter genus, they have long, thick stems, well developed leaves and can form easily recognized masses. The fruits are berries which contain sticky seeds. These are ingested and dispersed intact by birds. The sticky mucilage coat allows them to stick on any surface. Attack symptoms are similar to those of dwarf mistletoe, but the effect on the host is generally less severe.

Figure 28. ***Arceuthobium vaginatum.***

Figure 29. ***Struthanthus quercicola.***

8. ABIOTIC FACTORS

The effect of the interaction of chemical and physical soil factors along with climatic or environmental factors on tree growth is extremely complicated, so that it is difficult to describe the effect of one isolated factor and ignore the influence of others.

While the soil and environment are fundamental for plant growth, certain extreme conditions can often adversely affect the tree's development. For example, clay soils impede deep root growth, excess water limits the oxygenation of the root system, frosts destroy foliage, nutritional deficiencies reduce growth, etc. These factors can cause diseases and are known as abiotic factors or causes.

This subject is included in the Handbook not only because these factors are important in themselves but also because any change of abiotic origin can induce symptoms which can be confused with those of biotic origin. Furthermore, certain adverse abiotic factors can predispose the tree to insect or pathogen attack.

A. MINERAL NUTRITION IMBALANCE

The soil should provide the plant with adequate supplies of nutritional elements, mainly nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). In natural forests nutritional deficiencies are rare since the species have evolved adapted to the sites which provide them with the necessary nutrients. However in plantations with exotic species or those not in their optimum site, nutritional deficiency symptoms are often seen. The causes and consequences of these deficiencies are very varied. They may be due to the interaction of several climatic and/or edaphic factors and produce chlorosis, dwarfism, deformation or darkening of the foliage. The mineral requirements of different forestry species may vary so that it would be inadvisable to establish diagnoses for them all. Furthermore, there is little information available to date on mineral deficiencies and forest soils. Generally speaking, deficiency symptoms are more visible and more easily corrected in young plants than in adult trees.

The methods most used for verifying nutritional deficiencies are visual diagnosis, leaf analysis and the use of plants in pots of soil lacking one specific element. The latter is done to induce deficiency symptoms and make comparisons.

Although generalizations are impossible, some deficiency symptoms are described here. Nitrogen is an element that is essential for plant development and its deficiency produces chlorosis in the foliage of the lower part of the plant. Phosphorus deficiency induces a purple or violet coloration in the leaves. Potassium deficiency has been very little studied, but seems to be related to desiccation of the leaf margins. Lack of calcium causes deformations in young leaves and deficiencies in magnesium, a constituent of chlorophyll, causes intervenal chlorosis in leaves.

Nutritional deficiencies also predispose the tree to attack by weak pathogens. This is the case with ***Pestalotia*** sp. infection in cypress. The infection is intimately associated with boron deficiency.

B. SOIL HUMIDITY IMBALANCE

Water is an essential component which plays a part in the processes of absorption, translocation and growth. Lack of water can result in damage, sometimes irreversible, such as wilting, chlorosis, damage to leaf margins and apices and partial or total plant death.

The nature and physical characteristics of the soil influence the degree of drought. Water deficiency is more common in sandy soils and stony areas which retain little moisture. In sandy and rocky areas, isolated dead trees or groups can be seen during severe droughts. These trees may be surrounded by others that are still green because their root system is in deeper soil.

Excess water can produce similar damage. Saturated soils inhibit root development due to lack of oxygen. Thus certain forest species which normally grow on waterlogged soils are less drought-resistant since their roots do not have the capacity to absorb enough water during periods of low rainfall.

Damage caused by drought or flood varies according to tree species, age, location and origin. There is very little information on the resistance of forest species to these conditions mainly due to the fact that it depends on many external factors and because the effects are not immediate. One thing that is certain is that the more developed the root system, the better the tree tolerates drought. For this reason young trees or those in nurseries suffer more from insufficient watering since their root system is poorly developed and shallow. As trees grow, so does their drought tolerance, especially when they grow in dense clumps. Here only the trees at the margins are directly exposed to the action of hot, drying winds and greater evaporation from the soil.

In mature plantations there is almost nothing that can be done to minimize the damage caused by drought. Far better to choose both the site and the species to be planted with greater care beforehand.

Symptoms produced by drought are often similar to those of flooding. In cypress, for example, drought causes dwarfism, yellowing and a reddish tone in the foliage (Fig. 30) whilst excess water causes chlorosis in the lower third or even death of the tree which subsequently re-sprouts from the base (Fig. 31).

Figure 30. *Casuarina equisetifolia* affected by drought.

Figure 31. Drainage problems in ***Pinus*** sp.

In eucalypts, the exudation of gum (which later crystalizes and darkens the trunk) along with damage to the leaf margins and young buds is due to water imbalance affecting the plant.

C. SOIL ACIDITY OR ALKALINITY

Excessively high or low levels of soil salts can result in pH changes which can lead to deficiency or mineral toxicity. Depending on the characteristics of the soil and the plant involved, the absence of one nutrient can affect the capacity to absorb another or others. The opposite can also happen, that is to say that one element may be present at such high levels that, when absorbed by the plant, it causes direct toxicity or impedes the absorption of sufficient quantities of another element.

D. SOIL AERATION

This factor is strongly related to that discussed in section B. Oxygen is essential for the root system and the rest of the plant. The optimum level is similar to that found in the atmosphere (approximately 20%).

Soils which are heavy, clay type, compacted or saturated through poor drainage or excessive rainfall, reduce the gaseous exchange with the atmosphere and hence the oxygen content. Under these conditions, there is reduced root growth and micorrhizal development and so less absorption.

E. EXTREME TEMPERATURES

Generally speaking, plants show optimum development between 15 and 30°C. Temperatures above or below this range are damaging, especially for young tissues.

Damage from high temperature is less frequent than from low temperature, but the former destroys organs more quickly. Apparently, high temperatures damage tissues by inactivating or accelerating certain enzymic mechanisms resulting in abnormal biochemical reactions and cell death. In ***Bombacopsis quinatum***, for example, the plant responds to high temperature by exhibiting damage to the base of the stem. This appears as ringing or strangulation which sometimes halves the normal stem diameter. ***Bombacopsis quinatum*** has proven to be a species that is very susceptible to high temperatures. It is common to find up to 30% of trees with this ringing in nurseries exposed to high temperatures (Fig. 32).

Figure 32. ***Bombacopsis quinatum*** ringing.

Low temperatures or frosts produce a different type of damage. Generally speaking, species native to temperate zones are better able to resist low temperature than those originating in the Tropics because they have a dormant period. The type of damage produced depends on the age of the plant, its adaptation characteristics and the nature of the soil. During frosts, the roots which are found in the upper layer of the soil do not absorb water so that there is no replacement of water lost through transpiration. Furthermore, water in the cells crystalizes and breaks the cell wall. In conifer nurseries, it is common to find plants with reddish foliage which recovers with a slight rise in temperature. In trees, this coloration may affect all the foliage or just the top one or two thirds, the bottom third remaining green. Sometimes this damage favors the attack of weak pathogens (Fig. 33).

Figure 33. Cypress affected by frost and smut attack.

F. WIND

Strong winds can break branches and trunks, cause permanent leaning in trees or uproot them. Wind action on trees is complex and unpredictable since it involves a variable force which acts on asymmetric and irregularly flexible structures anchored in soils with differing characteristics. It is thought that breaks start in areas of the trunk where the wood is compressed rather than in places where the tissues have been reinforced by the effects of the wind. Winds that uproot trees are generally strong and blow from different directions. Damage is more severe in clearings or at the edge of a plantation. Forest species most susceptible to toppling or leaning are those with slender trunks and a broad crown.

G. AIR POLLUTION

The effects of pollutants in the air have been known for some time but they have only recently been given the attention they deserve. Perhaps this is because of the increasing number of industries growing up around cities and causing toxicity in ornamental plants through their wastes.

Although there is little information regarding forest species, the damage caused to eucalypts by the gaseous eliminations of nearby charcoal works is well known. Furthermore, an increase in air pollution has been observed resulting from the emission of gases, particles, ash or vapor from volcanic activity. Sulfur, nitrogen, chlorine and fluorine in the atmosphere react to form acid compounds which are subsequently deposited on plants by the wind or rainfall. Under normal conditions, rain has a pH of about 5.6 but this drops when there is atmospheric pollution. The compounds deposited on plant foliage are toxic and produce symptoms of burning. It has been observed that the presence of chlorine and sulfur compounds in water disturbs the vegetation and that the alteration in microclimate and pollution of soils and water sources causes a growing simplification of forest ecosystems.

DAMAGE TO PLANT PARTS AND ITS CONSEQUENCES

CHAPTER II

DAMAGE TO PLANT PARTS

Practically all parts of the tree (Fig. 34) can be damaged by the harmful agents mentioned in the previous chapter, whether they be organisms specialized in attacking one particular structure or more generalized agents affecting several parts.

On occasion there may be a combined effect of several adverse factors. For example, a deficiency in the planting site may make the tree more susceptible to attack by a certain pathogen which, in its turn, creates favorable conditions for opportunistic insects such as termites or bark beetles. For this reason, it is essential to find the real cause of the problem so as to target control measures adequately.

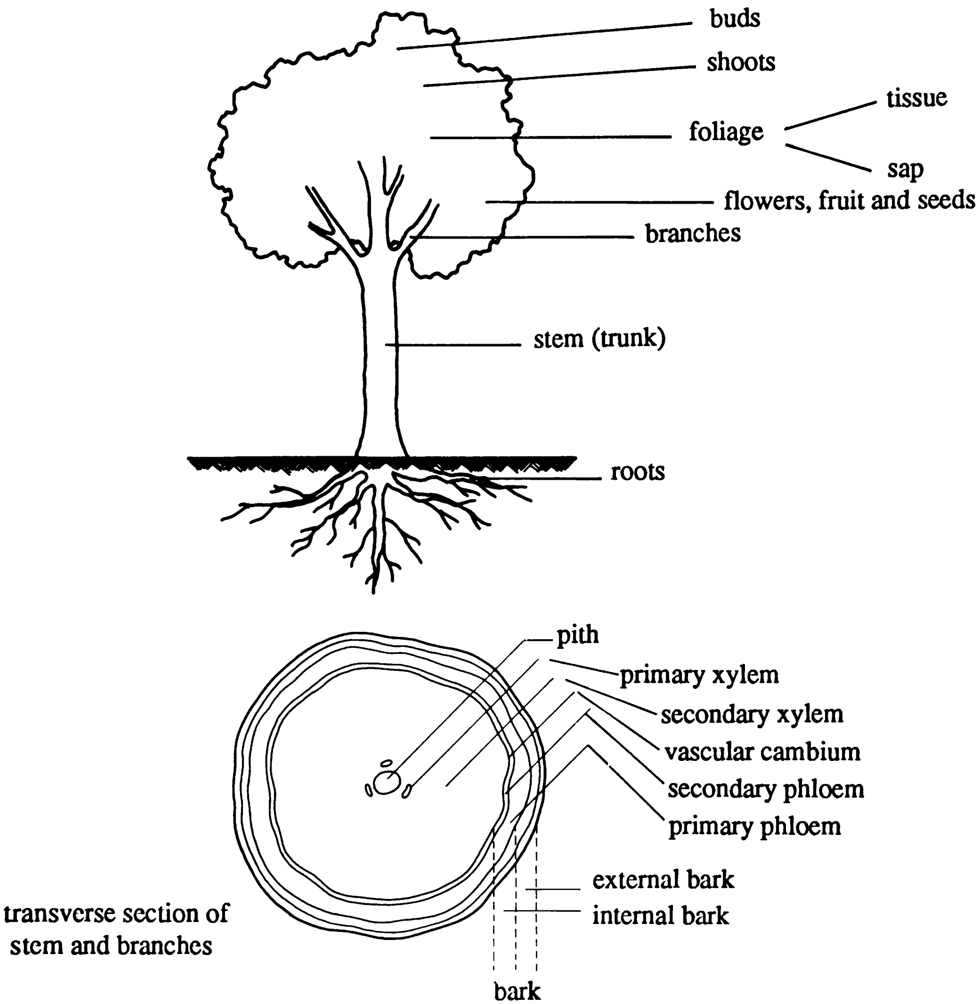


Figure 34. Tree parts and transverse section of stem and branches.

1. DAMAGE CAUSED BY ANIMALS

A. REPRODUCTIVE STRUCTURES

The reproductive structures of the tree (flowers, fruits, cones and seeds) may be attacked by insects, mites, mollusks and vertebrates.

Some animals, such as bugs, homopterans and bees, may completely destroy the flowers and so prevent seed production. One example of this is the damage caused by a cercopid in ***Gliricidia sepium*** (Fig. 35). Fruits of some species, such as ***Gmelina arborea***, are eaten by parakeets. Seeds may be seriously damaged by insect larvae which destroy the internal tissue (endosperm and embryo), impeding germination or establishment (Fig. 36). Notable examples of these are the seed beetles (Bruchidae) and snout beetles (Curculionidae). Some caterpillars of the family Pyralidae, such as ***Dioryctria*** spp., attack the cones of conifers and ***Hypsipyla*** spp. attack the seeds of the Meliaceae. ***Rhyacionia frustrana***, of the Tortricidae family, attacks pine cones.

In nurseries, ants, birds and rats can all eat seeds that have been sown.

Figure 35. Cercopidae damage to ***Gliricidia sepium*** flowers.

Figure 36. Seed boring larva on ***Caesalpinia velutina*** seed.

B. ROOTS

Root-feeding insects are very important in nurseries and newly established plantations. Here the plants have poorly developed root systems and can die as a result of the attack.

These insects, of which the white grubs (***Phyllophaga*** spp.) predominate, consume not only secondary roots, but also the bark of the main root, impeding the flow of water and nutrients. The seedlings or saplings consequently turn yellow, lose their leaves and die (Figs. 37 and 38).

In new plantations, pocket gophers (***Orthogeomys*** spp.) can cause damage similar to that described above by gnawing tree roots (Fig. 39).

Figure 38. ***Phyllophaga*** sp. damage in cypress nursery.

Figure 39. ***Orthogeomys heterodus*** damage in avocado.

Figure 37. ***Phyllophaga*** sp. damage in cypress root.

C. SEEDLINGS AND STUMPS

Seedlings may die because their roots are cut or because they are totally destroyed. Stumps are normally killed by ants (Fig. 40) or rabbits removing the bark or by armadillos (***Dasypus novemcinctus***), ctenosaurs (***Ctenosaura similis***) or Jesus Christ lizards (***Basiliscus basiliscus***) which pull them up.

Although seedlings may be lost through the action of vertebrate animals such as rabbits, ctenosaurs, lizards, peccaries (***Tayassu tajacu***), hispid cotton rats (***Sigmodon hispidus***) or deer (***Odocoileus virginianus***) it is more often due to insects or mollusks.

In the nursery, slugs may completely consume seedlings in germination or seedling beds. Of the insects, the cricket ***Acheta assimilis*** cuts plant stems and feeds on the leaves and roots. The cutworms of the family Noctuidae (***Agrotis*** spp. and ***Spodoptera*** spp.) normally cut the stems at soil level or a little higher and feed on the foliage of the cut seedling (Fig. 41). The stingless bee ***Trigona silvestriana*** cuts the seedlings of several species of ***Pinus***.

Figure 40. Ant damage on ***Gmelina arborea*** stump.

Figure 41. Cutworm damage in ***Bombacopsis quinatum***.

D. BUDS AND SHOOTS

These constitute the active growing points of the tree or meristems. They may be attacked by lepidopteran and dipteran larvae or by bees. Although the damage rarely kills the tree, it gives rise to deformations and forking which may reduce the commercial value of the wood. In young trees it may cause serious growth retardation and repeated attacks can cause death by using up the sapling's reserves and so its ability to recover.

In tropical countries of the American continent, the most serious pest in this group is ***Hypsipyla grandella***, which attacks 16 species of Meliaceae. These include trees with woods of considerable commercial value such as ***Swietenia mahagoni*** (mahogany) and ***Cedrela*** spp. (cedars). Another important pest is ***Rhyacionia frustrana*** which attacks several species of ***Pinus*** (Fig. 42). The stingless bee ***Trigona corvina*** cuts the terminal bud of ***Eucalyptus deglupta*** causing the stem to fork.

Figure 42. Response of ***Pinus*** sp. to ***R. frustrana*** attack.

E. FOLIAGE

Animals which attack the foliage of seedlings, stumps and trees may affect them in many ways, but the end result is nearly always the same since it reduces the plant's photosynthetic capacity and causes changes in transpiration and the translocation of nutrients. This can lead to retarded growth which is undesirable not only from the commercial point of view but also as it means the plant is less able to compete with weeds. Defoliating insects rarely cause the death of the plant, except when it is very young and lacks the reserves to recover.

Since there is a wide range of habits among the defoliating insects, some will be described below.

a) Exposed chewing animals

These animals feed on the foliage without entering it. They may stay hidden in some form of refuge or be protected by structures stuck to the body. They may affect the foliage in three different ways.

The first type of damage, caused by slugs, grasshoppers, crickets, bees, and leaf cutting ants (***Atta*** spp.), is easily recognized (Fig. 43) since they cut relatively large pieces from the leaves. In the second type, the insect only feeds on the lamina leaving the veins intact. These are often called skeletonizing insects (Fig. 44). Lastly, there are insects such as thrips (Fig. 45) and most mites, which scrape the leaves to obtain sap. In these cases, the leaves become deformed, shrivel and fall.

Figure 43. ***Atta*** sp. damage on ***Gmelina arborea.***

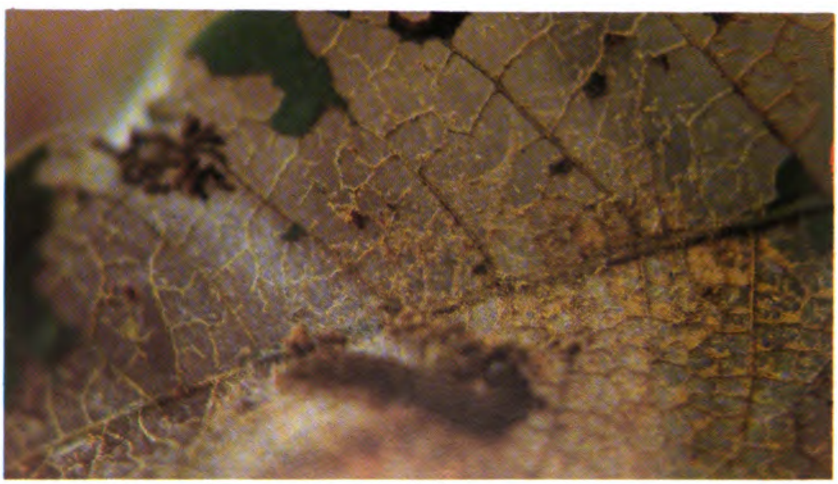


Figure 44. Skeletonizing larva on ***Quercus*** sp.

Figure 45. Thrips attack on ***Eucalyptus*** sp.

b) Leaf miners

These are chewing insects which enter and feed on the internal tissue such as the parenchyma of the leaf. The damage can be seen as transparent blisters or tunnels, sometimes serpentine in shape, when the leaf is held to the light (Fig. 46). Where the damage is severe, the leaf may distort and fall from the tree. Species of the dipteran family Agromyzidae are exclusively leaf miners as are some species of beetles, lepidopterans and wasps. The lepidopteran ***Phyllocnistis meliacella*** attacks several species of Meliaceae.

Figure 46. Leaf miner attack.

c) Gall formers

These organisms cause the plant to produce galls, which are protuberances or tumors of variable appearance (Fig. 47), inside which the immature forms develop. These structures may appear in any part of the plant, but their presence is most important on the foliage. If there is severe gall damage to the leaves, they twist and fall. Gall formers belong to one family of mites (Eriophyidae) and a few insect families such as Cecidomyiidae (gall midges), Cynipidae (gall wasps), Tenthredinidae (sawflies) and Psyllidae (jumping plantlice).

Figure 47. Galls on ***Cordia alliodora.***

d) Sucking insects

These insects have the piercing-sucking type of mouthparts which allow them to suck the sap from plant tissues. They can affect the foliage, such as ***Dictyla monotropidia*** on ***Cordia alliodora*** (Fig. 48), or the stems and young branches, such as the nymphs of some Psyllidae (Fig. 49) and some Cercopidae.

The leaves turn yellow or chlorotic and fall. This can lead directly to the death of the tree or weaken it and leave it susceptible to attack by disease or opportunistic insects. Some sucking insects transmit viruses by introducing their stylets into infected plants and then into healthy ones.

