Chapter 8

Insect Pest Management

This chapter gives a brief overview of **insect pest management**. Firstly the term **pest** is defined and **favourable conditions** for pest outbreaks are discussed. This knowledge allows deduction of strategies for the **prevention** of outbreaks which are - at least in the forestry sector - the only effective and feasible tool to overcome pest related problems. The pros and cons of various pest control strategies are then outlined. Finally the concepts of **integrated pest management** (**IPM**) including the assessment of economic loss are introduced.

8.1 Insects as Pests

What is a pest?

The term pest is defined as an organism that is judged by man to cause harm to himself, his crops, livestock or his property in general. Pests do not have any ecological significance and according to the definition, a species is only considered as pest by man. This is illustrated by the following example:

In natural forests termites are utterly beneficial insects that decompose dead plant material so that nutrients become available after a short period of time. Termites are not considered as pests since they rarely cause any problems in the natural forest. In a tree plantation however, this is different. From man's point of view termites are pests in a tree plantation because they severely conflict with man's endeavour to grow tree crops.

In general there are **direct pests** that have a direct impact on the crop, for instance the taro beetle feeding on the tuber of taro, or wood borers affecting the stem of a tree. **Indirect pests** effect the growth of a plant by damaging eg. the root system or the foliage. As a result of the injury the crop is affected indirectly, for instance by decreasing the diameter increment of a tree.

Host-specific or **monophagous** pests only attack one particular host species whereas **oligophagous** and **polyphagous pests** feed upon several or many host species of a particular genus or family, respectively.

Apart from **insects** crops can be affected by various other pest organisms like **weeds**, **fungi**, **bacteria**, **nematodes**, **mites**, **protista**, **viruses**, **mammals** and **birds**. This chapter however, will only focus on insect pests including mites.

Why insects become pests

Apart from the considerations of **chapter 4.7.5**, there is a number of reasons why insects can become pests. The introduction of an initially innocuous insect can create problems when the species is no longer under the control of its natural enemies. Similarly, an introduced crop can fall prey to pest infestation as is the case with the introduced *Pinus patula*, and the defoliator *Lymantria ninayi*, naturally occurring on the Yar tree *Casuarina*. **Host-switching** is common for oligo- and polyphagous pests. Insects are considered as pests when they become the vector for a pathogen. In Simbu Province for instance, mosquitoes were present for a long time, but did not cause malaria. Recently there has been an increase in the number of malaria-carrying mosquitoes infected with *Plasmodium*. Finally, agricultural or silvicultural practices are a major reason for insects being judged as pests. The conditions in monocultural systems for instance usually strongly encourage insect infestation, as outlined below.

Monoculture versus Polyculture

In the above example the termites attacking tree crops in a plantation are considered as a pest. In fact the termites are not a pest *per se*, but the conditions in the plantation are suitable for the termites to multiply and to cause damage to the tree crops and therefore man judges the termites to be a pest. Actually man is responsible for an insect becoming a pest, because man creates artificial conditions unsuitable for the crop and suitable for a pest.

A cultural system with only one particular crop species, called **monoculture**, is far more susceptible to insect attack than natural systems. The plants in a monoculture are often weakened and their natural resistance is decreased because there is high competition between the plants for nutrients, light, water, etc. Additionally, because of the low diversity in a monoculture there are hardly any suitable conditions for enemies that control a pest in a natural way. Furthermore, the source of food for a particular pest is abundant in a monoculture. This condition is most favourable for a pest to multiply rapidly, because the availability of food is the most important limiting factor for the growth of insect populations. Finally, a monoculture is not only reduced in terms of the number of species but also in terms of age classes since all plants are the same age. This is important because many pests attack their host only at a particular age. For instance only four to eleven year old Hoop pines are attacked by *Hylurdrectonus araucariae*. If all trees belong to the same age class, all of them will quite likely become the target of a pest attack.

In contrast, a **polycultural system** has a higher diversity of planted crops. As a result there is less competition between the different species due to the different requirements of each species. Furthermore, the food plant of a particular pest is less abundant and might be dispersed, occurring only here and there so that it is more difficult for the pest to locate its host. Due to the species diversity in a polyculture there is a variety of predators and parasites that help to control the pest naturally. Therefore, a polyculture is usually less susceptible to insect pests.