Figure 48. ***D. monotropidia*** damage in ***Cordia alliodora.***

Figure 49. ***Mastigimas*** sp. attack on ***Cedrela odorata.***

F. TRUNK AND BRANCHES

The trunk and branches consist of several different regions such as the bark, phloem, xylem or wood and the pith (Fig. 49). Each type of tissue is attacked and damaged by specific insects.

a) Phloem borers

These borers not only attack the phloem zone but also the region of soft xylem tissue adjacent to the vascular cambium. Severe attack by insects that build continuous galleries through the entire perimeter of the trunk (Fig. 50) interrupts the flow of sap from the leaves to the lower parts and the roots die. Lack

Figure 50. ***Scolytodes alni*** damage in ***Alnus acuminata.***

of water absorption causes the leaves to yellow and fall and the tree eventually dies. In some cases this damage does not kill the tree but reduces the photosynthetic capacity and hence its growth in length and breadth.

The bark beetles belong to the family Scolytidae. Several species of the genera ***Dendroctonus***, ***Ips*** and ***Scolytodes*** are important pests in Central America.

b) Xylem borers

The secondary xylem consists of tissue which is no longer functional metabolically (except for a small part transporting water and elements), but which gives the tree support. The xylem forms the wood of the tree and is the part used commercially. Because of this, pests attacking this region are considered the most serious from the economic point of view. Important pests include members of the coleopteran families Cerambycidae and Buprestidae.

Some species bore horizontal and vertical galleries in the wood (Fig. 51) which reduce its commercial value. Furthermore, the trunk or branch may break at the point of attack (Fig. 52).

Other species damage the outer part of the wood (Fig. 53) creating weak points which subsequently break. When breaks occur in the trunk, the regrowth produces a fork.

Figure 51. Buprestidae damage in ***Bombacopsis quinatum***.

Figure 52. ***Plagiohammus spinipennis*** damage in ***Tectona grandis.***

Figure 53. ***Steirastoma histrionicum*** damage in ***Bombacopsis quinatum.***

c) Xylem and pith borers

These insects cause less damage to the xylem, only using it as a route to the pith or heart of the tree. However, when pest populations are high, there can be serious economic consequences from the intensity of attack. Also, as the tree grows broader some tunnels fail to reach the pith and, for all practical purposes, the insect can be considered a xylem borer. One example of this is ***Aepytus*** sp. in ***Gmelina arborea*** (Fig. 54).

Some termites can attack the xylem and pith at the base of the tree, but these have usually been attacked previously by fungi which predispose the tree to insect attack.

Figure 54. ***Aepytus*** sp. damage in ***Gmelina arborea.***

d) Vectors

These are beetles of the families Platypodidae and Scolytidae which bore tunnels in the xylem and deposit the spores of fungi to feed the larvae. The larvae do not actually feed on the wood, but the fungus degrades it and reduces its commercial value (Fig. 55). In some instances, spores are deposited in the phloem and the fungal growth can eventually block the flow of sap, resulting in root death, leaf loss and death of the tree.

e) Bark-chewing animals

Some adult beetles of the family Cerambycidae can affect the bark at certain points (Fig. 56), by chewing and removing it from the stem or branches and leaving an exposed area in the shape of an hourglass or ring (Fig 57). In the latter example, the female lays eggs in the upper part of the strip so that when the stem or branch dries out and falls, the larvae feed on the dry wood.

Figure 55. Platypodidae damage in *Casuarina equisetifolia*.

Figure 56. Adult ***Steirastoma*** sp. damage in ***Bombacopsis quinatum***.

In other cases, such as the stingless bees (***Trigona*** spp.), the insects perforate the bark (Fig. 58) or use already existing wounds to collect resin. These perforations can act as an entry point for some pathogens.

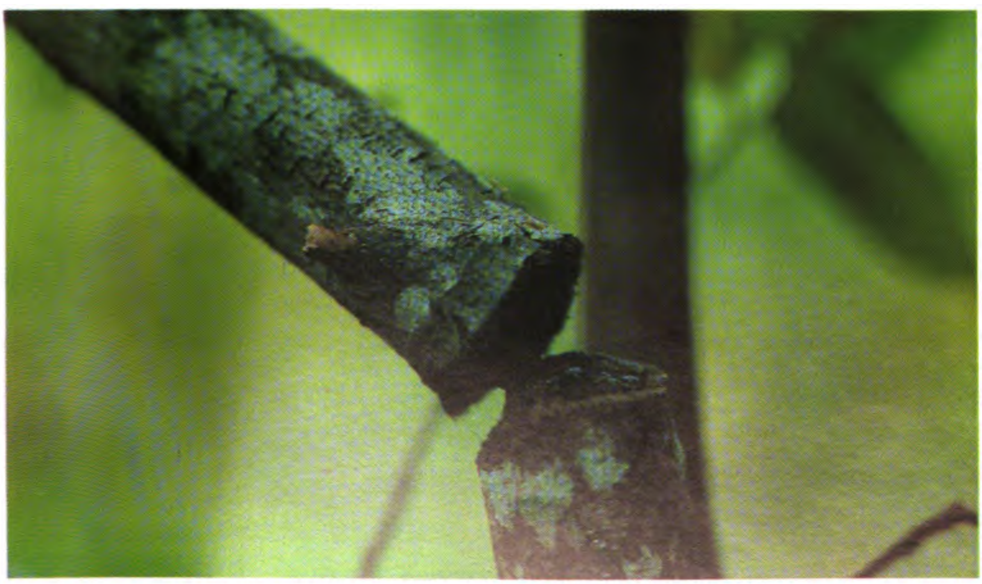


Figure 57. ***Leptostylus*** sp. damage in ***Guazuma ulmifolia***.

Figure 58. ***T. silvestriana*** damage in ***Acacia mangium***.

The bark can also be gnawed by vertebrates such as rats (Fig. 59), squirrels (Fig. 60), porcupines and rabbits. These wounds in the trunk or branches can result in breaks or the entry of pathogens.

Figure 59. ***Sigmodon hispidus*** damage in ***Tectona grandis***.

Figure 60. ***Sciurus*** sp. damage in ***Eucalyptus*** sp.

f) Damage by oviposition

Cicadas can lay such a large number of eggs that in thin branches and stems (Fig. 61) a physical obstruction to the movement of water can arise. The affected part becomes desiccated and growth of the tree can be limited.

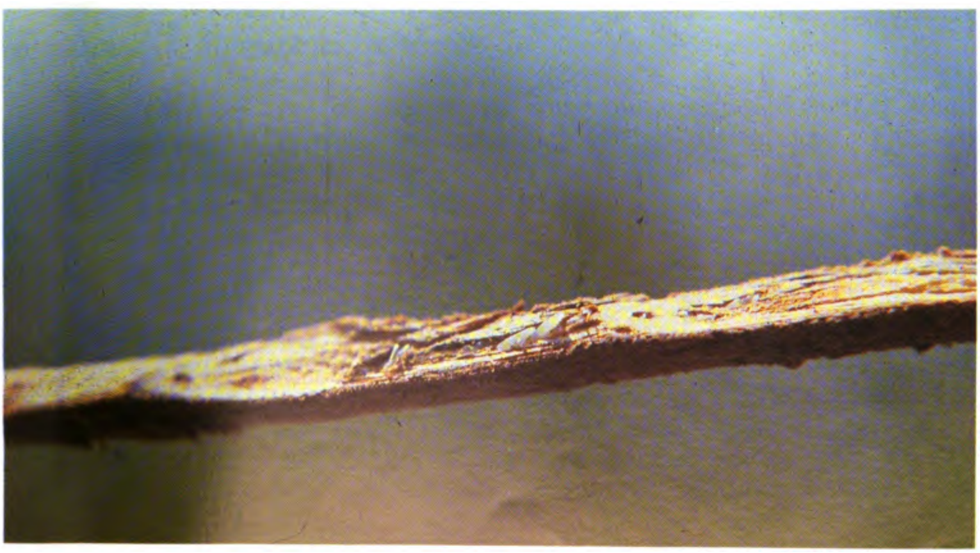


Figure 61. Cicada eggs in ***Psidium guajava*** (guava).

g) Timber borers

Unlike the previous groups, which all attack living wood, some insects feed on dead wood and timber, either as logs or planks or when it has been made up into furniture, building materials, etc. These include beetles of the families Bostrichidae, Lyctidae, Anobiidae, Buprestidae and Cerambycidae and the termites ***Cryptotermes brevis*** and ***Coptotermes testaceus***. All these are important pests since they destroy wood products with a high aggregate value, especially in the case of furniture and buildings etc.

2. DAMAGE CAUSED BY PATHOGENS

A. ALTERATIONS TO PLANT PROCESSES

Vigorous development and productivity in any plant species depends on the availability of soil water and nutrients and a combination of environmental conditions that are favorable to the plant according to its genetic potential, growth habits, adaptation and nutritional requirements.

Like any living organism, the plant carries out complex, synchronised physiological processes which form a mechanism for producing a healthy individual. The main plant processes, in ascending order, are: absorption and translocation of water and minerals; photosynthesis; transportation of photosynthetic products; reproduction and survival. Any alteration in these processes upsets the internal equilibrium and can result in tissue or organ loss or even the death of the plant (Fig. 62).

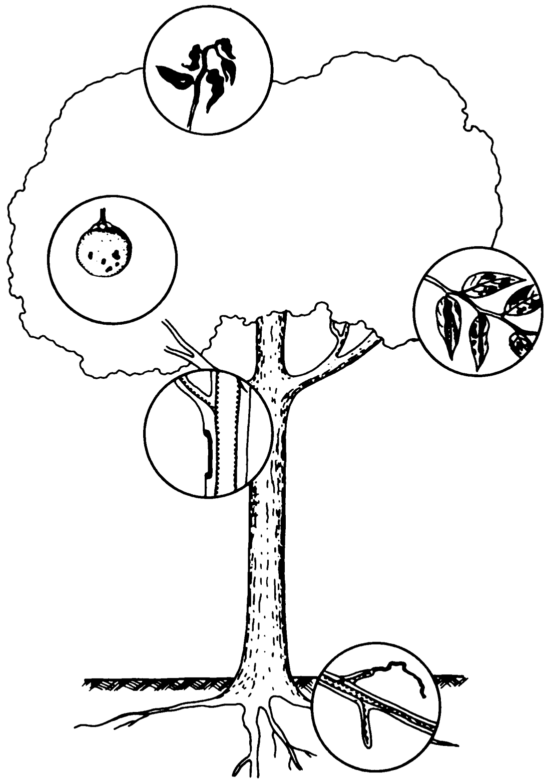


Figure 62. Parts of the tree which may be attacked by pathogens.

a) Absorption of water and nutrients

The roots are one of the organs most susceptible to fungal attack which can produce changes in water and nutrient absorption. The root surface is in permanent contact with pathogenic or saprophytic soil microörganisms. As the plant maintains continuous growth of the lateral roots, with new epidermis and bark, there is a constant advance into new areas of the soil mass.

Pathogens causing root rot are characterized by the liberation of enzymes which cause tissue degradation through disintegration of the cell wall and membrane and death of the protoplast. The enzyme action is so fast that the fungus can penetrate and colonize before the plant's defense mechanism comes into action. Since root tissue is growing tissue, it is immature and most susceptible to attack. Disintegration of the root tissue reduces the absorption capacity of the plant and, in many cases, leads to wilting and nutritional deficiencies. Plant death may result from the transportation of toxins from the diseased tissue or through nutritional imbalance caused by the breakdown of the selective absorption system.

b) Transport of water and nutrients

Alterations to the process of water and nutrient transport from root to crown can also have serious consequences for the tree's development.

After being absorbed by the roots, water and minerals are transported via the xylem to the leaves. Here they are used for the synthesis of substances that are sent to other organs via the phloem. Interruption of the ascending flow by a pathogen can cause a disease condition in the parts or organs where the minerals are required. These are then unable to carry out their own functions or the functions required by the plant. For example, if water is not available for the leaves, these cannot function properly, photosynthesis is reduced and many of the compounds generated fail to reach the roots. The plant is then under stress and may die.

Certain fungi and bacteria which invade the vascular system can affect water and mineral transport. Those affecting upward (xylem) transport include ***Fusarium*** sp., ***Verticillium*** sp. and ***Pseudomonas*** sp.

Generally speaking, the effects on the plant are the symptoms of wilting, nutritional deficiency or poor storage of products synthesized by the plant.

c) Photosynthesis

This process is vital to the plant. It consists of using light energy for the synthesis of organic compounds for use in cellular metabolism. In other words, through photosynthesis, the plant produces the food for its growth and reproduction.

Pathogens affecting photosynthesis do so by the destruction of leaf tissue, either by necrosis or defoliation, induction of deformation or dwarfism or by growing on the leaf surface and physically blocking the source of light. Photosynthesis reduction, especially in foliar disease, is proportional to the area of tissue affected.

Reduction in photosynthesis may be caused by the destruction or death of the active photosynthetic layer, as is the case in leaf spot, blights and other diseases where there is leaf tissue damage. It can also be caused by destruction of the chlorophyll, as in chlorosis or necrosis.

In the case of diseases which induce wilting, the stomata (respiratory pores) close and restrict gaseous exchange, so reducing photosynthesis.

The release of toxins by chlorophyll degrading pathogens has the same effect.

d) Reproduction

Any pathogen which interferes with the reproductive process is, by implication, affecting the survival of the species. The development of the ecological community through succession depends on, amongst other things, the efficiency of dispersal of seeds to new sites.

Reproductive damage can be seen from the stage of pollen production to fruit and seed formation.

Viruses sometimes produce male sterility in self-pollinating plants by inhibiting pollen formation. Pathogens can also reduce pollen vigor causing a deficiency in pollination. Occasionally, virus damage occurs at a later stage, for example during ovule or ovary formation.

More noticeable is the total destruction of the flower by fungal or bacterial attack. ***Botrytis cinerea*** is the most common fungus to damage flowers, along with ***Erwinia amylovora***.

One of the commonest ways in which the reproductive process is affected is by fungal or bacterial attack on seeds. Forest species seed pathology is a poorly studied area, which may have great importance. The microbial population that adheres to the seed integument is very variable. Some organisms are weak parasites which merely use the seed as a vehicle. These are normally picked up during transport or storage. Others are important pathogens which infect the seed and inhabit its internal tissues. Whatever the case, both types of parasite can affect the vigor and viability of the seed.

Pathogen transmission via seeds is of importance since it constitutes a suitable medium for the pathogen's survival and is a simple way for it to be spread to new areas.

B. INDICATIONS IN THE PLANT

When there is an infection caused by a pathogen or an adverse abiotic factor, the plant suffers morphological and physiological changes which are externally visible. These observable changes, some of which have already been mentioned, are known as **symptoms**.

Symptom recognition is of great assistance when evaluating or describing a disease with accuracy. The most common types of symptoms may be grouped as follows: spots, necrotic lesions, blisters, abnormal growths, rotting and wilting.

Spots (Fig. 63) include chlorotic lesions, translucent and intervenal lesions, chlorotic haloes, mosaics and corky patches. **Necrotic lesions** (Fig. 64) occur through tissue death and may be round, oval or angular. Terminal necrosis can also be seen where a bud or flower dies. **Blisters** (Fig. 65) are small lesions which start the size of a pinhead and later grow or unite with other blisters.

Figure 63. Leaf spots on *Tectona grandis*.

Figure 64. Necrotic lesion on *Acacia mangium* leaf.

Figure 65. Blisters on *Cordia alliodora* leaf.

The most common **abnormal growths** are galls or tumors (Fig. 66). These are caused by an increase in the size of the cells (hypertrophy) or by increased cell division (hyperplasia). Also seen are dwarfism (hypotrophia) or ridging of the leaves. **Rotting** (Fig. 67) covers tissue disintegration and may be wet rot or dry rot located in fruits or roots. **Wilting** (Fig. 68) is due to damage to the root system which impedes water absorption or due to water deficiency (drought).

Figure 66. ***Cronartium*** sp. gall in pine.

Figure 67. Rot caused by excess water in ***Bombacopsis quinatum***.

Figure 68. Wilting in ***Tectona grandis***.

In addition to the lesion, other growths may be found on the wound which are structures produced by the damage agent itself. These are referred to as pathogen **signs**. Mushrooms and bracket fungi are some of the most well known and visible. Others include the cottony or powdery mildew produced by certain pathogens.

GENERAL POINTS ON PEST MANAGEMENT

CHAPTER III

GENERAL POINTS ON PEST MANAGEMENT

The presence of pests is inevitable in any forest project and producers and scientists must learn to coexist with them. There are no easy answers or fixed rules for dealing with pests and each must be dealt with according to its own criteria. One thing that is certain is that preventative measures should form the basis of any forest protection program. Although at first sight these may appear expensive or difficult to implement, the advantages will be appreciated in the medium and long term.

Forest plantations have only recently been established in Central America so that there is little available information on pest control. For this reason it is not always easy to give concrete or specific recommendations. In this chapter, the little information that is available from the region, together with that from other countries with a longer tradition in forestry, is given with the aim of assisting the direction of pest control in Central America.

1. PREVENTATIVE MEASURES

Plant health problems should be controlled before they even appear. In the majority of forest projects, few resources are allocated for prevention programs, and these are only incurred as expenses when the problem arises. There is justification for allocating funds for preventative measures when the losses from the appearance of just one pest are considered. An adequate program should take into consideration all of the following points.

A. SITE QUALITY

The quality of the site where a forest project is planned is closely linked with the prevention of attack by pests. A poor site will produce weak trees which are more susceptible to attack.

It is essential to know the environmental factors which affect the project site. Some species, such as ***Alnus acuminata***, are susceptible to environmental conditions that differ from those where the species naturally grows.

It must be taken into account that the majority of plantations are established on marginal sites, previously used for agriculture, where it is difficult to achieve the complete development of a group of trees. Forest species are affected by factors such as low fertility, extreme pH (low or high), poor soil drainage, winds and altitude.

In view of this, the following rules should be followed:

a) If the project already has a specific site, only tree species shown by observation and experience to be well suited to its conditions should be planted.

b) If the project already has a specific species, a site which fulfills that species' environmental requirements, determined by observation of sites where the species naturally grows, should be sought.

In certain cases, some factors such as poor fertility or drainage, which affect quality of site, can be modified through fertilizer application or improving drainage.

It should be pointed out that just as a better quality site better suits forest species, it also favors the growth of unwanted or weed species. This implies increased weed control measures. In good sites, the species which becomes dominant early on is the one with the best chance of colonizing. For this reason it is imperative to prevent weed dominance and stimulate that of the trees.

B. SELECTION OF PLANTING MATERIAL

Strict quality control should be applied when selecting material for planting. Plants with a poor appearance compared to the established prototype, should be eliminated. Only plants with the best characteristics of appearance and behavior should be selected since weaker specimens may be more vulnerable to pest attack (Fig. 69).

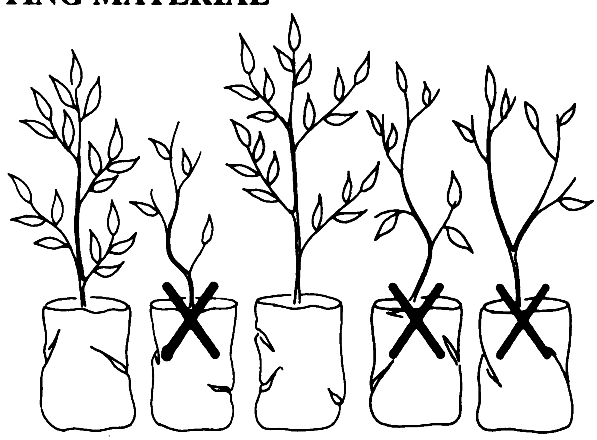


Figure 69. Selection of planting material.

Occasionally forest projects use unmarked seeds of unknown age, origin or physiological state. Buyers should take care when purchasing seeds, stumps or seedlings, to ensure that the material is guaranteed. This may result in the establishment of more satisfactory conditions of supply and demand and with it an improvement in the standards of material available.

Unfortunately, in Central America, commercial transactions in genetic material are mostly made on the basis of the greatest quantity for lowest cost, with little consideration of quality. Sometimes, for a slightly larger investment, the buyer can not only guarantee the genetic quality but also reduce the risks of pests and increase the stability of the project.

C. QUARANTINE

Even though a forestry project may fulfill all the conditions to avoid the development of plant health problems, these may arise.

For this reason plant quarantine procedures are required to prevent the unrestricted movement of seedlings, stumps, saplings and soil which may carry forest pests. Of the quarantine measures most important for forest species, the following are of particular note:

a) Sterile field standards

The expression "sterile field" refers to the physical conditions established to prevent the entry of damage agents to the seedlings or trees. A forest project, especially a nursery, can be affected by poor standards of hygiene even from its own personnel. A healthy nursery can be contaminated by the introduction of infected seed, contaminated work tools or workers from areas with a high incidence of pests. For this reason access to the site should be well defined to restrict the entrance of certain materials and carry out disinfection measures etc. before entry. This is not a new concept nor is it hard to implement and it is commonly seen in flower and ornamental plant nurseries.

b) Movement of material

There is clear justification for the prohibition of introducing plant material through ports of entry to a country. Any seed, seedling, stump or soil sample introduced from another country may contain insect eggs, fungal spores, bacteria or nematodes which may be harmful for forest or other species. Some insects, such as ***Megastigmus*** spp. can enter as larvae inside the seeds of some conifers, making them very hard to detect.

Nurseries and forest projects should adopt the policy of isolating all new material in a "quarantine zone" well away from the project where it can be kept isolated until pesticides have been applied (Fig. 70). Laboratory examination of new material requires the investment of additional resources but does prevent the entry of contaminated material. These measures should not only be taken for material entering from abroad, but also for material from within the country. Of course, this work can be avoided by demanding a health certificate from the seller which forms a written guarantee that the material has been inspected and treated against pests.

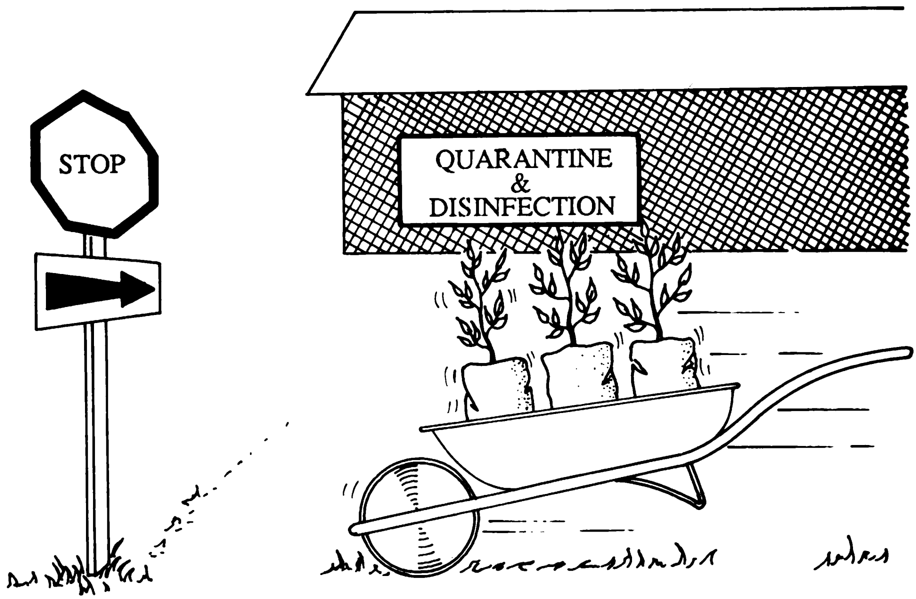


Figure 70. Isolation of new materials.

c) Establishing barriers

Because of their small size, insects and pathogens can easily be spread, especially by the wind. However, insects and fungal spores can be contained by the construction of barriers (Fig. 71). One way is to make sure there are wide, empty spaces between activities. Another is to plant high hedges thick enough to act as a wall. Hedges of plants which have a repellent effect on certain insect species constitute a biological barrier. The windbreaks designed to stop the wind in forestry projects are a good example of external barriers.

d) High risk zones

It is advisable to avoid planting a certain species in areas where there is a high incidence of pests. For example, if a site is selected where there are many pine plantations and these have been or are attacked by ***Rhyacionia frustrana***, it would be an error to select the same forest species for planting, since this would almost certainly be affected unless effective control measures were taken.

There are also risk zones that occur within a forest project depending on the arrangement of the areas of activity. In badly planned nurseries, germination beds, seedling beds, compost heaps, seed storage areas etc.

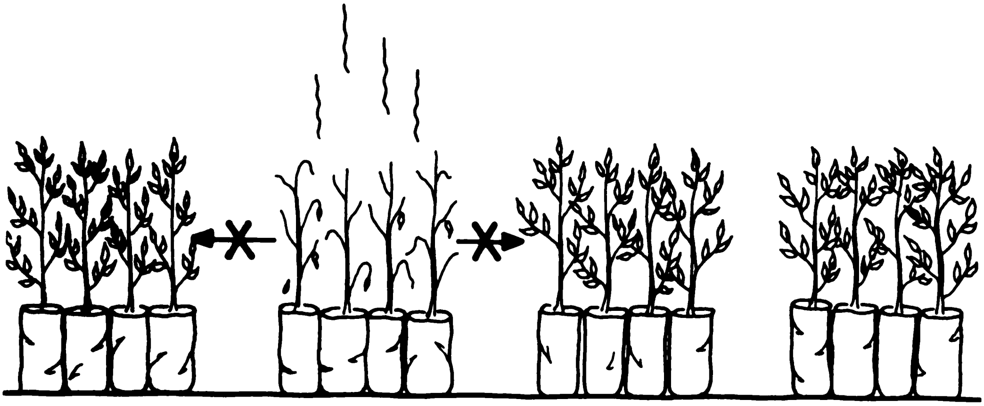


Figure 71. Isolation of infected material between barriers.

are constructed in a limited space and any pest can quickly spread without meeting obstacles. For this reason, each activity should be in its own well defined area, isolated from others.

e) Legislation

The adoption of laws to protect plants of economic value is important not only to stop the entry of pests to a country but also to avoid the spread of those already there. Although some Central American countries have valuable plant health legislation, it is rarely applied or complied with, especially in the case of internal quarantine.

D. SILVICULTURAL PRACTICES

Silvicultural practices cover a range of activities which imply change in the composition or features of forest projects. Some of these, as well as increasing production, may prevent more than cure attack by pests. Since some have a curative value, they will also be discussed in section 2 of this chapter.

a) Plantation diversity

Instead of planting vast tracts of land with a single forestry species, the equivalent of monoculture in farming, other alternatives which produce more heterogeneous plantations should be explored. Certain experiences in Central America have shown that it is possible to reduce the incidence of pests by creating mixed plantations where rows or blocks of a different species are interspersed (Fig. 72). Similarly, there is a reduction where species are planted to "enrich" natural forest or secondary growth areas. In both cases not only is the food supply for the more specific pests reduced, but it is also harder for them to locate.

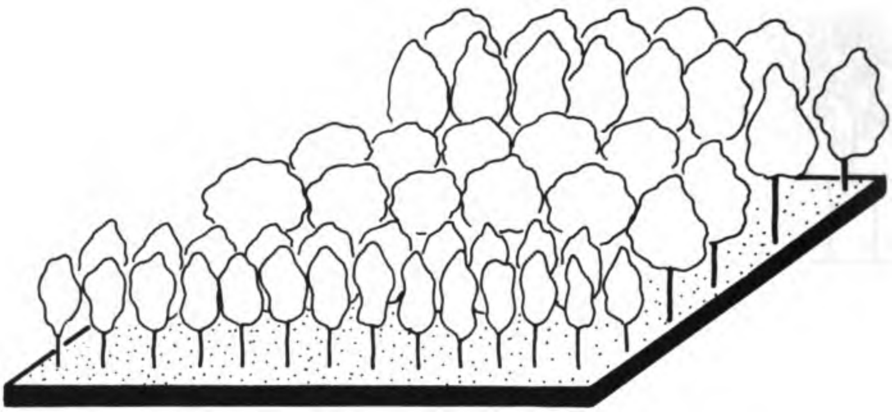


Figure 72. Block of species in a diversified plantation.

Lack of information on the character of the species to plant and the profitability present major obstacles to diversification projects.

Age is also a factor which must be considered in diversification. Plantations of the same age are more vulnerable to pests which affect trees of a certain age and, if affected, the whole project can be lost. For this reason it is advisable, wherever possible, to establish mixed-age plantations to reduce the risks.

b) Planting density

Planting density in forest plantations should be controlled so as to plan the number of individuals and the distance between them.

In order to compete with other trees, each individual needs a certain amount of space which varies from species to species. Under natural conditions, some species grow along with others but are found separate, surrounded by a large space, for example ***Cedrela odorata***, ***Bombacopsis quinatum***, ***Platymiscium pinnatum***, ***Astronium graveolens*** and ***Albizzia guachapele***. Other species occur naturally in denser stands of the same species, such as ***Eucalyptus*** spp., ***Alnus acuminata*** and several conifers.

Once a forest plantation contains, for example, more than one thousand individuals per hectare of a single species with the same age and spacing, they become overcrowded and can react unfavorably. They can become weakened and susceptible to adverse conditions such as poor soil fertility, poor drainage, extreme temperatures, high winds etc. and also pests.

c) Thinning

The main aim of this is to select the most vigorous trees with the best characteristics and stimulate their growth by removing competition from individuals with less desirable characteristics. In practice it also confers some protection against pests. By stimulating the upward growth of the trees left standing, these will more quickly reach the critical height where they are out of reach of insects and fungi which attack the terminal bud or of those which are poor fliers or less effectively dispersed. Similarly, removal of less vigorous or stunted trees eliminates the risk that these may prove to be targets for some pests (Fig. 73).

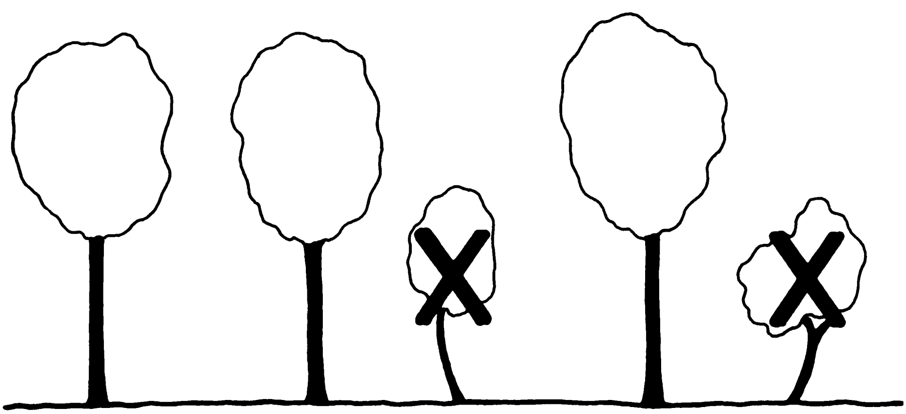


Figure 73. Thinning stunted trees.

Thinning can change the microclimate by affecting temperature, humidity and light intensity. Although it can reduce the incidence of certain damaging agents, it can increase the incidence of others, a fact which must be borne in mind in each particular case.

Of course, thinning can be harmful if it is carried out in such a way that falling trees damage those that are to be left standing. Consequent wounds on the trunk or branches of remaining trees can act as a focus for infection or infestation allowing diseases or insects to gain entry.

d) Weed management

Traditionally, weeds have been viewed as harmful to seedlings and trees in nurseries and plantations since they compete for space, water and light. Most management methods have included complete weed elimination, usually using herbicides. However, in some cases, weed removal can prove counterproductive.

As has been demonstrated for some weeds associated with crops, weeds can produce nectar for the adults of insect parasitoids. If these are left, the parasitoid populations increase providing a biological control tool for harmful insects. In other cases, some forest plants may be preferred by herbivorous insects and can be left as a trap or distraction from the seedlings or trees that need protection.

The effects are also variable with respect to pathogens. For example, the removal of weeds under ***Bombacopsis quinatum*** exposes the soil to the sun's rays and raises the temperature at the base of the stem. This causes alterations in the plant. On the other hand, in other species, leaving weeds can raise the relative humidity and create a microclimate favorable to some pathogens. Moreover, for pathogens with a wide spectrum of hosts, weeds can represent an alternative substrate for survival or multiplication of inoculum.

For these reasons, the beneficial or harmful effects of weeds must be evaluated in specific situations on the basis of field observations. Their compatibility with the tree species can then be established and the weeds either controlled or utilized.

e) Pruning

Pruning to avoid knot formation in the wood can, like thinning, alter the microclimate of the plantation and this may encourage or discourage certain pests.

Pruning must be carried out with great care since cutting the branch causes a wound through which fungi, bacteria and even some boring insects can enter the tree. Exposed surfaces should be covered with a mixture of fungicide and sealant, such as copper sulfate in an oil based paint (Fig. 74). There is also the risk that the tree being pruned has a disease which could be carried to healthy trees. To avoid this, tools should be disinfected after each pruning by submerging in or cleaning with sodium hypochlorite (commercial bleach), formalin or alcohol.

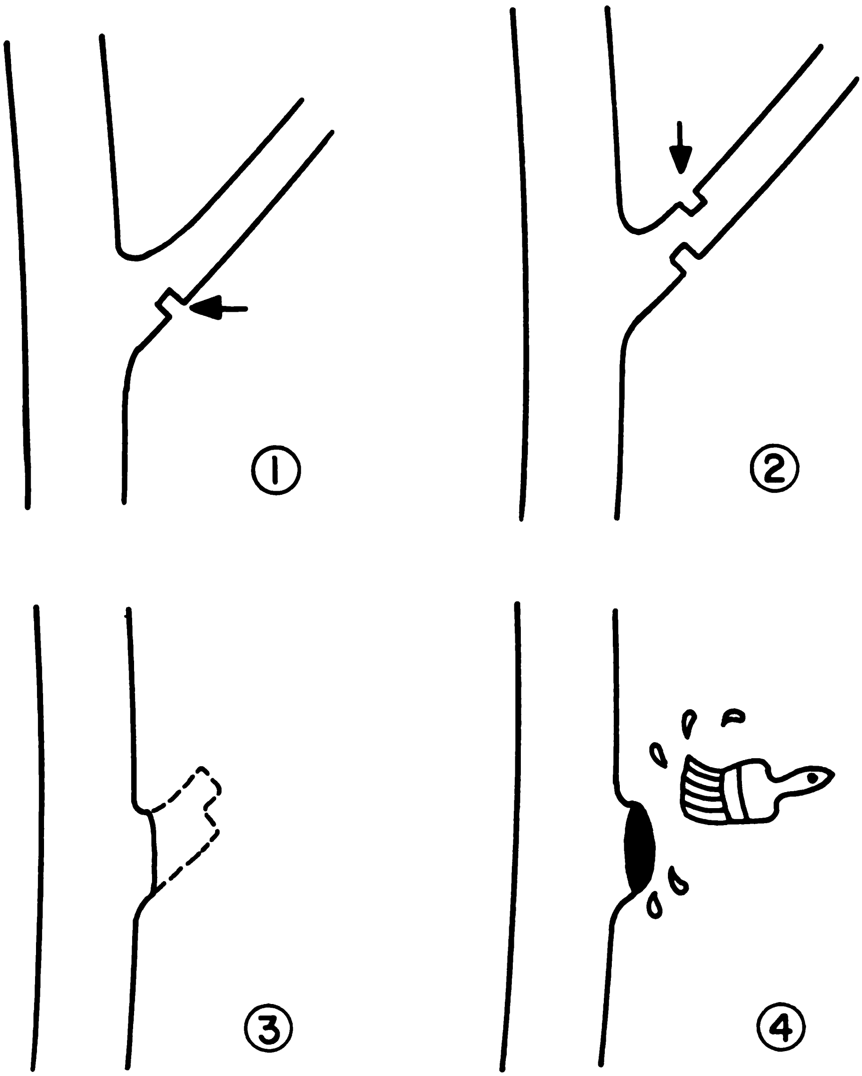


Figure 74. Pruning and wound protection scheme.

In plantations, pruning should be avoided in the rainy season. Not only are the trees more susceptible to pruning then, but the rain water is an excellent medium for spreading fungi which subsequently enter the wounds.

Without doubt the preferable way is to select species with the ability to "discard" branches naturally as they grow. This saves a great deal of work and lessens plant health risks, but obviously, is not always possible.

f) Hygiene measures

Waste plant material should not be allowed to accumulate but should be eliminated as it is produced (Fig. 75). In many forest projects, accumulated material such as compost heaps, fallen trunks, prunings and thinnings etc. can be seen left lying about and these can act as a source of inoculum. Leftover bags of seedlings can accumulate water and become breeding grounds for fungal spores. The excessive use of organic matter that has not fully decomposed can pose risks in nurseries. The same microorganisms that saprophytically degrade the material can also be facultative pathogens and become a plant health problem. Furthermore, the fermentation process produces temperature rises which may affect the plant's normal development.

Figure 75. Burning waste material.

Activities that are unrelated to the activities of the project should be avoided. It is common to see farm animals, fowl and vegetable plots in the nurseries, especially in rural areas. This presents many risks as both vegetables and animal wastes can serve as a substrate for several pests.

g) Maintenance

These measures are especially relevant to nurseries and include temperature, humidity and soil and water pH and organic matter content.

In many nurseries, watering is carried out indiscriminately. Neither the amount of water applied nor the real needs of the plant are taken into consideration. This often results in excessive soil humidity and encourages pathogen infections. The soil should be kept damp but without flooding. The exact amount of water and frequency of application depends on the location, climatic conditions, developmental stage of the plant, soil texture and other factors. Soil humidity can also be regulated by avoiding high planting densities and removing shading weeds.

All seedlings as well as pathogens have an optimum temperature for development, although this is a factor over which the nurseryman has little control. In ***Pinus*** spp. it has been observed that ***Fusarium*** sp. is associated with high temperatures whilst ***Phytophthora*** and ***Rhizoctonia*** spp. are more common during cooler conditions. In ***Bombacopsis quinatum***, a blight affecting the collar of the stem has been observed in seedlings at the beginning of the rainy season. Currently, it is believed that elevated temperatures in the upper layer of the soil are responsible for the damage, but ***Macrophomina*** sp., a fungus favored by high temperatures, has also been isolated from diseased trees.

The effects of high temperature can be alleviated by covering seedlings, especially those grown out in the open. These covers should not be dense as this would increase temperature and humidity and hence favor pathogens. Once the seeds have germinated or after transplanting, the covers can be eliminated to improve aeration.

Soils with a high organic matter content encourage the development of diseases such as "damping off", so that the recommended content for producing seedlings with naked roots is between 1.5 and 5%.

The majority of fungi develop well under neutral or slightly alkaline conditions. For conifer production, the soil pH should be between 4.5 and 5.5 and never above pH 6. Irrigation water should have a pH of about 7. There is a connection between pH and nitrogen fertilization since the continuous application of nitrogen fertilizers over years tends to raise pH whilst application of sulfates tends to lower it. Liming tends to raise pH. Excess nitrogen before or after germination increases pH so favoring "damping off" in pines. For this reason nitrogen should not be applied until eight weeks after planting.

E. GENETIC RESISTANCE OR TOLERANCE

Some forest species show a natural tolerance or resistance to attack by certain insects or diseases. It would be preferable to use these in reforestation projects, but this is rarely practicable since they are not tolerant or resistant to all the pests that occur. An interesting example occurs in species of ***Eucalyptus*** and ***Pinus***. ***E. grandis*** and ***P. tecunhumanii*** are tolerant of diseases most commonly found in ***E. deglupta*** and ***P. caribaea***, the two species most often used for reforestation projects. Similarly, the Australian cedar ***Toona ciliata*** var. ***australis*** shows resistance to ***Hypsipyla grandella***.

The possibility also exists of artificially conferring resistance or tolerance via interspecific pollination (transferring the genes for tolerance to susceptible species) but this is a lengthy and complex procedure.

F. DETECTION AND EVALUATION

Although detection and evaluation of plant health problems do not as such constitute preventative measures, they are fundamental in forming part of the prevention effort in any forest project. The sooner a problem is detected and dealt with, whether it be in stored seed, nursery or plantation, the cheaper and easier will be its control.

This topic will be discussed in more depth in Chapter V, but some general points will be covered here.

Plant health prospection includes the prediction of future events based on actual occurrences. Since it depends on the biology and epidemiology of each pest, it will be more effective when more is known about each species concerned. For this reason it is important to construct a prototype or model both for individual trees (age-size relationship, branching, response to treatment etc.) and for the project in question (spacing, site quality, labor requirements, etc.).

Periodic inspections are essential, and should be carried out at the very least whenever there are climatic changes (rains, drought or high winds), optimal environmental conditions (months of higher temperature and humidity) or environmental changes (floods, fires or soil movements). Inspections should be as detailed as possible, checking seed stores, germination beds, seedling beds and plantations to evaluate insect densities and detect any plant abnormalities or the presence of pathogens.

Most of the time, any problems will be due to one factor, but situations may arise where the symptoms are due to the interaction of more than one factor. For example, there may be an interaction between a genetic problem, a physiological response to the environment, a nutritional deficiency, pathogen infection and damage caused by an insect. This situation must be rigorously analyzed to avoid diagnostic errors which could have serious economic, social or environmental consequences.

2. REMEDIAL MEASURES

Although the preventative measures outlined in this chapter will help prevent or reduce pest attack, there are occasions when they will prove insufficient. Once a plant health problem has arisen, the second phase of the protection program must be implemented. This includes the following activities.

A. APPRAISAL OF THE PROBLEM

Obviously the first appraisal must be the identification of the agent causing the problem. Secondly a cost-benefit analysis of any control measures must be made. Both these aspects are discussed in Chapter V.

The purpose of pest control is not its eradication, which in any case is practically impossible. Erradication of a pest from a region or country is only feasible where the damage agent has a poor dispersal capacity and/or has only recently been introduced to a well defined and confined area. Since complete erradication is almost impossible, producers and extensionists must learn to coexist with the pest, reducing its economic impact.