Cultural Diversification

Agriculturalists often benefit from the advantage of a more diverse system like a polyculture in terms of pest susceptibility. In large-scale forestry however, it is a bit more complex since the planted species ideally require the same time from planting to harvesting so that the whole plantation can be clear-felled. Furthermore, particular crop species might suppress the growth of an adjacent species.

A diversification of a monoculture can be gained, for instance by planting small but long strips of different crops next to each other as shown in **plate 11 J**, **figs. 8-1 C** and **D**. The diversity is usually higher in the transition zone (**ecotone**) between two different habitats or compartments with different crops. Higher species diversity in general contributes towards the increased natural resistance of the crops as well as higher numbers of natural enemies. The diversification by means of age classes, as

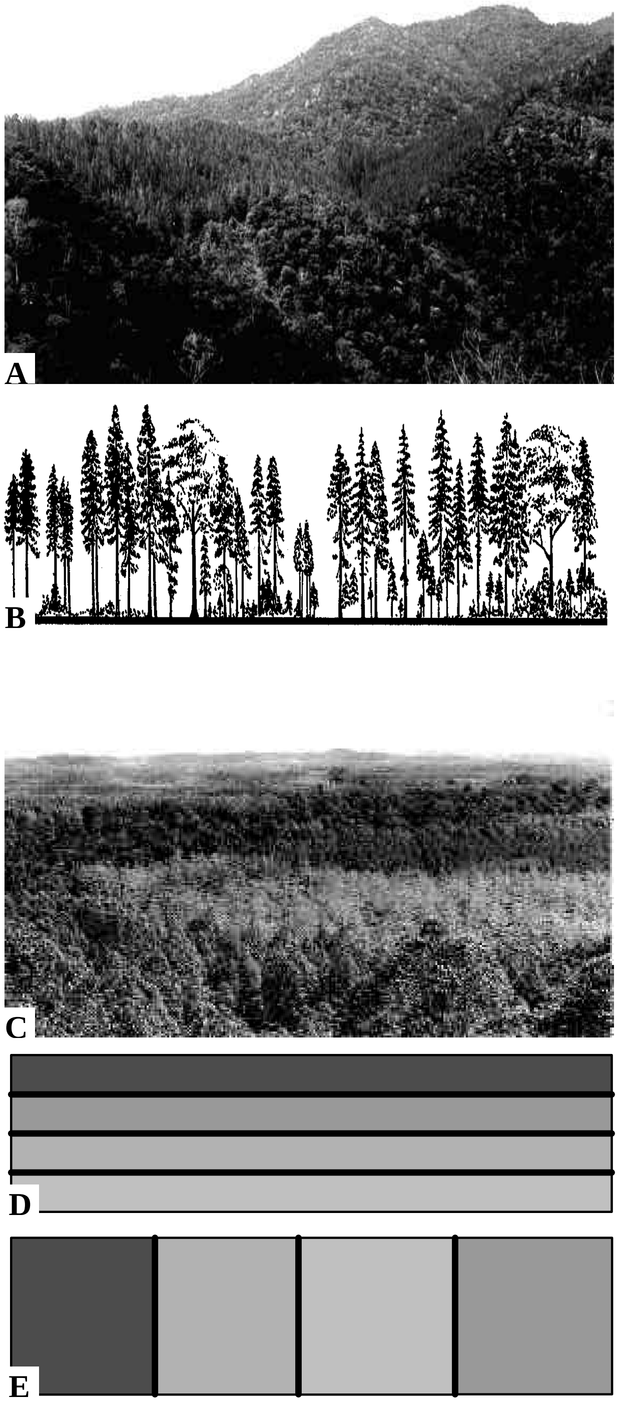


Fig. 8-1: Diversification of Cultural Systems: (A) small patches of Hoop pine in secondary forest at Wau, Morobe Province; (B[‡]) several tree species of different age classes planted together; (C) small strips of Kamarere in the foreground followed by Erima, Talis and secondary forest in the background at the Stettin Bay Lumber Company reforestation area near Kimbe, West New Britain; this setup has more diverse ecotones indicated by thick black lines in (D) than the theoretical setup shown in (E); see text for details (reprod. from Stern, H., 1983[‡]; graphics and photos Schneider, M.F.)

shown in **fig. 8-1 B**, can further help to increase plant resistance and decrease the susceptibility to pest infestation. These considerations are a basic concept of pest control and should be part of the planning and establishment of plantations.