Once it has been decided that control measures are required, all the possibilities available should be evaluated so that the closest to the ideal can be selected. Selection should be made with regard to the following criteria: efficiency, availability, of lasting effect, expense, environmental impact. The ideal method will depend to a large extent on the magnitude of the problem and the biological characteristics of the damaging agent.

It should be emphasized that one control method alone can rarely solve a problem and that in all probability, a combination of compatible methods may have to be used. The preventative measures discussed in this chapter should be a fundamental component in this combination. The goal of any forestry project should be to **manage** plant health problems rather than control them. This means reducing pest populations to levels where economic damage is nil or at a minimum, with no or little environmental impact and using more than one method simultaneously. These are basic elements in the concept of **integrated pest management**, which is so in vogue today.

B. DIRECT CONTROL MEASURES

a) Isolation

The aim of isolation is to prevent the spread of a pest within the project or between projects.

When a focus has been discovered, excessive movement of personnel through the area should be avoided and all tools (saws, knives, wheelbarrows, etc.) should be disinfected since these can carry infections.

b) Salvage felling

This measure should only be applied in extreme situations and as a last resort. It is effective against insects and diseases that affect the phloem or bark since it interrupts the life cycle and eliminates some of the population. The felled trees may have some commercial value, depending on their age. Once the tree has been felled, the bark should be removed and burned. The insects or pathogens die as a result of exposure to the outside or from the application of pesticides.

Felling should be combined with the establishment of a "cordon sanitaire" or guard line outside the felled area to prevent the spread to healthy areas. The thickness of this line will depend on the damage agent's ability to spread.

c) Thinning

This differs from salvage felling in that it aims to remove the foci of insects or diseases and can be used against any pathogen. Every effort should be made to save as many trees as possible, but moribund specimens should be removed since they assist the increase and spread of the damage agent.

d) Pruning

This can be done to remove branches affected by pests. It can also be useful for pests that attack the terminal bud. A sanitary prune can be carried out to re-establish growth followed by a later pruning to re-establish apical dominance and prevent the tree forking.

e) Hygiene

In all the measures mentioned previously, it is essential to completely destroy all the affected parts. This applies to tree trunks and branches and to seedlings and stumps in nurseries as well. Infected material should be buried or burned in one place to reduce the risk of spread. If the wood is to be used commercially, it should first be treated with pesticides.

Tree stumps left after felling or thinning should be left as low as possible to lessen the risks of residual insects and pathogens in the bark or phloem.

f) Biological control

Classical biological control has arisen from the principle that all organisms in nature have antagonistic organisms which can kill them. These are called natural enemies and are classified as predators, parasitoids and pathogens.

Predators (Fig. 76), capture and consume their prey. The groups that attack pests include insects, spiders, some mites, reptiles, amphibians, birds and mammals. Predators are not normally specific in their choice of prey and each individual can consume many during its life.

Figure 76. ***Cycloneda sanguinea*** predator of ***Mastigimas*** sp.

Parasitoids (Fig. 77) are nearly all members of the orders Hymenoptera and Diptera. Their adult stages are free living and feed on nectar and other sources of sugars. The larva develops inside the body of another insect (host) slowly producing its death. They are usually quite specific with respect to their hosts and each destroys only one host individual during its lifetime.

Pathogens (Fig. 78) are a diverse group of organisms that feed exclusively on animal, especially insect, tissue. There are pathogens among the viruses, bacteria, fungi, protozoans and nematodes. They are all highly specific to their host, have a low capability of dispersal and are most effective when the host population density is high, as in epidemics.

Figure 77. ***Eulepte*** sp. (Pyralidae) larva parasitized by a braconid.

Figure 78. Chrysomelid attacked by fungi.

All of these organisms can be used by man in biological control programs since they have the capacity to kill insects. In order to do this, it is first essential to know whether the pest is of native or foreign origin.

In the first case, it is assumed that there are natural enemies of the pest which should be preserved and efforts made to increase their populations. This can be achieved through silvicultural practices, by management of weeds which provide food (nectar, pollen, alternate hosts or prey) or shelter, through the use of artificial food or supplements and by avoiding the indiscriminate use of pesticides which may reduce their populations. The goal, in other words, is to restore the environment so that the natural enemies can act. In the monograph section of the Field Guide, the natural enemies of the major Central American forestry pests known to date are mentioned.

In the case of foreign or exotic pests, it is assumed that they have entered without their natural enemies. It is necessary to explore the pest's sites of origin to try to find natural enemies and import them if necessary. Once imported they should be reared under laboratory conditions to be later released in the field. The type of colonization they will carry out is called **inoculative** since the numbers released are relatively small. Measures should be taken to ensure their establishment and subsequent reproduction and multiplication.

Another method, suitable for both types, is a massive rearing programme from a few individuals in specialized laboratories. This permits the release of large numbers of natural enemies for **inundative** colonization when the situation arises. This method is, however, fairly expensive and complex and not applicable for all pests.

Since many natural enemies are very small, they are often overlooked and undervalued. They quietly carry out a useful task and, often, only require a little encouragement to reach levels where they can work at optimum efficiency.

Diseases can also be controlled using microorganisms. There are bacteria which parasitize fungi, but this method has, so far, not been applied as much as in the case of insects. This is mainly due to the fact that the management, reproduction and inoculation of fungi is strongly influenced by environmental conditions, as much in the laboratory as in the field. For this reason the results so far have not been so spectacular.

g) Attractants and repellents

Insects generally respond to certain odors which attract them in the search for food, mates or oviposition sites. Some of these substances when liberated by plants, can be used to produce toxic lures or as plant traps to keep the insects away from the forest species. There are also attractants produced by the insects themselves, called pheromones, which have practical importance.

Pheromones are volatile chemicals released by insects and carried by the wind. They provoke reactions in other insects of the same species. The most important ones from the forestry perspective are the sexual pheromones used by females to attract males and the pheromones used by bark beetles for recruitment. These insect pheromones can be extracted, chemically analyzed, synthesized and produced commercially for use in pest control.

Sexual pheromones can be impregnated on plastic and put in sticky traps or cages to catch males. These are either prevented from mating or inoculated with a virus that they later spread to the population. Another tactic is to swamp the area with pheromone so confusing the males and impeding their search for females to mate with.

The recruitment pheromones are produced by bark beetles when they find a tree suitable for colonization. They attract both sexes to attack the tree together. The most important of these hormones is frontalure which is being assessed for possible future use in practice.

Bark beetles also produce pheromones such as verbenone and endobrevicomin which act as repellents. Their potential is also being studied. Other substances such as creosote and sulfur have been used with success to repel some insects and there are, without doubt, many more repellent compounds of plant origin yet to be discovered.

h) Reproduction inhibitors

There are two methods of inhibiting reproduction. The first consists of crossing different races of the same insect species to produce sterile hybrids. This is still at the experimental level. The second method is the release of millions of male insects sterilized by gamma radiation or chemical means. Females copulating with these sterile males do not produce offspring. For this method to be successful, the female must only mate once and the pest should appear in well defined foci, such as an isolated plantation or island, preferably at low population densities.

i) Mechanical methods

These include a wide variety of techniques which depend on the use of a mechanical device to either prevent access or capture the pest.

Access can be prevented by bagging developing fruits to stop insects and grain eating vertebrates, covering terminal buds with fine mesh to stop bud borers, sticking adhesive bands round tree trunks to stop defoliating larvae and placing metal cylinders round the base of seedlings and saplings to stop rodents such as rats.

Pests can be captured either manually, as in the case of pupae which stay for some time on the base of the trunk, or by traps.

Traps exist in the form of snares or gins (Fig. 79) for pocket gophers and ultraviolet light (Fig. 80) or pheromone traps (Fig. 81) for insects. Ultraviolet light traps are inconvenient since they are not specific and need a battery. Pheromone traps cannot be used for all species of pest since only a few pheromones are available. In the case of bark beetles, tree baits have been used as traps. Trees are felled so that as the phloem dries it will attract the bark beetles to attack the tree. When the beetles are concentrated, the bark of the trees is removed and burned.

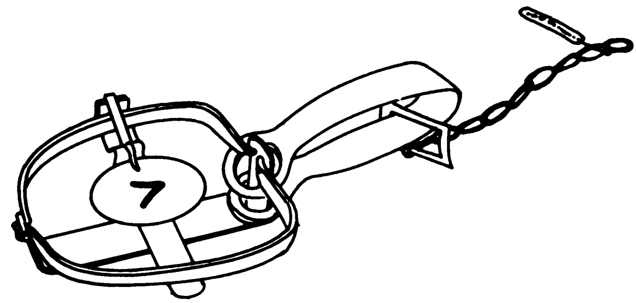


Figure 79. Pocket gopher trap.

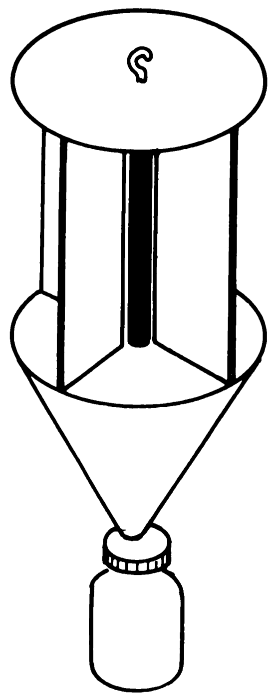


Figure 80. Ultraviolet light trap.

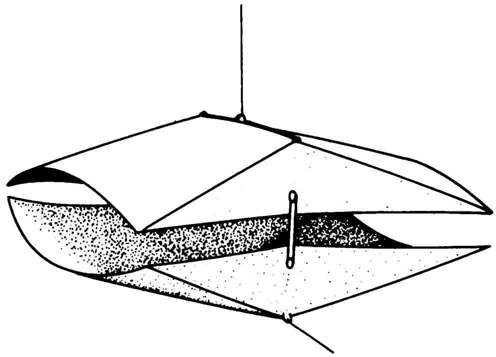


Figure 81. Pheromone trap.

j) Chemical methods

Chemical substances which affect the physiology of pests include growth hormones and pesticides.

There are two types of hormones which regulate an insect's development from egg to adult: molting hormones (ecdysones) and juvenile hormones (neotenins). The latter have been isolated from several insects and are already used in their control. Their action gives rise to deformed insects that have impaired reproduction. They are used successfully against pests of stored seeds, but in the field, operative difficulties have limited their success. Commercial production of these substances has advanced very little.

Pesticides are the most frequently used control method, both in forestry and agriculture, since they are widely available and their effect is immediate. They should be used rationally and cautiously, however, to avoid the many adverse effects which have been seen in agriculture. The whole of Chapter IV is dedicated to pesticide use for this reason.

3. POST-CONTROL MEASURES

It is a commonly made mistake in forest projects that once control measures have been taken against a certain pest and damage symptoms improve and the pest population decreases, the problem is solved. It should never be assumed that pest control is over once measures have been applied.

There are a series of standards which should be considered after application of control measures:

A. CAUTION

The state of emergency imposed from the moment the problem was first detected in the project should not be lifted until it is certain that the pest has been completely controlled.

B. RE-EMERGENCE

To avoid the re-emergence of the problem, all dead plants should be removed from the project. Similarly all those which were affected but recovered should also be removed. On these plants there may be populations of insects or pathogens temporarily decimated by the control measures but waiting for the appropriate conditions to re-establish themselves. There may also be pathogens in their incubation period showing no signs of further attack.

C. REPLACEMENT OF MATERIAL

Where there have been losses of plants in nurseries, it would be a mistake to replace these with material from the same source and with the same characteristics. Although it is more expensive, it is wiser to replace with certified material.

D. ENVIRONMENT MODIFICATION

Obviously, if a certain environmental factor such as soil characteristics, humidity or wind has been shown to favor the appearance of a pest, this should be modified. In extreme cases where there has been poor initial planning, the site of the project, or part of it, may have to be changed.

E. REORGANIZATION OF ACTIVITIES

If it is found that certain silvicultural activities have favored the problem, these should be changed or avoided. For example the problem may have been exacerbated by frequency of watering, weeding, time of transplanting or the amount of organic matter in the soil.

F. EVALUATION OF LOSSES AND COSTS

This is fundamental, not only at the project level, but for forest production of the country and the Central American region. Quantifying losses in terms of seedlings, stumps or wood volume along with the cost of control, allows evaluation of the risks of using a particular species and estimation of the economic requirements for protection in any project.

CONTROL USING PESTICIDES

CHAPTER IV

CONTROL USING PESTICIDES

Pesticides are substances of chemical (and in some cases biological) origin which can eliminate living things which are causing economic losses. According to the type of organism affected, they are classified as insecticides (insects), acaricides (mites), molluscicides (slugs and snails), rodenticides (rodents), avicides (birds), nematicides (nematodes), fungicides (fungi), bactericides (bacteria) and herbicides (weeds).

Without doubt, they are a powerful tool in pest control, not only because of their killing capacity, which produces almost immediate results, but also since they are relatively easy to obtain. However, they are not a permanent solution to pest problems, and must be repeatedly applied each time the problem appears.

In Central America, there is little experience of pesticide use in forestry. For this reason, there has been an uncritical adoption of the methods used in agriculture, which have sometimes proved unsuitable. On the one hand, trees have a longer life span to harvest (6-30 years) so that frequent use of pesticides is limited by economic considerations. On the other hand, pests attacking agricultural crops have a relatively long history of exposure to certain pesticides which has resulted in cases of the development of genetic resistance. This has resulted in farmers using increasingly toxic pesticides as they reject the ones that have become ineffective. Despite this, those pesticides that have been rejected do have an important role in forestry where there has been little or no previous exposure.

1. BASIC ASPECTS

To guide the user in their application, some basic concepts about pesticides should be presented. Without this, chemical control may not be so effective and may have undesirable consequences.

Herbicides are not included in this chapter, which concentrates on insecticides and fungicides since insects and fungi are the organisms which most directly affect seeds, seedlings and trees of forestry importance. There are many similarities between insecticides and fungicides, but also great differences, which will be specified correspondingly.

A. PESTICIDE NAMES

All pesticides have several names: the scientific or chemical name, the generic or common name and the commercial or trade names. The scientific name describes the molecular structure of the chemical compound, for example dithiophosphate 0,0-dimethyl S-(N-methylacetamide). Since these names are often fairly complicated it is easier for general communication to use an abbreviated or common name. The common name for the previously mentioned compound is dimethoate and is the name used in scientific publications and official manuals and handbooks, always written in lower case. Since this insecticide is manufactured by several commercial houses (American Cyanamid, BASF, Bayer, Sumitomo, etc.)*, each of these gives it a trade or commercial name always written starting with a capital letter e.g. Cygon, Perfekthion, Rogor or Roxion.

B. RELATIONSHIP OF PESTICIDE TO DAMAGE AGENT

Although the majority of pesticides act with little or no specificity, this does not mean they can kill any damage causing agent. There are different levels of specificity not just to the organism's group (insect, mite, nematode, fungus, bacteria etc.) but also within each group.

The biology and epidemiology of the organism along with the type of damage caused, largely determine the pesticide used to control it. Chapter II of this Handbook and the tables at the end of this chapter should be consulted on this point.

C. LETHAL DOSE

Since all chemical pesticides are poisons, to one degree or another, their toxicity to vertebrates, including man, must be evaluated during the manufacturing process.

Pesticides may enter the body across the skin, through the mouth or through the nose, and some through other routes. For this reason both oral and dermal toxicity must be determined in terms of acute or short term effects. Chronic effects, in other words the results of long term and repeated exposure, must also be evaluated. The level of toxicity is determined on laboratory animals (mice, guinea pigs, rabbits, monkeys) to find the lethal oral and dermal dose. From this the LD_{50} is calculated.

The LD_{50} is defined as the dose in mg/kg body weight which kills 50% of the animals in one dose through the route indicated. For example, methyl parathion has an oral LD_{50} of 9-25 mg/kg in rats and a dermal LD_{50} of 300-400 mg/kg in rabbits. By comparison, fenvalerate (Belmark) has LD_{50}s of 451 mg/kg and 2500 mg/kg respectively for the same species. The lower the LD_{50}, the more toxic the chemical, so it can be seen that parathion (an organophosphate) is much more toxic than fenvalerate (a pyrethroid).

* The use of commercial names does not imply any recommendation whatsoever on the part of CATIE.

A ranking system of pesticide risk has been established based on the oral, dermal and inhaled lethal dosage along with their effects on the eyes and skin. This system has been adopted internationally and consists of a a color coded band on the product label. The color codes are as follows: green (slightly toxic), blue (moderately toxic), yellow (very toxic) and red (extremely toxic). In this way, a glance at the color code will tell what risks there are in using the product.

It should be pointed out that the toxicity of a product does not by itself indicate all the risks of poisoning from that product. Long term exposure to a pesticide with low toxicity may have chronic effects such as the later appearance of cancer.

D. TOXICITY

The toxicity of a pesticide can refer to the effect on humans and vertebrates (always expressed as the oral or dermal LD_{50}), plants of commercial value (expressed as phytotoxicity) and on the pests themselves. In this sense, toxicity can be defined as the ability a pesticide has to eliminate a pest.

The toxicity of a pesticide varies according to the species concerned and the product label bears a "dosage" in units of kilograms or liters per hectare. For example acephate (Orthene) kills several species of bugs and homopterans at a concentration of 0.5-1.0 kg active ingredient per hectare, although only 0.25-0.5 kg/ha is needed to kill some thysanopterans.

E. PERSISTENCE

Persistence of a pesticide refers to how long its effects last or how long its metabolites or residues stay in existence under field conditions. This varies from product to product; some such as fumigants and pyrethroids are ephemeral whilst most organochlorines and copper based fungicides are very persistent.

F. FORMULATION

In some specialized laboratories it is possible to find the pure toxic compound known as technical grade. However, for most purposes (convenient storage, ease of application, ability to cover etc.) and for economic and security reasons, the substance is mixed with additives in the process of formulation.

The result is available in the national market and contains the active ingredient (technical grade material) plus inert additives such as carriers, surfactants, propellants, adherents etc. In this way there may be several formulations of the same active ingredient giving different commercial products. This will be discussed in more detail later.

G. COMPATIBILITY

Sometimes, more than one problem is encountered by the producer (for example, an insect pest and a fungus) or he may wish to apply a pesticide product along with a foliar fertilizer. In order to save time and labor costs the producer may wish to mix two or more products in one application. Although some products remain unaltered when mixed with others, the action of some is changed in the presence of other compounds. In some cases the mixture of two products is more potent than each of the two separate. This phenomenon is known as synergism or potentiation. Other products show antagonism so that the combination is less effective or totally ineffective and may result in problems of phytotoxicity caused by some new reaction product.

Information regarding pesticide compatibility appears on the product label and several books contain reference tables or lists of compatibility which should be consulted.

H. CALCULATING THE AMOUNT TO APPLY

The quantity of any product that should be applied depends on several factors such as the toxicity of the active ingredient, the product formulation, the equipment for application, droplet size, spraying frequency, area size, plant height, foliage or trunk type and the biology and epidemiology of the pests involved. Each situation must be evaluated on its own merits in order to optimize chemical control.

Some of these aspects have already been studied by the product manufacturers who then recommend a certain dosage for a specific pest in a certain crop. This means that the label will give a dosage or range of dosages expressed in kg or l/ha according to the formulation. However, these recommendations are for agricultural crops and care should be taken before using them for forestry applications.

For use in nurseries, the recommendations given on the label for small plants such as vegetables, rice or ornamentals can be used. For larger plants such as saplings up to 4 or 5 m in height, the recommended dosage for coffee and fruit trees (cacao, citrus, soursop etc.) should be used. For mature trees the situation is more complex and it is better to consider concentration rather than dosage, following this procedure:

a) Prepare a known volume of water (a barrel or tank for example) plus any coadjuvants necessary.

b) Spray this over the application area until it is all used up. This will allow calculation of the volume needed to protect one tree according to its height, leafiness, texture, etc.

c) Determine the number of trees to be protected (or number of hectares) and from the previously calculated volume, calculate the total volume of spray required (e.g. 12,000 liters).

d) It has been shown that foliar applications usually require between 0.05 and 0.1% **active ingredient** and soil applications 0.25 to 0.5% active ingredient. For foliage application the amount of active ingredient needed will be:

0.1 ---> 100
X ---> 12,000

X = 12 liters

e) If the product label says that the concentration of active ingredient is 40% then the quantity of **commercial product** required will be:

40 ---> 100
12 ---> X

X = 30 liters

f) This figure found in e) is the quantity of the commercial product that should be mixed with the amount of water plus adjuvants already measured to give the required **concentration.**

I. THE LABEL

The container (bag or bottle) of any pesticide will bear a label containing the product's trade name and other information such as common name, chemical composition, type, formulation, concentration, toxicity, warnings, symptoms of poisoning, first aid, medical treatment and antidotes, protection methods for the applicant and the environment, storage and transport methods, guarantee, instructions for use, preparing mixtures and application methods, recommended use, dosage and application method, intervals between applications and harvest and phytotoxicity.

There are many indications on the label and the user should comply with them so as to best utilize the product. Although there are many similarities between some pesticides, it must be emphasized that each has its specific characteristics which can only be understood by carefully reading the instructions.

J. PESTICIDE ATTRIBUTES

Pesticide use should be rationalized on the basis of economic (damage level, risk of expansion of a pest, etc.) and environmental considerations (protection of forest organisms, beneficial insects, water sources etc.).

If after deliberating all the economic considerations, the use of pesticides is unavoidable, the following criteria should be used for choosing a product: specificity or selectivity, toxicity, persistence and price.

The pesticides that are widely available in the market are not very or at all specific, with the exception of some fungicides and viral or bacterial products that have an insecticidal action. Selectivity is desirable to avoid negative effects on beneficial insects (pollinators and natural enemies), other forest animals, plants and forest workers. The toxicity should be high with respect to the pest but low for all other life forms. It should only be sufficiently persistent to carry out its function and then disappear from the environment since prolonged effects increase the possibilities of damage to other fauna. In restricted areas such as nurseries or saw mills where the resource to be protected (seedlings and logs) stay for fixed periods of time and there is little risk of affecting other organisms, a more persistent pesticide may be preferable. Price is an extremely variable factor since some products may cost ten or twenty times that of others.

Although it is practically impossible to find the ideal pesticide with high specificity and toxicity to the damage agent, low persistence and not expensive, these four criteria should assist in choosing the best pesticide for each situation. Other criteria that should also be taken into account include: biology of the animal pests and epidemiology of the diseases, type of action of the pesticide and its formulation. These will be discussed later.

2. PESTICIDE CLASSIFICATION

Pesticides are classified according to two general criteria: their chemical nature and mode of action.

A. CHEMICAL NATURE

The chemical composition of the pesticides currently available is so diverse that it is hard to establish categories which allow them all to be classified. The following categories cover the majority of pesticides:

a) Botanical products

These are derived from plants which have the natural capacity to kill insects. Amongst the most notable of these natural insecticides are nicotine, derived from tobacco leaves (***Nicotiana tabacum***), rotenone extracted from the roots of ***Derris*** spp. and ***Lonchocarpus*** spp. and pyrethrum from the flowers of ***Chrysanthemum cinerariefolium***. The chemical extraction of these substances is quite expensive, but there are now synthetic compounds such as pyrethroids which show the same characteristics as the natural analog. They are generally fast acting insecticides with a short residual effect. With the exception of the synthetic pyrethroids, these botanical insecticides are little used.

b) Inorganic compounds

These were the first insecticides used and are crystalline substances similar in appearance to salt. They are highly toxic to mammals and birds. The main products contain copper, sulfur, arsenic and mercury. Some have a specific action (fungicide, insecticide, acaricide, rodenticide) whilst others have a mixed action.

c) Organochlorines

These contain the elements carbon, hydrogen, chlorine and sometimes oxygen and sulfur. They are usually very stable and hence extremely persistent (from a few months to years) with a prolonged residual effect. They have a wide spectrum of action affecting many species of insects and mites. They are mostly contact poisons though some are stomach poisons or fumigants. Although they are not directly highly toxic to mammals and birds, they accumulate in the fat of several body tissues and by biological magnification can have fatal consequences to organisms occupying the top of the food chain. Their chief advantage is price since they are relatively cheap to produce.

d) Organophosphates

These are phosphorus-containing organic compounds. They are the most toxic for vertebrates since they inhibit the enzyme cholinesterase in the nerve endings. This leads to the accumulation of acetylcholine resulting in incessant impulse transmission, paralysis and death. They are characterized by rapid action, a short residual effect and moderate price. Some show acaricidal, nematicidal or fungicidal effects but most act as insecticides. In insects they may act as contact or stomach poisons and even as fumigants.

e) Carbamates

These products are derived from carbamic acid and are very similar to organophosphates in their mode of action. Some are slightly and others extremely toxic to mammals and birds. Fortunately, their action on cholinesterase is reversible. They are usually fast acting, with a short residual effect, quickly dislodged from animal tissue and have a wide spectrum of action (some are insecticides, acaricides and molluscicides). They can act as stomach or contact poisons.

f) Dithiocarbamates

These products are derived from dithiocarbamic acid and have a strong fungicidal action, mainly due to their wide spectrum and low phytotoxicity. They form one of the biggest fungicide groups.

g) Heterocyclic compounds

These compounds have a fungicidal action and may act as inhibitors of nitrogenated heterocyclic compounds in fungal metabolism. They are widely applied on foliage, fruits and seeds without danger of phytotoxicity. Some may remain active in the soil for several weeks.

h) Phenolic tin compounds

These products are protective fungicides of limited use in horticultural crops because of their toxicity to man. They are used to control foliage fungi but the dosage must be carefully controlled since phytotoxicity can result.

i) Benzimidazols

These are very low toxicity fungicides. They can be absorbed by the plant and transported internally so that they are known as systemic fungicides. They are versatile and effective compounds that act on many phytopathogenic fungi, with the exception of the Oomycetes. They are used for foliar applications or seed treatment. Use in the soil is not recommended.

j) Oxatiino compounds

These are systemic fungicides used for seed treatment and control of blights.

k) Pyrethroids

These products are synthetic analogs of pyrethrum, a plant product, and have an insecticidal action. They can be effective in concentrations as low as 0.11 to 0.23 kg/ha (in contrast to carbamates, organophosphates and organochlorines which need between 1.1 and 2.3 kg/ha active ingredient). They have high toxicity to insects (and also fish) but are normally not very toxic to mammals and birds. They have a very short residual effect and their major inconvenience is cost. They can act as stomach or contact poisons.

l) Mineral oils

These are aliphatic hydrocarbons obtained from the distillation of petroleum fractions. Light (or summer) mineral oils can be used to control sessile homopterans and mites by covering them with a thin film of oil that prevents respiration. Their major problem is that they are to some extent phytotoxic. Apart from that, they are relatively safe for forest fauna, quite inexpensive and there is little risk of the pest developing resistance. They have a good penetration capacity and can be mixed with other insecticides to act in otherwise inaccessible places. For example, an insecticide can be transported by the mineral oil to the phloem of logs and posts where it can kill bark beetles.

m) Biological pesticides

These differ from pesticides mentioned previously since they are derived from living organisms. A few insecticides based on a virus or bacteria are already available, such as Thuricide, Dipel and Bactospeine which contain ***Bacillus thuringiensis***. There are also antibiotics which act against bacteria and fungi. These include streptomycin, terramycin and mycostatin. Biological pesticides are normally highly specific, act in low concentrations and are very expensive, especially the antibiotics.

B. MODE OF ACTION

There are great biological differences between the organisms that affect seeds, seedlings and trees and these differences determine how a given pesticide acts. According to their mode of action, pesticides such as insecticides, acaricides, rodenticides etc. are classified as contact poisons, stomach poisons or fumigants. Fungicides are divided into protectors or residuals and systemic or curative.

a) Contact poisons

These act by rapidly and directly penetrating the cuticle of the insect either when they are sprayed onto them or when the organism moves over a sprayed area. Their effectiveness depends more on the exposure and mobility of the insect than its feeding habits and they act on chewing, sucking and pollinating insects, etc. Some poisons known as **translaminar** or **penetration** products, can be translocated across the leaf lamina or other plant tissue and act on contact with larvae hidden in, for example mines, galls, inside buds and thin stems. The majority of these are organophosphates. Contact poisons are found in all the chemical groups, but predominate in the organochlorines.

b) Stomach poisons

To be effective, these poisons must be ingested along with the pest's food and move to the midgut or stomach. In the case of exposed chewing insects which eat foliage, roots, seeds and parts of stems and buds, the product is ingested along with the treated plant tissue. In the case of non-exposed or hidden insects, translaminar stomach poisons will reach the chewing insects and some piercing-sucking insects.

For most sucking insects, **systemic** products are used. These penetrate the tissues of the plant when applied as foliar sprays, soil application of granules, or injections or bands on the trunk. They are spread through the transport tissue and collect in the sap, especially in areas of high metabolic activity. When a hemipteran, homopteran or thysanopteran ingests the sap, the poison is carried to the insect's stomach. It should be noted that systemic products move more rapidly via the xylem than the phloem so that new buds and terminal meristems will be protected long before the lower parts of the tree. Also, the metabolic activity of the tree and the flow of water this implies, encourages the dispersal of the insecticide, so that in times of water shortage, dispersal of the product will be lessened. Systemic products have the advantage of only affecting those insects which suck the sap and will not harm other fauna.

Stomach poisons appear in all chemical groups but predominate among the organophosphates. Of the systemics, nearly all are organophosphates with some carbamates.

In the case of rodent control, there are two types of stomach poison: **acute** and **chronic**. The first act almost instantaneously but the animal can quickly learn to avoid these poisons. The second type are normally anticoagulants which produce haemorrhages in the digestive tract of the animal. They act gradually or accumulatively and must be eaten several times. They have the disadvantage of taking a long time (2-4 weeks) to act but there is less risk of learned avoidance.

c) Fumigant poisons

These products act in their gaseous state and should be used in confined spaces such as areas covered by canopies, hermetic chambers and silos. To be effective they should be volatile enough to reach all hidden areas. They are very useful for controlling insects and pathogens that attack seeds, not only in seed banks but also in plant quarantine centres. They can penetrate the upper layer of the soil and make contact with propagules and vegetative structures of bacteria, fungi, nematodes and insects. They can also be used in the underground tunnels of some rodent pests. Application to the soil can be very useful in relatively small areas such as nurseries prior to planting.

Since they are normally non-specific in their activity and can cause phytotoxicity problems, it is important that they should have disappeared from the soil before sowing or transplanting.

d) Protective or residual fungicides

One of the main characteristics of residual fungicides is their toxicity against a wide spectrum of microorganisms.

Their use in plant protection is widespread and they are applied in a more or less insoluble form over the surface of the host where they kill germinating spores. They do not penetrate the internal tissues of the plant.

These products are mainly used on plant parts above ground. They must already be on the susceptible plant part before the pathogen arrives since their residues impede spore germination or penetration of the germ tube. They are also used for seed treatment.

e) Systemic or curative fungicides

These fungicides can move through the transport tissue of the plant without causing phytotoxicity. With a few exceptions, they are carried in the transpiration column from the soil to the leaves. The products are selectively toxic towards one site or physiological process in the fungus. Transport of the product within the plant is not always efficient since it is influenced by environmental conditions and the physiological state of the plant. In applications to trees, the movement is translaminar, that is to say that the product is absorbed by the upper surface and translocated to the lower surface of the leaf. It should be noted that no systemic product can spread throughout the entire plant conferring total protection. It should also be noted that the product is normally effective for 10-12 days after application.

3. FORMULATIONS

As already mentioned, the active ingredient of any pesticide is never applied by itself. Non-toxic substances known as adjuvants are added to improve the efficiency of the product and this gives rise to the many types of formulations.

A. FORMULATION TYPES

a) Dry powders or dusts

The active ingredient, which may be 0.1 to 25% of the mixture, is impregnated onto a suitable powder (talc, clay, ground nut flour etc.) to improve distribution. These powders are applied in the form that they are purchased but are not favored by many users since they have little coverage potential. Particle size is very important since the smaller the particle size, the better the coverage.

b) Wettable powders

These have the same appearance as dry powders, but the concentration of active ingredient is higher (sometimes up to 75%). They can be mixed with water and sprayed like liquids, but in order to achieve a homogeneous suspension, a surface-active (dispersal) agent and constant stirring is needed.

c) Soluble powders

The active ingredient is a powder itself (in concentrations from 75-95%) and is formulated with surface active agents to dissolve readily in water. The result is a true solution that has no sedimentation problems.

d) Emulsifiable concentrates

In this formulation, which is the commonest and perhaps the most useful, the active ingredient, in concentrations of 20-75%, is mixed with an oil and an emulsifying agent similar to a detergent.

e) Suspensions

These products look like a thick cream. The active ingredient is insoluble in oil or water and is mixed with clay or molasses to form a paste which is ground up. This damp material can be mixed with water but suffers from the same problems as wettable powders.

Microcapsules are a more refined form of suspension and are discussed below.

f) Oil-based solutions

In this case the active ingredient is dissolved in mineral oil. These solutions should be used with caution on live plants because of phytotoxicity problems. Some products come already diluted whereas others must be diluted with diesel or kerosene.

g) ULV concentrates

The active ingredient is formulated either in its original liquid form or with the minimum of solvent and sprayed with no further dilution. The sprayer type used (Ultra-low-volume) produces an extremely fine spray. Instead of the usual volumes of 11-38 l/ha, these sprayers use only 0.6-4.7 l/ha, representing an enormous saving.

h) Aerosols

To be used in this form, the active ingredient must be soluble in a volatile, petroleum-based solvent, under high pressure. When the solvent makes contact with the air it rapidly evaporates leaving the minute particles of active ingredient (0.1-50 microns) suspended in the air.

i) Smokes

Here the active ingredient is mixed with substances that produce a smoke when burned. The smoke acts as a carrier with particles about 5 microns diameter. These condense on contact with cooler surfaces leaving a film of pesticide.

j) Fumigants

These are toxic products formulated as liquids under pressure in cans or tanks. When liberated, the product forms a volatile gas which kills the damage agent on contact.

k) Microcapsules

These are microscopic spheres, 15-50 millimicrons in diameter, containing the active ingredient and dispersed in an aqueous medium. The capsules are permeable, allowing the pesticide to slowly be released. In this form, the product can be effective for 2-4 times as long as in the form of an emulsifiable concentrate.

l) Granules

The active ingredient is mixed with a solvent and poured over clay particles. Once the solvent has evaporated, the granules are packaged ready for use. The pesticide is liberated as the granule disintegrates. The concentration of active ingredient varies between 2 and 25%. Granules are particularly useful for application to plant roots as contact or systemic products.

m) Baits

Toxic lures consist of a mixture of the active ingredient with a substance which will attract the pest either through smell or taste. On consumption of the attractant, the pest ingests the pesticide and dies. Among the most notable are the anticoagulants used against rodents, metaldehyde and bran mix used to kill slugs and Mirex which is used against ants.

n) Pastes

The active ingredient is dissolved in an organic petroleum based solvent containing a special mixture of tiny quantities of plastics and shellac. The resultant paste or paint is applied to tree trunks or branches. As the solvent evaporates, a thin film containing the pesticide is left behind. The product is slowly liberated over long period of time making it effective against animals that walk over these surfaces.

o) Injections and implants

The first of these options uses high pressure to inject systemic pesticides into the soil. Implants are small plastic tubes, (1 x 2.5 cm for example) inserted into the trunk in holes made by drilling. These tubes contain a gelatine capsule filled with a powder that dissolves in the sap. It is also possible to insert a tube leading to a container of systemic product.

B. ADJUVANTS

These substances either come ready mixed with the product or must be added to the mixture prior to application. Some of the more important ones are described below. Some commercially prepared adjuvants have a mixed role.

a) Dispersants

These are used with wettable powders to prevent the powder floating or sedimenting and to give a homogeneous suspension.

b) Emulsifying agents

These are similar to detergents and allow oils to fragment into millions of tiny droplets which remain suspended in the water, forming an emulsion.

c) Wetting agents or surfactants

These reduce the surface tension of liquids and permit the formation of emulsions. They also assist in distributing the mixture on the surface being treated allowing better coverage and more uniform penetration for more efficient action.

d) Humidifiers

These retard water evaporation from the mixture and are mainly used with herbicides.

e) Penetrants

These help the mixture to penetrate the plant tissues or the tissues of the damage agent.

f) Adherents or "stickers"

These allow the mixture to adhere better to the sprayed surface so that it is not washed off or blown off so easily by the wind or rain.

4. APPLICATION EQUIPMENT

The choice of equipment to use for applying pesticides depends on the characteristics of the nursery or plantation (plant height, topography, area, etc.) and the formulations available. There is a wide range of equipment available from manual sprayers to booms for helicopters. Only those suitable for forest applications will be discussed here. Pesticides may be applied from ground level (using portable or tractor mounted sprayers) or from the air (using light planes or helicopters fitted with sprayer booms).

A. LIGHT PORTABLE EQUIPMENT

These include manual and motor driven backpack sprayers. The manual type sprayers (Fig. 82) have a handle which must be pumped continually to release the liquid stored in the tank. They have a small capacity (15-20 liters) and have to be refilled frequently. The upper reach of the spray is about 2-3 m. They are very effective in nurseries, young plantations and for spraying logs. The spray can reach up to 5 m with the addition of an extension lance.

Motorized sprayers (Fig. 83) are superior since the droplet size is smaller allowing better coverage. Since the spray is propelled by compressed air, the penetration is greater within the foliage of dense trees. Spraying can be achieved faster and with less effort and filling is automatic. They are very versatile since by changing the nozzle and fitting other attachments, the sprayer can be used for dusting, applying granules and for fogging. With the regular attachments this type of sprayer can reach heights up to 9 m.

Figure 82. Manually operated backpack sprayer.

Figure 83. Motorized backpack sprayer.

Some sprayers are used exclusively for fogging (Fig. 84). A stream of hot, oil based, concentrated pesticide is injected into a hot gas and vaporized. The product is expelled in the form of minute particles in a fog. These particles are not deposited on any surface and are useful for killing insects in flight. The fog has great penetration capacity and so is useful for high, dense plantations. However, application is restricted by atmospheric conditions. To avoid up draughts displacing the fog, fogging should be done when the ground is cooler than the air (early evening or early morning when there is a temperature inversion). For the same reason, fogging should not be carried out in nurseries or plantations of short trees.

Figure 84. Thermal fogging machine (fogger).

B. TRACTOR MOUNTED EQUIPMENT

These have tanks with a capacity between 100 and 1000 liters and must be mounted on heavy agricultural machinery. Although some are used for dusting, most are for use with liquids, such as hydraulic sprayers and air carrier sprayers.

Low pressure, low volume hydraulic sprayers (Fig. 85) are frequently used in agriculture and are also useful in large, flat nursery areas. The spray boom is normally mounted on a tractor and the plants are sprayed at a rate of 1-25 gal./min. The low pressure and volume limit the penetration of product to the foliage. High pressure, high volume sprayers (Fig. 86) can apply 8-85 gal./min. and easily penetrate dense foliage. When fitted with extension hoses, the spray can reach up to 20-30 m in height.

In air-carrier sprayers (Fig. 87), the pesticide comes into contact with a stream of air generated by an internal fan. The airstream breaks up the product into a fine spray of droplets and carries it to the nozzle. The large volumes employed along with the homogeneity of droplet size allows better control of damage agents. They can be used in forestry plantations where there is good spacing between rows and the trees are of uniform height. There are also air-carrier sprayers designed to spray more concentrated product. They apply the same quantity per unit area but use less water.

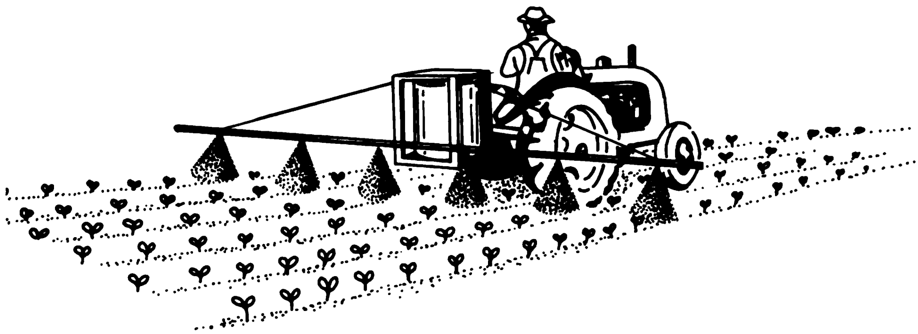


Figure 85. Low pressure, low volume hydraulic sprayer.

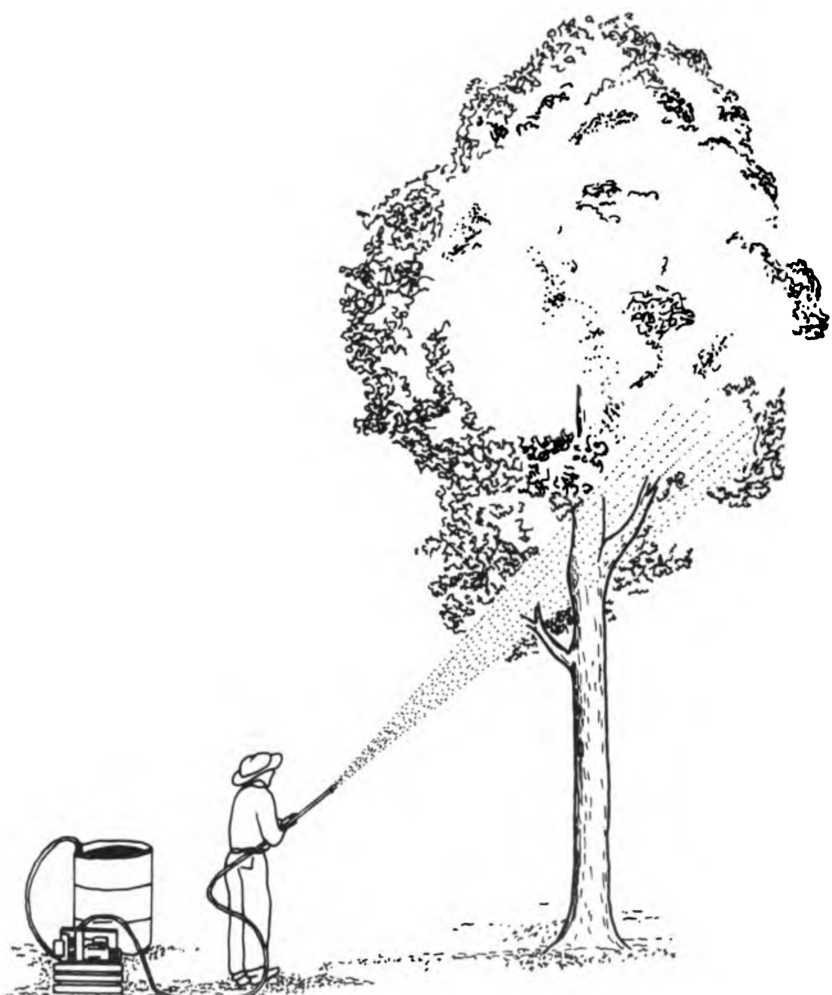


Figure 86. High pressure, high volume hydraulic sprayer.

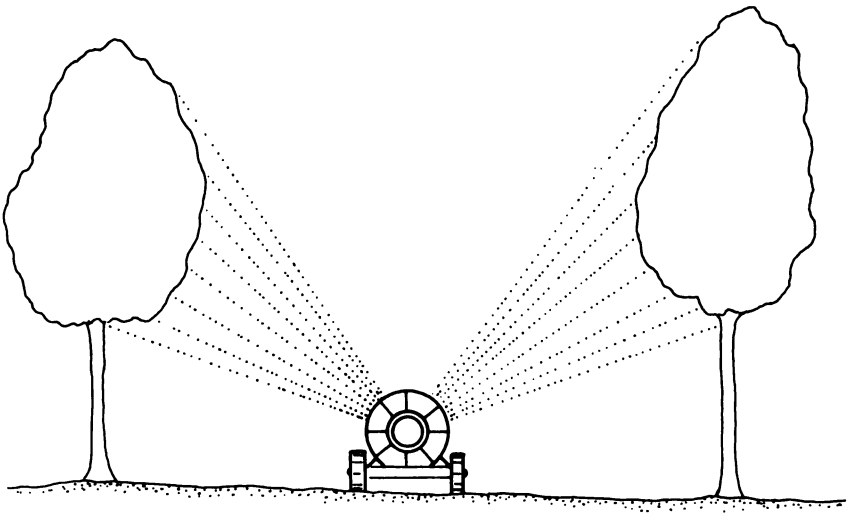


Figure 87. Air-carrier, blower, air-blast or air-mist sprayer.

There is also apparatus for producing cold fogging which can be tractor mounted and uses the spray boom as a fan. This produces an air current which, with the help of special nozzles, forms a fog and can be used for oil based pesticides and those in emulsion.

All tractor mounted apparatus has the great limitation of only being usable where the land is fairly flat. This is not the case for most Central American plantations.

C. LIGHT PLANES AND HELICOPTERS

This method of application only makes sense for large plantations that are inaccessible or very high. In order to be economically viable, the area to be sprayed should be no less than 200 ha.

Light planes used for spraying (Fig. 88) are normally low speed (100-150 km/h) and only need a short landing strip. Helicopters (Fig. 89) can be adapted to carry pesticide tanks and sprayer booms and are superior to planes because of their greater maneuverability and because the rotor blades create a downdraught which assists penetration of the spray into the canopy. The major disadvantage of aerial application is the risk of spray drift into water sources, crops or areas of habitation bordering the plantation.

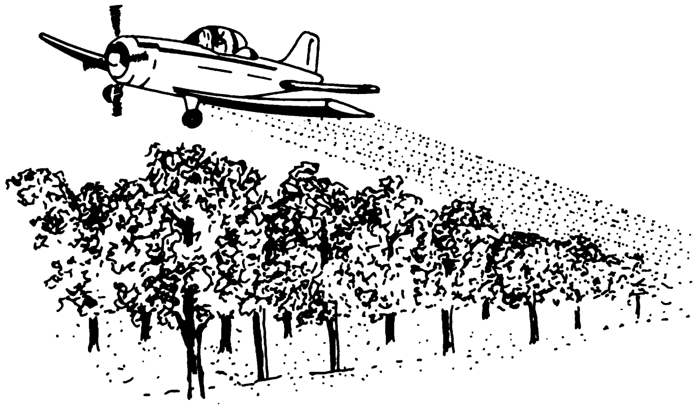


Figure 88. Spraying from light plane.

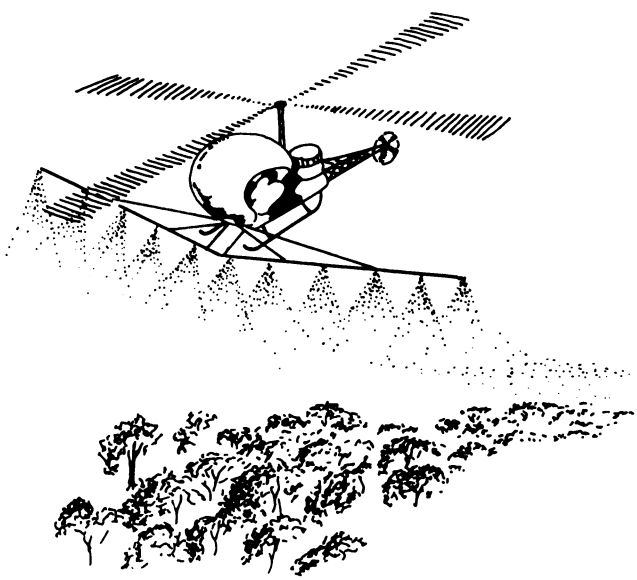


Figure 89. Spraying from helicopter.

5. SIDE EFFECTS

As already discussed, all chemical pesticides are to a greater or lesser extent poisons which should be handled with great care. There are some pesticides whose intrinsic properties make them harmful to humans since they may cause cancer (carcinogenic), mutations (mutagenic), sterility (spermatogenic or gonadotropic), congenital deformities (teratogenic) or fetal death, premature birth (fetotoxicity), etc. These products should be banned despite their usefulness as pesticides. There are other pesticides which, whilst not intrinsically harmful, can cause serious problems through incorrect usage. These problems include reduction of beneficial insect populations, development of resistance or immunity, death of forest fauna, soil and water pollution, phytotoxicity and residues in food (in agriculture). Although all these problems are important, four merit further discussion here.

A. EFFECTS ON BENEFICIAL ORGANISMS

In forestry plantations there are not only larger animals but also insects which act as predators or parasitoids of the pest, as mentioned in Chapter III. These insects keep in check the populations of insects which could otherwise be problematic. For this reason the latter are known as secondary or potential pests. The uncontrolled use of pesticides can result in a perceptible reduction in the population of natural enemies and the potential pest can then become a primary pest.

Another consequence of pesticide misuse is the reduction of populations of pollinating animals (especially lepidopterans, hymenopterans, bats and birds). This can result in a reduction in fruit and seed production, not only for forest species, but also in nearby agricultural crops. In the specific case of the honey bee (***Apis mellifera***), this can have a serious impact on honey production.

B. DEVELOPMENT OF RESISTANCE

Resistance can be defined as the ability of a group or race of organisms to survive after exposure to an amount of pesticide that would normally kill the majority of the population to which those organisms belong. Resistance has been found in insects, mites, rodents, fungi and bacteria. There may be resistance because there is no contact between the pest and the pesticide or because through mutation or genetic recombination, the organism has developed mechanisms to employ other means of survival and still cause damage.

It must be emphasized that resistance is not a static phenomenon. Although it depends to some extent on the intrinsic characteristics of the damaging organism (short life cycles and high fecundity in insects, and short incubation periods and high levels of spore production in pathogens) it depends more on the selection pressure exerted by the pesticide. In this way the more often that pesticides are applied, the more selection pressure operates on organisms whose genes confer tolerance. The survivors will give rise to resistant strains. The situation is complicated by the fact that not only can an organism develop resistance to more than one pesticide through different mechanisms (multiple resistance), but it can also develop resistance to products it has never been exposed to (cross resistance).

There are no specific guidelines to avoid or slow the development of resistance but rotation of products (alternating products with a different mode of action) or mixing them, using half the dosage for each, is recommended. In any case, this should be accompanied by practices which reduce the use of pesticides, incorporating control measures such as those described in Chapter III.

C. HUMAN POISONING

Although there is a risk of poisoning for anyone who comes into contact with the pesticide, the dangers are greatest for those who mix and apply the products in the field.

It is important to distinguish between the two types of poisoning which occur: immediate and long term. The first kind appear shortly after exposure to the pesticide. Although the symptoms may vary due to the different chemical compositions that exist, the most frequent are headaches, stomach and chest pains, dizziness, sweating, vomiting, blurred vision, mouth and nasal secretions, diarrhea, muscular spasms, respiratory difficulties, convulsions and paralysis. In cases of acute poisoning it is often relatively easy to establish a link between the symptoms and the pesticide.

Pesticides can occasionally produce chronic or long term effects giving rise to diseases of the skin, mucous membranes, nervous system, blood, internal organs etc. or be carcinogenic, mutagenic, spermatogenic, gonadotropic, teratogenic and fetotoxic. These are the more worrying aspects since it is not easy to associate the pesticide with the health problem and so take precautionary measures when dealing with that product.

D. PHYTOTOXICITY

Phytotoxicity is the ability of a pesticide to produce lesions in or cause the death of a plant. The effect may result from the active ingredient, from one of the inert additives, an incompatible mixture of products or from the application method (high pressure or concentration). Similarly, there are variations in the susceptibility of the plant according to its age and species.

Although the risks of phytotoxicity are always given on the label, these usually refer to agricultural crops and not to forest species. For this reason it is advisable to consult an extensionist or other person familiar with the product or, failing that, experiment on a small scale, starting with a dosage lower than that recommended.

6. SAFETY

In view of the dangers implicated in the use of pesticides, safety precautions should be taken from the moment the product is acquired. Care should be taken in its transportation, storage, application, the destruction of containers, disposal of leftovers, washing equipment and protective clothing and in personal hygiene. Both governmental institutions and private businesses have published guidelines on the safe handling of pesticides. These should be consulted thoroughly since there is no space to cover these aspects in great detail here.

By attacking the root of the problem using the control methods outlined in Chapter III, it is hoped that the need for pesticides will decrease and with it the risks of poisoning, environmental pollution etc. Nevertheless, it cannot be emphasized enough that it is essential to read all the information on the product's label and follow it, despite the unfortunate fact that a high proportion of the population of the region is illiterate. This, combined with the use of adequate protective clothing will lessen the risks, especially those of poisoning in field workers.

7. GUIDELINES FOR PESTICIDE USE

As already mentioned, there is little experience of chemical control of forest pests in Central America. Because of this it is somewhat premature to offer specific recommendations. The following guidelines are given more to help avoid some of errors frequently seen in the region's forest projects. It is hoped that by following these guidelines, pesticides will be used more rationally and that the results of their application will be made known so that there is more accurate information available in the medium term. For this reason the following guidelines should be regarded more as working proposals than recipes for rapid solutions.

A. INSECTICIDES

For the sake of simplicity, all information on insecticides appears condensed and in alphabetic order in Tables 1 and 2. In the descriptions that appear below, code numbers are used for each insecticide so that from Table 1 the user can find the common name, chemical nature, type of action, toxicity and known formulations. Table 2 gives the trade names for these products.

It should be noted that although these tables contain information on a wide range of insecticides, not all are available in all Central American countries. This may be because they are not registered in a certain country, or because their use is restricted or prohibited, as has happened with organochlorines. Similarly not all types of formulations may be available in the region and trade names may vary from country to country.

The guidelines for pesticide use are made according to the plant structure damaged by the insect. Where the use of a certain insecticide is indicated, no consideration has been made for cost or toxicity to man. The information presented has been gathered, largely, from the works of HOCHMUT & MANSO (1975), JIMENEZ & FERNANDEZ (1983), KING & SAUNDERS (1984) and THOMSON (1989).

a) Flowers

Contact and stomach poisons can be used for exposed insects and translaminar products for those that attack the internal organs. It is important to choose products which will not affect pollinators, e.g. 1, 15, 25, 32, 33, 45, 56 and 69.

b) Fruits

In the field, some flies attack the pulp of fruit and these can be controlled using contact or stomach poisons such as 5, 13, 14, 18, 36, 49, 58, 61, 63 and 70.

c) Cones and seeds

These can be protected in the field with contact or stomach poisons such as 4, 9, 18, 19, 40, 61 and 63. For stored products, fumigants such as 29 can be used as long as the dosage has no effect on viability.

d) Roots and seedlings

Soil insects such as white grubs and cutworms can be controlled in two stages. At the time of sowing or transplanting, contact products in granular or powder form (3, 7, 12, 13, 14, 16, 18, 21, 28, 30, 37, 46, 61, 63 and 69) should be applied to the soil with fertilizer. When the trees are already established it is difficult to apply these especially if the ground is hard. There are liquid formulations of the same products that can be used at this stage.

e) Buds and shoots

Since these are soft, thin structures, the larvae within them can be controlled using products with translaminar action (1, 36 and 47). In the nursery, granular formulations of systemic products (2, 9, 24, 38, 54 and 62), some of which are persistent for up to two months, can be used. Adults of the species can be controlled with contact insecticides.

f) Foliage

Exposed chewing insects can be controlled directly using contact poisons and also by spraying the foliage with stomach poisons. Some products (18, 30, 33, 51, and 56) act simultaneously as stomach and contact poisons, and have shown effectiveness against exposed chewing insects. In the specific case of thrips, which have a rasping-sucking type of mouthparts, contact, stomach and systemic products can be applied, e.g. 1, 3, 5, 18, 19, 22, 26, 27, 30, 32, 36, 40-43, 49, 51-55, 59 and 68. Leaf miners and gall formers are best controlled using translaminar products (1, 36, 47), systemics (20, 51) or Evisect (Thyocyclam), a biological product.

Sucking insects can be attacked with contact products (5, 7, 8, 13, 18, 19, 23, 25, 27, 32, 33, 40, 45, 49, 63) or systemics (1, 22, 24, 36, 42, 44, 47, 51, 53-55, 57-59, 68). However, scale insects and some aphids with waxy coverings should be controlled using contact poisons mixed with mineral oil, such as 4, 9, 32, 36, 45 and 49. Product 62 is highly specific to aphids and very effective.

g) Vascular tissue

The major obstacle to controlling bark beetles is the thickness of the bark tissue. Materials such as oils should be used so that they can cross the barrier and carry the insecticide with them. Contact or stomach insecticides such as 5, 6, 8, 10, 14, 19, 48, 49, 66, 69 and 70 should be used taking care that the oil carrier is compatible with the product and also that it is not phytotoxic. In general, oils damage thin, succulent bark but function well for dryer, thicker barks.

h) Xylem and pith

Control of xylem and pith borers, along with fungus carrying beetles, is more complex than that for pests of the vascular tissue, since the product must penetrate deeper into the tissues. The same contact and stomach poisons mentioned in the previous paragraph should be used but mixed with oils that have greater penetration capacity. In the case of borers whose galleries are wide, easily seen and accessible, the insecticide can be injected directly into the tunnel using a syringe and the entrance sealed up. Contact products that vaporize (5, 14, 19, 40, 57 and 64) are best for this.

For termites, the best products are organochlorines such as 3, 12, 21 and 37. For timber pests, the best is BHC mixed with oil or fumigants such as methyl bromide or ethylene dibromide.

B. FUNGICIDES

There are fewer fungicides available for sale compared to insecticides, and they are less specific. The advantage of fungicides is that they are broad spectrum in action and affect large groups of fungi. For this reason they can be used where there are several pathogens. They are also very versatile in application, since the same product can be used on the soil, foliage and seeds. Perhaps the most important factor is that they have no injurious effect on other forest organisms, unlike most insecticides.

Information relating to fungicide use is also presented in the tables. The common and trade names appear in Table 3 along with their mode of action: systemic (S), protective (P), fumigant (F) or antibiotic (A). A code letter is used for each common name and this is used in Table 4. The last column refers to the most frequently recommended use i.e. whether for soil application (S), foliage (F) or seed treatment (T).

Table 4 shows a list of the commonest pathogens attacking forest species, the code number of products that can be used to control them and some general observations.

C. OTHERS

The following covers the action of pesticides on other animals such as mites, nematodes, mollusks and vertebrates.

a) Acaricides

There are products that are specific to mites such as Bromopropilate (Acarol, Neoron), chlorobenzilate (Acaraben, Akar), dicofol (Kelthane, Acarin), dienochloride (Pentac), fenbutatin oxide (Vendex, Torque), propargite (Omite, Comite) and tetradifon (Tedion, Duphar). In addition, several insecticides act as acaricides, as in the case of 2, 9, 13, 19, 22, 24, 25, 27, 36, 40, 42-45, 51-55, 57-60, and 68.

b) Nematicides

There is one specific product against nematodes: fenamiphos (Nemacur). Several insecticides also have nematicide activity, such as 2, 9, 18, 28, 31 and 54 and the fumigants methyl bromide and ethylene dibromide.

c) Molluscicides

Metaldehyde (Ortho-B, Ariotox) is effective against slugs and snails, especially when formulated as a bait and used at night. Insecticides 25 and 46 are also effective.

d) Rodenticides

Since rodents are the most problematic of all vertebrates, most efforts have been directed at them. Acute action poisons such as zinc phosphate, strychnine and sodium fluoroacetate are formulated as bait, likewise the chronic anticoagulants such as difacinone (Matex), cumatetralyl (Racumin) and brodifacoum (Klerat). Lastly there are fumigants such as aluminium phosphate (Phostoxin, Detia Gas-Ex-T) formulated as tablets. When these are placed in the underground tunnels, they react with the humidity to produce a gas which suffocates the rodents.

Table 1. Basic characteristics of insecticides used in forest protection*.

Code	Common name	Chem. nature	Mode of action	Tox.	Formulations
1	Acephate	OP	C,St,Sy	M	SP
2	Aldicarb	C	C,St,Sy	E	G
3	Aldrin	OC	C,St,F	M	D,EC,G,O,WP
4	Azinphos-Methyl	OP	C,St	H	D,EC,WP
5	BHC	OC	C,St,F	H	D,EC,O,WP
6	Bromophos	OP	C,St	M	D,EC,WP
7	Bufencarb	C	C	S	EC,G
8	Carbaryl	C	C,St	S	C,D,EC,G,WP
9	Carbofuran	C	C,St,Sy	H	G,S
10	Carbophenothion	OP	C,St	E	D,EC,WP
11	Cartap	C	C,St	H	D,G,SP,WP
12	Chlordane	OC	C,St	M	D,EC,G,SP,WP
13	Chlorfenvinphos	OP	C	S	EC,G,WP
14	Chlorpyrifos	OP	C,St,F	M	EC,G
15	Cypermethrin	P	C,St	M	EC,ULV
16	DDT	OC	C,St	M	D,EC,G,S,WP
17	Decamethrin	P	C,St	S	EC,ULV,WP
18	Diazinon	OP	C,St	M	D,EC,G,O,ULV,WP
19	Dichlorvos	OP	C,St,F	H	E,EC,SC,WP
20	Dicrotophos	OP	C,St,Sy	H	EC,ULV
21	Dieldrin	C	C,St	M	D,E,EC,G,S,WP
22	Dimethoate	OP	C,St,Sy	M	D,EC,WP
23	Dioxacarb	C	C,St	M	ULV,WP
24	Disulfoton	OP	C,St	E	G,S
25	Endosulfan	OC	C,St	H	D,E,EC,SC,G,ULV, WP
26	Endrin	OC	C,St	H	D,EC,ULV,WP
27	Ethion	OP	C	H	D,EC,G,WP
28	Ethoprop	OP	C	E	EC,G
29	Ethylene dibromide		F	E	Fumigant
30	Fenitrothion	P	C,St,Sy	M	D,EC,G,O,ULV,WP
31	Fensulfothion	OP	C	E	G,SC

* See end for key to symbols

Table 1. Continued.

Code	Common name	Chem. nature	Mode of action	Tox.	Formulations
32	Fenthion	OP	C,St	M	D,EC,G,SC,ULV,WP
33	Fenvalerate	P	C,St	M	D,EC,G,ULV,WP
34	Flucythrinate	P	C	M	EC
35	Fonofos	OP	C	E	EC,G
36	Formothion	OP	C,St	S	EC,ULV
37	Heptaclor	OC	C,St	H	D,EC,G,SP,WP
38	Isofenphos	OP	C	H	EC,G
39	Leptophos	OP	C	M	D,EC,G,WP
40	Malathion	OP	C,St	M	D,E,EC,SP,ULV,WP
41	Malathion + M.P.	OP	C,St	E	E,EC,ULV
42	Mecarbam	OP	C,St,Sy	H	D,EC,G
43	Mephosfolan	OP	C,St,Sy	E	E,EC,G
44	Metamidofos	OP	C,St,Sy	E	SC
45	Methidathion	OP	C	E	EC,ULV,WP
46	Methiocarb	C	C,St	H	C,D,WP
47	Methomyl	C	C,St,Sy	E	SC,SP
48	Methoxychlor	OC	C	S	D,EC,WP
49	Methyl parathion (M.P.)	OP	C,St	E	D,E,EC,M,WP
50	Mirex	OC	C,St	M	C
51	Monocrotophos	OP	C,St,Sy	H	EC,SC
52	Naled	OP	C,St	H	D,E,EC
53	Omethoate	OP	C,St	H	EC,SC,ULV
54	Oxamyl	C	C,St,Sy	H	G,SC
55	Oxydemeton - methyl	OP	C,Sy	H	EC,SC
56	Permethrin	P	C,St	M	EC,WP
57	Phorate	OP	C,F,St,Sy	E	EC,G
58	Phosphamidon	OP	Sy	E	EC,L,SC,ULV
59	Phospholan	OP	C,St,Sy	E	EC,G
60	Phosmet	OP	C	M	WP
61	Phoxim	OP	C,St	M	D,EC,G
62	Pirimicarb	C	C,F,St,Sy	H	EC,G,WP
63	Pirimiphos - ethyl	OP	C,F	M	EC,G,M

Table 1. Continued.

Code	Common name	Chem. nature	Mode of action	Tox.	Formulations
64	Pirimiphos - methyl	OP	C,F,St	S	D,EC,ULV
65	Profenfos	OP	C,St	M	EC,WP
66	Promecarb	C	C,St	H	D,EC,WP
67	Terbufos	OP	C	E	G
68	Thiometon	OP	C,St,Sy	M	EC,ULV
69	Toxaphene	OC	C,St	M	D,EC,WP
70	Trichlorfon	OP	C,St	H	G,SC,SP,ULV,WP

Key:

Chemical nature

C = carbamate; OC = organochlorine; OP = organophosphate
P = pyrethroid

Mode of action

C = contact; F = fumigant; St = stomach; Sy = systemic

Toxicity

S = slight; M = moderate; H = high; E = extreme

Formulations

C = clay; D = dust; E = emulsifyable; EC = emulsifiable concentrate; G = granules; L = soluble liquid; M = microcapsules; O = oil; S = suspension; SC = soluble concentrate; SP = soluble powder; ULV = ultralow volume; WP = wettable powder.

Table 2. Most common trade names for the insecticides cited in Table 1.

Code	Common name	Trade name
1	Acephate	Orthene
2	Aldicarb	Temik
3	Aldrin	Aldrin
4	Azinphos-methyl	Gusathion
5	BHC	Lindane
6	Bromophos	Brofene,Nexion,Netal
7	Bufencarb	Bux
8	Carbaryl	Sevin,Sevimol
9	Carbofuran	Curater,Furadan
10	Carbophenothion	Trithion,Nephocarb,Dagadip
11	Cartap	Padan
12	Chlordane	Clordane,Attaclor
13	Chlorfenvinphos	Birlane,Sapecron
14	Chlorpyrifos	Lorsban,Dursban
15	Cypermethrin	Cymbush,Ripcord
16	DDT	DDT
17	Decamethrin	Decis,K-Othrin
18	Diazinon	Diazinon,Basudin
19	Dichlorvos	Nuvan,DDVP,Vapona
20	Dicrotophos	Bidrin
21	Dieldrin	Dieldrin
22	Dimethoate	Dimethoate,Perfekthion,Cygon
23	Dioxacarb	Elocron,Famid
24	Disulfoton	Di-Syston,Solvirex
25	Endosulfan	Endosulfan,Thiodan,Cyclodan
26	Endrin	Endrin,Insectrin,Endrex
27	Ethion	Nialate,Hylemox,Ambathion
28	Ethoprop	Mocap
29	Ethylene dibromide	EDB,Bromofume,Soilbrom
30	Fenitrothion	Agrothion,Sumithion,Dybar
31	Fensulfothion	Dasanit,Terracur
32	Fenthion	Lebaycid,Baycid,Entex
33	Fenvalerate	Belmark,Pydrin,Sumicidin
34	Flucythrinate	Pay-Off
35	Fonofos	Dyfonate

Table 2. Continued.

Table 2. Continued.

Code	Common name	Trade name
36	Formothion	Anthio
37	Heptachlor	Heptachlor,Chlorahep
38	Isofenphos	Oftanol,Amaze
39	Leptophos	Phosvel,Abar
40	Malathion	Malathion,Crisofos 900, Cythion
41	Malathion + M.P.	Cygard
42	Mecarbam	Murfotox
43	Mephosfolan	Cytrolane
44	Metamidofos	Tamaron,Monitor
45	Methidathion	Ultracide,Supracide
46	Methiocarb	Mesurol,Draza
47	Methomyl	Lannate
48	Methoxychlor	Marlate,DMDT,Methoxo
49	Methyl parathion M.P.	Folidol,Metidol,Penncap
50	Mirex	Mirex,Zompex,Paramex
51	Monocrotophos	Azodrin,Crisodrin,Nuvacron
52	Naled	Dibrom,Dibrocen
53	Omethoate	Folimat
54	Oxamyl	Vydate
55	Oxydemeton-methyl	Metasystox
56	Permethrine	Ambush,Pounce,Talcord
57	Phorate	Thimet
58	Phosphamidon	Dimecron
59	Phosfolan	Cylan,Cyolane
60	Phosmet	Imidan,Prolate
61	Phoxim	Volaton,Baythion,Valexon
62	Pirimicarb	Pirimor
63	Pirimiphos-ethyl	Primicid
64	Pirimiphos-methyl	Actellic
65	Profenfos	Curacron,Selecron
66	Promecarb	Minacide,Carbamult
67	Terbufos	Counter
68	Thiometon	Ekatin
69	Toxaphene	Phenatox,Phenacide
70	Trichlorfon	Dipterex,Dylox,Crinex

Table 3. Main fungicide products in use or with potential for use in controlling forest diseases.

Code	Common name	Trade names	Mode of action	Use
1	Benomyl	Afungil Benlate Benocric Benomal	S	T,F
2	Captafol	Difolatan	P	F
3	Captan	Cafudan Captan Merpan Orthocide	P	S,F,T
4	Carbendazim	Bavistin Derosal	S	F
5	Carboxin	Vitavax	S	T
6	Copper hydroxide	Cupravit Kocide	P	F
7	Copper oxide	Copper Sandoz Cuprocide Perenox	P	F
8	Copper oxychloride	Cobox Blue copper Copper F.W. Cupravit Cuprox Kocide	P	F
9	Copper sulfate	Basicop Tricop	P	F
10	Chloroneb	Cloroneb Demosam	P	S,T
11	Chlorothalonil	Bravo Bravonil Daconil	P	F
12	Cyproconazol	Alto 100 Atemi 100	S,P	F
13	Dazomet	Basamid	F	S
14	Dichlone	Phygon	P	F,T
15	Dinocap	Dinofum Karathane	P	F

Table 3. Continued

Code	Common name	Trade names	Mode of action	Use
16	Diodine	Melprex Venturol	P	F
17	Fentin acetate (Triphenyltin acetate)	Brestan Trimastan	P	F
18	Ferbam	Ferbam Fermate Karbam	P	F
19	Mancozeb	Dithane M-45 Fungineb Manzate 200	P	F
20	Maneb	Dithane M-22 Maneb 80 Manzate Polyram M Superior 80	P	F
21	Metalaxyl	Ridomil	S	S,F
22	Methyl bromide	Methyl bromide Dow Fume	F	S
23	Methyl thiophanate	Banrot Cercobin M Cycosin Fumgo Topsin	P,S	S,F
24	Metiram comp.	Polyram-CCombi	P	F,T
25	Oxycarboxin	Plantvax	S	F
26	PCNB	Banrot Brassicol PCNB Terraclor Terrazan	P	S
27	Phenyl mercury acetate	Ceresan	P	T
28	Streptomycin	Agrimicin Distreptina	A,S	F
29	Sulfurs	Wettable S Azufral	P	F

Table 3. Continued.

Code	Common name	Trade names	Mode of action	Use
		Elosal Kumulus Sulfan Thiovit		
30	Thiabendazol	Mertec TBZ Tecto Termazol	S	F,T
31	Thiram	Arasan Pomasol Forte Thylate	P	F,T
32	Triadimefon	Bayleton	P,S	F
33	Triadimenol	Bayfidan	P	F
34	Tridemorph	Calixin	S	F
35	Triphenyl tin hydroxide	Du-ter	P	F,T
36	Vapam	Vapam	F	S
37	Zineb	Dithane Z-78 Lonacol Z Parsate Tritoftorol Zineb	P	F

Table 4. Common pathogens of forestry species and fungicides recommended for their control.

Pathogen	Products	Observations
Alternaria sp.	19,20	Weekly application in nurseries.
Botrytis sp.	13,22,36	Fumigate substrate.
	1+31,1+3	Apply weekly for 21 days; alternate mixtures.
Ceratocystis sp.	1,4,16,30	Paint affected part weekly.
Cercospora sp.	1,2,8,11,19, 20	Apply every 10 days in nurseries; use 4 alone for first application.
Colletotrichum sp.	1,7,8,11,37	As for ***Cercospora***.
Corticium sp.	8,12,17,23,34	Paint affected part weekly.
Corynespora sp.	1,11,19	Apply weekly.
Cylindrocladium sp.	13,22,36	Fumigate substrate.
	1+31,1+3,3+31	Apply once a week for 4 weeks in nursery.
Dothistroma sp.	1,8,9	Apply weekly in nursery, every 2 weeks in plantation.
Fusarium sp.	13,22,30,36	Fumigate substrate.
	1+31,1+3,3+31	Apply once a week for 4 weeks in nursery.
Macrophomia sp.	13,22,36	Fumigate substrate.
Oidium sp.	1,29	Apply every seven or ten days.
Pestalotia sp.	6,7,8,9	Apply weekly in nurseries.
Phytophthora sp.	7,8,16,19,21	Apply every 7 or 10 days, products 16,21 and 23 can be mixed.

Table 4. Continued.

Pathogen	Products	Observations
Prospodium sp.	19,25,33	Apply weekly. Can be applied as mixture to plants over 6 months old.
Puccinia sp.	8,25,32,33,34	Weekly application in nurseries.
Pythium sp.	13,22,36	Fumigate substrate.
	3,5,10,21	Apply weekly in nurseries.
Rhizoctonia sp.	13,22,36	Fumigate substrate.
	3,5,18,26 30,31,1+31	Apply weekly in nurseries.
Sclerotium sp.	13,22,36	Fumigate substrate.
	10,12,26	Apply weekly in nurseries.
Seiridium sp.	1,8,23	Apply weekly in nurseries.
Thanatephorus sp.	1,7,8,17, 32,35	Apply weekly in nurseries.

METHODS AND TECHNIQUES FOR DAMAGE INSPECTION AND COLLECTION AND PREPARATION OF SAMPLES

CHAPTER V

METHODS AND TECHNIQUES FOR DAMAGE INSPECTION AND COLLECTION AND PREPARATION OF SAMPLES

This chapter will cover some of the procedures, techniques and methods used for evaluating the damage caused by pests and also for preparing field samples. These are indispensable not only for correct identification of the damage agent but also for deciding whether control measures are called for. For this reason they play an important role in forest protection programs.

1. INSPECTION IN THE FIELD

In any forest project, protection against attack by pests has fundamental importance. However, this is of little value unless field inspections are carried out to detect harmful organisms before they cause considerable damage. Plantation inspection should not be just an occasional activity but should be carried out periodically and routinely.

Inspections include two important aspects: detection and identification of the damage causing agents and evaluation of the damage inflicted. These aspects will be analyzed below.

A. SYMPTOMS AND SIGNS

In general, insects, pathogens or other animals in the field can be detected either by direct observation of the organism, the traces they leave (excrement, nests, tracks, etc.) or the damage they cause. To avoid wrong diagnoses, a relationship should be established between the causal agent and the symptom or damage produced.

The most common way to detect diseases is by the observable symptoms. These are more readily seen than the actual damage agent which is often tiny or microscopic. Symptoms are the external, visible manifestations of physiological and morphological disturbances caused by damage causing agents or abiotic conditions. Sometimes structures or growths of the pathogen can be found associated with the symptoms, and these are called signs. Chapter II contains a description of symptoms and signs useful for diagnosis.

In order to avoid confusion between damage of biotic and abiotic origin, an association must be established between the symptoms and the insect, pathogen or other agent. In the case of insects and mites this is relatively easy since larvae, nymphs and sometimes even adults can be found close to the site of damage. This is not the case with adult grasshoppers, bees, some beetles and ants which cut buds, stems and leaves, then leave the plant. This also occurs with slugs and the majority of vertebrates. In these cases the presence of indications such as teeth marks, spoor, nests and subterranean tunnels are essential to establish an association. With pathogens this is more difficult since signs are often absent because the pathogen is latent or in its incubation period or because some abiotic factors cause similar symptoms.

B. EVALUATION OF DAMAGE

Evaluation of the damage caused by an insect, pathogen or other agent is very important since it forms the basis for deciding whether or not to apply control measures. However, it is a complex and arduous task.

It would be preferable if, for each damage agent species, there was a single criterion or parameter governing how to judge whether the attack merited control. In the field of agriculture, certain parameters known as **economic injury level** and **economic threshold** have been established for a few species, but their application is not easy. In forestry, the situation is further complicated by the long time intervals to felling or harvest, which practically hinder their application.

What can be considered, and should be defined, are the **action thresholds or levels**. These are the densities of damage agents or the levels of damage which make control necessary. To calculate these values, the following factors must be taken into account: age of the tree, part attacked, frequency or incidence and severity or intensity of the damage.

The age of the plant at the moment of attack is very important, mainly because it is related to the amount invested up to that moment. Pests that attack mature trees are more serious than nursery pests, since the trees have aggregated more value.

The economic importance of a pest depends on the part that it attacks. Damage to the foliage may produce death in seedlings or young saplings but not in developing trees. The latter may be affected in terms of longitudinal and radial growth but normally have enough reserves of energy and minerals to allow them to recover. Damage to buds may retard growth, cause deformations in the trunk and even cause death. Damage to the vascular tissue causes defoliation, drying and ultimately the death of the tree. Direct damage to the xylem affects the quality of the wood and lowers its commercial value. The relative importance of damage also depends on the designation of the wood since deformities that would make it useless for the sawmill would not be a problem in wood destined for pulp, firewood or charcoal.

Before discussing incidence and severity of damage, it should be noted that, in general, there is a heterogeneous distribution of damage and causal agents on the same tree. A damage agent that affects the foliage may confine its attack to the periphery or to the center of the crown and those that attack the trunk may show preference for certain heights above the ground. Secondly, spatial distribution within the plantation may not be uniform, but clustered in "contagions" giving rise to foci of pests. This distribution follows various environmental factors, such as local topographic variations, effects of wind, relative humidity, soil fertility and drainage, which affect the trees along with particular habits of the insect pest (preference for particular microclimates, mobility, group behavior, egg distribution, etc.) or pathogen (incubation period, type of dispersal and survival, etc.).

Frequency or incidence of damage refers to the number of units of affected samples (trees, branches, leaves, cones, seeds, etc.) expressed as a percentage of the total sampled. Severity or intensity of damage is the magnitude of damage in each sample and may be expressed as a percentage or as some arbitrary value. Some form of damage scale running from "healthy sample" to "sample totally damaged or dead" must be fixed in order to obtain this index. The categories should not be too wide to avoid inaccuracy but neither should they be too narrow since this will be unnecessarily complicated and waste time.

To complement this information, it should be indicated whether the damage occurs in foci or is widespread and whether it is more common in certain areas of the plantation or not.

Action thresholds for agents causing damage to forest production in Central America do not currently exist, so it is imperative that more information be gathered to reach reasonable approximations. Once action thresholds have been established, a sampling program must be designed to define the size and number of samples, selection criteria and frequency of sampling in the plantations. Sampling will show how close levels are to the action threshold and optimize control of the damage causing agent.

2. SAMPLE COLLECTION

Collecting samples of insects, diseases, etc. is not an end in itself but the first step in a series that lead to the scientific or taxonomic identification of the agent causing the damage. Correct identification means that the organism can be researched in scientific literature to find out what is known about it and how it is controlled in other countries. Reliable reference collections can then also be established in local museums. The various steps in this process, each of which merits close attention, are given below.

A. SAMPLE SELECTION

As already mentioned, when an affected tree is found, it must first be established whether the cause is biotic or abiotic. Consultation of a research summary of the region's climate and soils will allow comparison with those needed by the tree species and indicate whether abiotic factors are implicated. That said, it is always wise to collect samples regardless of the origin of the damage.

Obviously the collection methods for parasitic plants and pathogens, which do not move, will be very different to those used for animals which will try to avoid capture.

In the case of pathogens, the sample should be as representative of the symptoms as possible and should arrive at its destination in the best state possible. The best samples are those where the damage is at an intermediate stage, showing clear symptoms and possibly also signs, but not so advanced that there is saprophytic invasion of the tissue. Whether to collect whole plants or just parts depends on several factors. If the disease shows localized lesions then a sample of leaves, a branch or a few fruits will be sufficient. If the disease is extensive or in the internal tissues, larger samples or sometimes even the whole plant, must be collected. The sample should not contain only diseased tissue since it is important to establish the pathogen's line of advance (the line separating diseased and healthy tissue).

There are several methods for catching insects including light traps, traps with attractants or butterfly nets, but these only work for adult stages. In the case of forest pests it is of more value to catch the larva which, in most cases, is the stage which causes damage.

Exposed insects on leaves and branches can be captured manually, carefully using fine forceps so as not to injure them. Small insects (ants, plantlice, aphids, etc.) especially those in hidden areas (termites, bark beetles, etc.) should be captured with an aspirator. There are several types of these, but all work on the same principle and can be made very cheaply. The first type (Fig. 90) is more durable whilst the other (Fig. 91) is more fragile as it is made with drinking straws. In either case a mesh filter prevents the user from inhaling insects.

Insects collected by aspirator should be killed in the field and put into tubes with 70% alcohol or diluted commercial 80% alcohol. Larger insects should be put in a killing jar (see below).

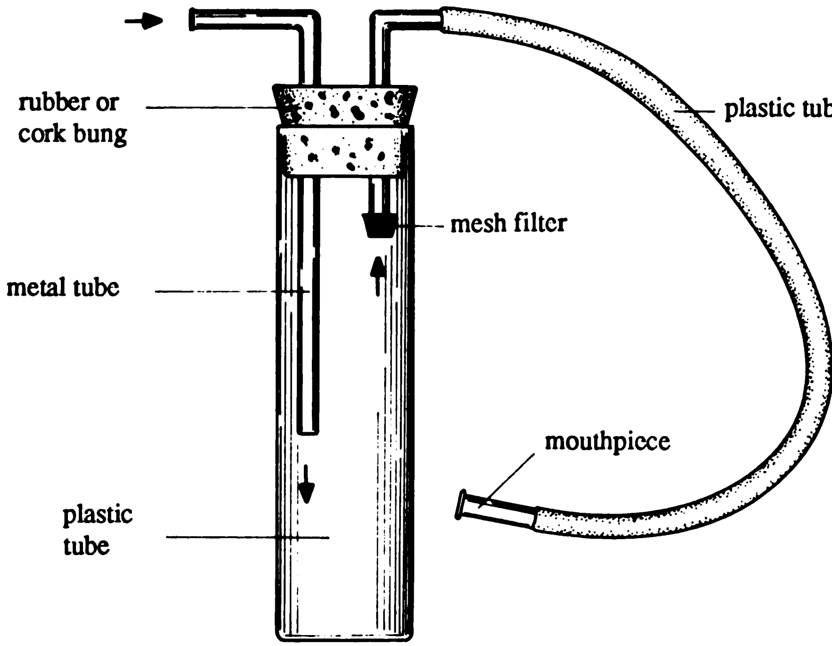


Figure 90. Standard insect aspirator.

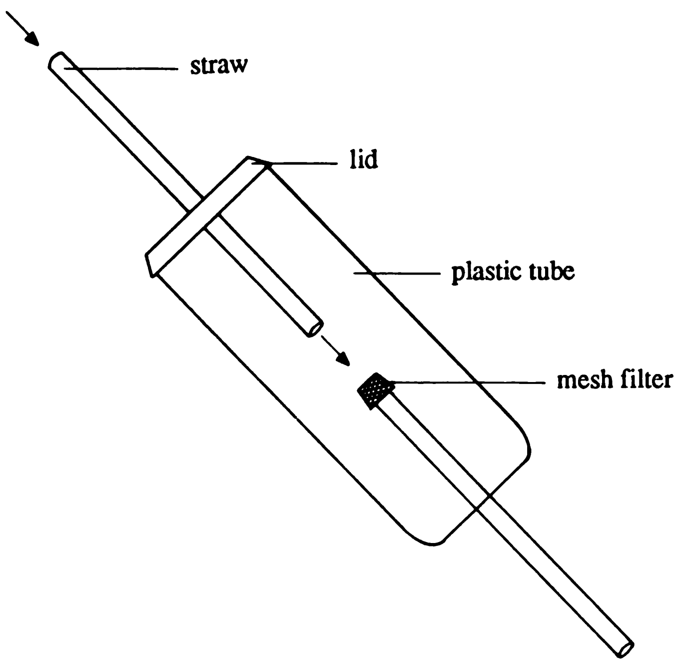


Figure 91. Inexpensive and easily made insect aspirator.

When dealing with larvae, a few should be killed and preserved and the rest reared through to the adult stage. Larvae that are placed in alcohol when still alive go black and this makes identification impossible. They should be killed before preserving, most commonly by immersion in a solution of KAAD (one part kerosene, two parts glacial acetic acid, ten parts commercial alcohol and one part dioxane) which can easily be taken to the field. However, there may be difficulty obtaining acetic acid and dioxane and both are quite expensive so that the following is preferable. Larvae should be taken to somewhere where water can be boiled. The container of boiling water should be removed from the heat and the larvae immersed for a few minutes. The larvae are then removed and placed on paper towel to dry, then put into a tube or bottle of 70% alcohol.

Mites can be placed in 70-80% alcohol with 2-5% glycerine added to prevent drying should the alcohol evaporate. Some prefer to use Oudeman's solution (87 ml 70% alcohol, 8 ml glacial acetic acid, 5 ml glycerine) since this keeps the appendages extended and helps for mounting.

B. PACKING AND SHIPPING

In the case of insects and other organisms preserved in alcohol, this is the last step. All that remains is to attach a label to the tube stating: geographic location of the plantation where the sample was collected (state, province or department, municipality, canton, district, name of the property), collection date, name and age of tree species affected, type of damage and the collector's name. More detailed information should be noted on the Field Data Form that appears at the end of the chapter.

Some of the insects or pathogens should be kept alive for rearing or isolation in a laboratory. Collection sites are generally far from where the material will be deposited, so it is important to ensure their care during the journey. The following measures are recommended:

a) Send material as soon as possible. If disease samples cannot be dispatched immediately, they should be stored at 5-10°C. Dead adult insects should be refrigerated in a hermetically sealed jar. Otherwise, they should be stored in a box or container with a solid preservative such as naphthalene or paradichlorobenzene. The recipient can use a relaxing chamber before mounting them.

b) Capture and send as much material as possible since some will inevitably die during shipping, rearing or isolation.

c) Only put one type of sample per container to avoid cross contamination or predation by insects.

d) Cover disease samples with damp newspaper (this has the best porosity and absorbency). Samples should be placed in a plastic bag which is inflated and tied off to keep the sample damp. Excess moisture should be removed to avoid the growth of saprophytic bacteria contaminating the samples.

e) Live larvae, nymphs and adults which feed on leaves should be kept in well ventilated containers or plastic bags along with a good supply of food. Plastic bags should be punctured with a needle to allow the organisms to respire. Bud borers should be left in the bud and sent with it in a container or plastic bag. Similarly, for trunk and branch borers, a piece of tissue, hopefully containing the larva, should be sent intact. The containers or bags should always contain some damp material such as leaves, pieces of bark, or damp cotton wool or paper.

f) The material should be protected from the sun and from knocks and jolts during the journey.

g) Extra food should be sent along with insect specimens for rearing in the laboratory. Any pupae or cocoons suspected of belonging to the pest species should also be sent, since these will assist in rearing and identification.

h) The material should accompany the information contained in the Field Data Form.

C. LABORATORY ISOLATION OR REARING

This step in the process leading to identification, is almost inevitable in the case of pathogens, especially for those unfamiliar with them. Identification of disease causing organisms should be carried out in a well equipped laboratory; insect or mite rearing, on the other hand, can be carried out under less sophisticated conditions.

Disease samples received by the laboratory are first examined under the stereoscopic microscope for any signs, which, for some pathogens, are sufficiently characteristic to give an immediate identification. If no fungal signs are present, sections of the sample are stained and examined under a higher magnification for the presence of bacteria.

If the damage causing agent is suspected of being a fungus, thin sections or "scrapings" of the wound should be examined under the microscope for spores or other structures which may give an identification to genus level. Several types of spore may be found in one microscopic preparation and this may lead to a false diagnosis. For this reason, it is wise to make several preparations from different lesions.

When the above fails to give a positive identification, the organisms should be isolated to obtain pure cultures. There are several methods of making isolations and many culture media, some of which may be specific for a particular pathogen group or genus. The most commonly used culture medium is PDA (potato, dextrose, agar).

Along with isolation on culture medium, part of the sample should be placed in a humid chamber to allow sporulation. This can be any container whose interior can be kept at saturation humidity: a plastic bag, food storage box or glass cabinet specially designed for the purpose, sealed with damp paper inside.

The main methods for pathogen isolation can be found in FRENCH & HERBERT (1982).

When dealing with a little known pathogen, the diagnosis should be corroborated with a check to show the isolated organism's pathogenicity. The procedure for this follows that proposed by KOCH:

1. The organism should always be associated with the disease.

2. The organism should be able to be isolated in culture and its characteristics should be noted.

3. The isolated organism should reproduce the symptoms when inoculated onto healthy plants of the same species.

4. From inoculated plants (3) it should be possible to isolate the same organism on culture medium showing the same characteristics as those from step 2.

These trials should always be carried out under conditions favorable to pathogen development and there should always be a check.

With respect to insects, the purpose of rearing larvae and nymphs to obtain adults not only demonstrates the relationship between the various stages of the life cycle but also generates adults which are, in any case, easier to identify than juveniles.

Samples should be reared in plastic or glass boxes covered in finely woven cloth secured with a rubber band, so that the organisms can breathe. Defoliating larvae and nymphs should be continually provided with fresh foliage until they molt into adults. Borers located in pieces of trunk or branch should be kept in containers, often for several months, until the adult emerges. It may be necessary to seal the ends of the piece of wood with paraffin wax to avoid drying or place one end in a small container of water. In the case of lepidopteran boring larvae which attack the trunks of trees the producer does not wish damaged, the emergence hole can be tied off with mesh so as to capture the adult as it emerges.

It is important to note that sometimes when insects are reared, instead of the adult of the sample emerging, small wasps or flies may appear. These should be collected, preserved and mounted because they are parasitoids of the pests and their inclusion is fundamental to any future biological control program. As part of this registry, the emergence date and whether the parasitoid emerged from a larva or pupa should also be noted.

Adult pests and parasitoids should be killed before mounting using a killing jar. This is a hermetically sealed glass jar containing a volatile poison (Fig. 92). The construction of a killing jar is quite easy.

One way of making a killing jar is to place a 1.5 cm layer of granules of potassium, calcium or sodium cyanide in a glass jar. This is in turn covered with a 2 cm layer of sawdust and sprinkled with a few drops of water. A small amount of plaster of Paris paste is used to cover this to a depth of 1.5 cm. After drying, this layer is perforated with a needle to allow diffusion of the poison. The jar should be left open in a well ventilated area for 12-24 hrs to allow the plaster of Paris to dry.

A simpler option is to make a 1 cm layer of sawdust covered with 1.5 cm perforated plaster of Paris. A liquid poison, (chloroform, ethyl acetate, ether, carbon tetrachloride) can be poured directly onto the plaster. This method has the disadvantage that the poison dissipates more rapidly than cyanide.

In both cases, the killing jars should contain paper towel to absorb excess water and prevent the insects from damaging each other. The base of the jar should be taped to avoid breakage and the outside should be clearly marked POISON.

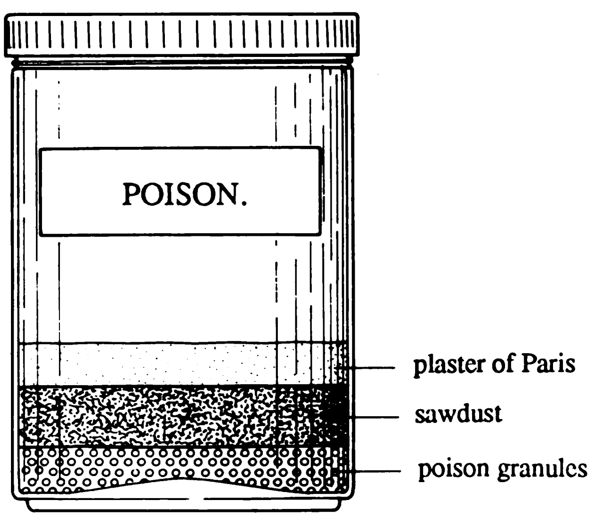


Figure 92. Killing jar for insects.

3. SAMPLE PREPARATION

Once the material has been isolated, in the case of pathogens, or reared through to adults, in the case of insects, it can preserved or mounted ready to send to a specialist for identification. Once identified, the material can form part of a museum reference collection.

A. PRESERVATION OR MOUNTING

Pathogens can be preserved in test tubes containing PDA medium and stored between 5 and 10°C. Other methods of preparation are described in texts of phytopathological methods.

Affected plant material can be preserved either dry or in formalin. The first method is especially used for leaves. These should be pressed between sheets of newspaper for two weeks in a cool, dry place. The sample can then be stuck to card or construction paper. Branches, trunks and roots can also be dry preserved. For liquid preservation, the sample is first heated in a solution of glacial acetic acid and copper acetate, then transferred to a 4% solution of formalin where it can be kept indefinitely. This procedure is described in more detail in STREETS (1982).

All preserved material should be accompanied by the following information: host, common name of disease or scientific name of causal agent, collection site, date, collector's name.

Insects must be properly prepared or mounted if they are to be included in a collection. Larvae and soft bodied adults may be kept indefinitely in containers of 70% alcohol. Specimens should be accompanied by two types of label, examples of which are shown below:

Collection area	Alajuela, Costa Rica
Specific site	La Fortuna, San Carlos
Date	9-X-89
Collector(s)	Luko Hilje-Felix Scorza

Host	***Cordia alliodora***
Habit	Leaf sucker
Order and family	Hemiptera, Tingidae
Species	***Dictyla monotropidia***

The name of the person who identified the specimen and identification date should appear on the reverse of the second card.

Larger insects and those with hard bodies should not be kept in alcohol, but mounted directly or indirectly on an entomological pin (Fig. 93). This is a special rust resistant pin which comes in a variety of sizes. Some insects are easily mounted, whilst others are fragile (Fig. 94) or tiny (Fig. 95) and require special mounting.

Since there are many different ways of mounting insects, a general entomology text should be consulted for greater detail.

All mounts should be accompanied by two labels which should be situated on the mounting pin as shown in Fig. 96. The specimens are then kept in hermetically sealed wooden boxes which have a soft bottom made of cork or Styrofoam and should contain a solid preservative such as naphthalene or paradichlorobenzene. The boxes should, ideally, slide into cabinets and be kept in an air conditioned room since collections are damaged by humidity.

Mites, being smaller than insects, are normally mounted as microscope preparations. Descriptions of the preparation of mites can be found in general entomology texts.

It may also be worth making a collection of damaged material. Samples of leaves and buds can be preserved in 4% formalin after boiling in a solution of glacial acetic acid and copper acetate. Seeds should be stored dry in airtight containers. Branches and trunks can be kept in their normal state for some time although they can be damaged

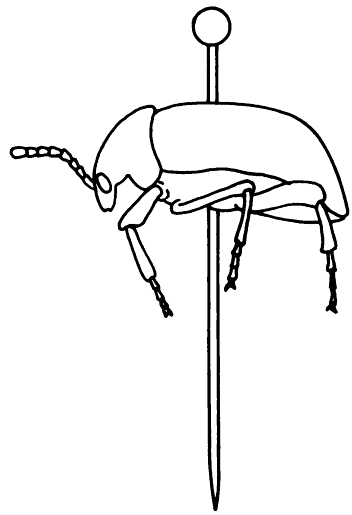


Figure 93. Normal mount on entomological pin.

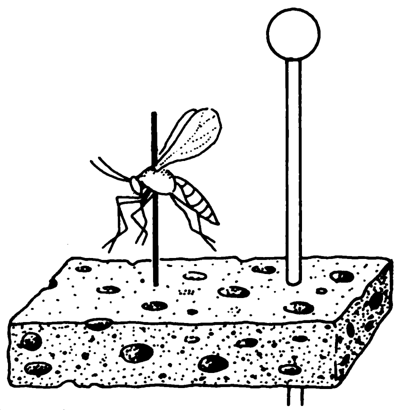


Figure 94. Insect mounted on cork with "minuten" pin.

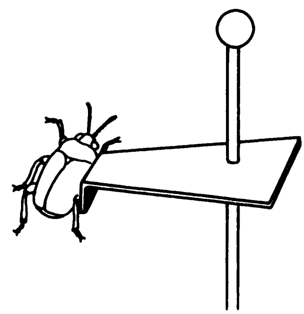


Figure 95. Insect mounted on cardboard point.

by beetles from the families Lyctidae and Bostrichidae.

All samples should bear an identification code which also appears on the Field Data Form or file card.

B. IDENTIFICATION

It is sometimes possible to identify fungi to genus level with the help of phytopathological identification handbooks. Some references that can be used are the keys by BARNETT & HUNTER (1972), BOOTH (1977) and FERNANDEZ (1978, 1979). Identification to species level needs the assistance of specialists outside the country.

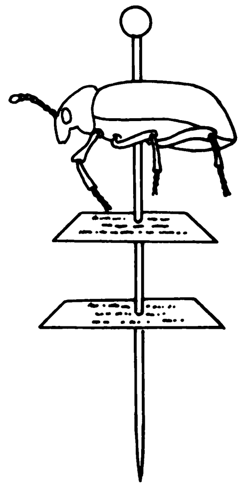


Figure 96. Mount showing the position of labels on the pin.

Identification of bacteria is very laborious since classification is based on their reaction to various biochemical or pathogenicity tests. Virus identification is even more complex.

In the case of insects, only a specialist can identify a specimen to species or sometimes only to genus level. Taxonomists often specialize in one single family and specimens should be sent to these authorities for identification. The process of identification is made more easy if the specimen has been carefully prepared.

Although nearly all the specialists live abroad, local entomologists using reference collections of insects previously identified by foreign experts can make an identification that will allow diagnosis. For this reason it is extremely important that national reference collections be set up.

FIELD DATA FORM

REPORT ON PLANT HEALTH PROBLEMS

INSTRUCTIONS: Fill out one form for each problem and send along with the sample. Please use pencil or permanent ink.

NAME OF FARM: ____________________

LOCATION: ____________________

PROPRIETOR: ____________________

ADDRESS: ____________________

____________________ PHONE: ____________________

INFORMANT: ____________________

____

INSPECTION DATE: ____________________

SPECIES
AFFECTED: ____________________

AREA PLANTED
AND AGES: ____________________

____

OTHER SPECIES PRESENT (beside each, note in parenthesis the area planted and ages: ____________________

____

____

____

____

____

ORIGIN OF SEEDS OR SEEDLINGS:______________________________

____

____

TYPE OF PLANT AFFECTED (Mark with X)

___ Commercial plantation

___ Experimental plot

___ Nursery

___ Seed bed

___ Windbreak

___ Ornamental trees

___ Natural stand

___ Protected area

___ Sawmill

Other:____

PARTS OF PLANT AFFECTED (Mark with X)

___ Flowers

___ Fruit

___ Seeds

___ Cones

___ Seedlings

___ Stumps

___ Roots

___ Buds

___ Terminal buds

___ New foliage

___ Old foliage

___ Branches

___ Bark

___ Wood (trunk)

___ Pith (trunk)

___ Timber

Other:____

DAMAGE DISTRIBUTION (Mark with X)

___ Borders

___ Isolated trees

___ Groups of trees (foci)

Other:____

INCIDENCE OR FREQUENCY OF DAMAGE (% OF TREES) (Mark with X)

___ 5% ___ 26-50%

___ 6-10% ___ 51-75%

___ 11-25% ___ 76-100%

SEVERITY OR INTENSITY OF DAMAGE (PER TREE) (Mark with X)

___ Light

___ Moderate

___ Severe

Other:____

____

____

DATE OF DAMAGE DETECTION:______________________

BRIEF DESCRIPTION OF SYMPTOMS:______________________

____

____

____

____

____

____

RECENT USE OF PESTICIDES AND FERTILIZERS:______________

____

____

____

FACTORS WHICH MAY HAVE ENCOURAGED DAMAGE (Mark with X)

___ Planting material

___ Weeding

___ Pruning

___ Thinning

___ Soil texture

___ Soil compaction

___ Soil pH

___ Topography of land

___ Wind

___ Fire

___ Rainfall

___ Flooding

___ Drought

___ Light/shade

Explain:____

____

____

____

____

POSSIBLE DAMAGING AGENT (Mark with X)

___ Virus

___ Bacteria

___ Fungus

___ Nematode

___ Mite

___ Mollusk

___ Insect

___ Mammal

___ Bird

___ Mistletoe

Other:____

OTHER IMPORTANT OBSERVATIONS:___________________________

____

____

____

FOR LABORATORY USE

DATE OF RECEIPT:______________________________________

CAUSAL AGENT (SCIENTIFIC NAME AND TAXONOMIC GROUPING):
____
____
____
____

OTHER PERTINENT INFORMATION:_______________________
____
____
____
____
____
____

MATERIAL IDENTIFIED BY (Name):_____________________
____

INSTITUTION:____

DATE OF DIAGNOSIS:_____________REPORT N°.____________

GLOSSARY

GLOSSARY

Apterous: Lacking wings.

Berry: Juicy, fleshy fruit containing seeds surrounded by pulp, e.g. grape.

Cheek pouches: Bags of skin located in the cheeks of some animals and used to store food.

Chelicerae: Buccal appendages of mites and other arachnids used for feeding.

Coxa: Basal segment of insect leg.

Crochets: Small hooks found on the prolegs of lepidopteran larvae.

Cuneus: Small, almost triangular area located in the apex of the corium in some hemipterans and separated from the rest of it by a suture.

Discal spot: Group of clear scales located in discal area or central area of wing in insects.

Elytra: Thickened or hardened front wing, present in most beetles.

Enzyme: Protein produced by living cells which can catalyze or accelerate specific reactions in cellular metabolism

Exoskeleton: In insects the hard, or sclerotized, outer body wall which acts as an external skeleton.

Exuvia: The cast skin of an insect or other arthropod.

Gametangium: Structure containing differentiated sexual cells.

Gregarious: An animal which, at some stage of its life, forms groups with others of the same species.

Halteres: Small, often knobbed or hooked structures which represent the hind wings in Diptera and male scale insects.

Haustoria: Absorption organ originating from the hypha of a parasite which penetrates the host cells.

Heterogametangium: Morphologically distinct male and female gametangia.

Humeral angle: In insects, the point of contact between the edge of the forewing and the thorax.

Micron: One thousandth of a millimeter.

Millimicron: One thousandth of a micron

Nanometer: 10^{-9} meters

Ocelli: Simple eyes of insect which have only one lens, as opposed to the compound eye.

Palps: Elongated buccal appendages (maxillary or labial) with sensory function.

Parthenogenesis: Development of the egg without fertilization and without the participation of the male.

Pathovar: Pathogenic variant of some bacteria.

Polyphagous: Feeding on a variety of material and not specific to any one plant. Opposite of monophagous.

Prolegs: Fleshy abdominal legs of certain insect larvae e.g. lepidopterans and some hymenopterans.

Pronotum: Dorsal surface of insect prothorax.

Protoplast: The entity formed by the cell contents and cell wall.

Sessile: Immobile, sedentary, attached to the substrate.

Seta: Bristle or thick hair, found on several parts of an insect's body.

Spiracle: External opening of tracheal system located along the side of an insect's body. Breathing pore.

Sporangium: Bag shaped structure whose contents become a large number of spores.

Sporangiophore: Hypha which supports the sporangium.

Stadium: Name given to each of the morphologically distinct periods between molts in an insect.

Stroma: Compact structure, on or in which develop fruiting bodies.

Taxon: Taxonomic category, e.g. phylum, class, genus etc.

Tegument: Testa or seed covering.

Toxin: Compound produced by microorganisms that is toxic to plants or animals.

Trachea: Tube of the respiratory system of insects leading from the spiracles to the interior of the body.

Tubercle: Protuberance on the body wall of some insects, usually associated with hairs or setae.

Veins: Thickened tubular lines which support the wings of insects.

Viviparous: Development of larvae or nymphs directly from the body of the mother.

Wing membrane: Soft part of the wing, usually transparent. In Hemiptera, the thin apical part of the hemelytron.

Wingspread: Distance between fully extended wingtips.

Zoospore: Asexual, mobile, flagellate spore.

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