8.2 Prevention or Cure?

In the ancient Greek society physicians were paid for maintaining their patient's health, the doctors' job was to prevent illnesses. Once a patient became sick the doctor was sacked because he apparently failed to do his job properly. The contemporary 'Western' health concept is different or even contrary. We visit the *Haus Sik* when we feel ill and most physicians do little to prevent their patients from becoming sick.

Since plants are living creatures, agriculturalists and foresters have the obligation to attempt to maintain our crops in a healthy condition and to prevent diseases. The nursery, garden and plantation should be a Health Centre rather than a *Haus Sik*.

The prevention of diseases is the key to the successful cultivation of crops. Prevention is often more effective, cheaper, environmentally more sound and more appropriate than curative measures. In forestry there are hardly any effective curative measures available and therefore in most cases there is no other choice apart form preventive measures.

Regular monitoring as outlined in **chapter 7.1** is also of great importance so that disorders can be recognised at an early stage and curative measures can be taken if necessary.

8.2.1 Preventive Measures in Forestry

This section outlines possible preventive measures to minimise the risk of pest infestation. The measures are recommended by the **Forest Research Institute** (**FRI**) as well as by experienced senior foresters and apply to any tree species.

- **Site preparation:** Termite-infested tree stumps should be removed immediately after clear felling if replanting is intended. Therefore the logged site should be searched for subterranean nests before the area disappears in tall *kunai* grass. Infested stumps can be easily found since they often have a hollow 'pipe'. Ideally the infested stumps are uprooted, an exercise which is very difficult. Even a bulldozer has difficulty pulling out the stump of a newly felled tree. Previously explosives, injected below the stump and ignited were used

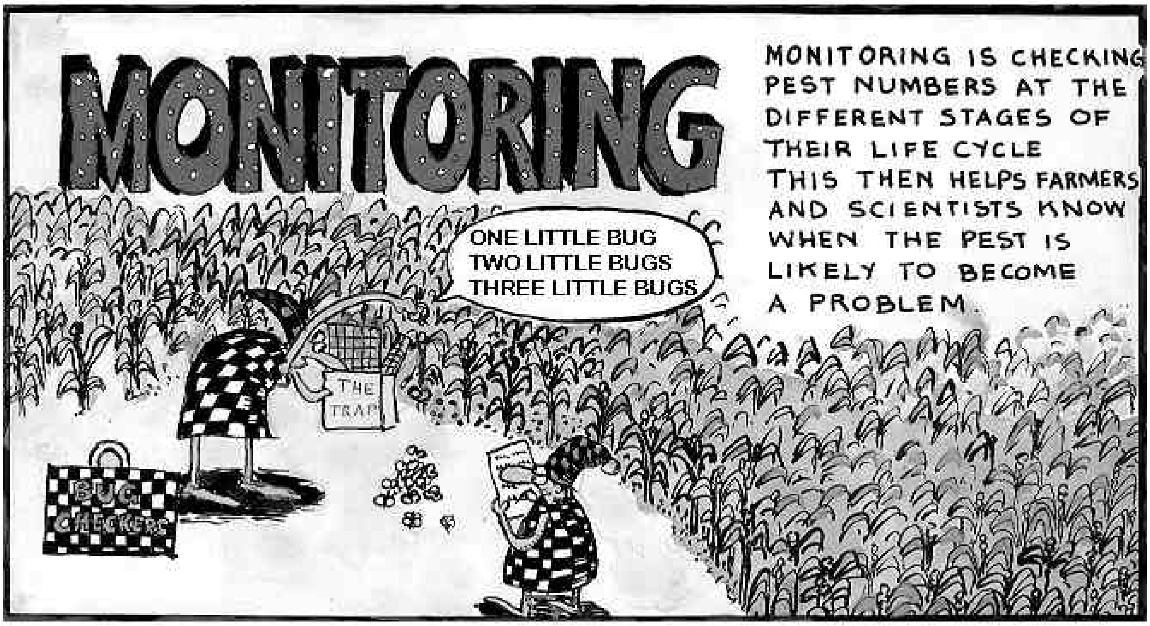


Fig. 8-2: Regular Monitoring - the first step in successful pest management (reproduced with permission from CRC TPM, 1992; Artist Gaynor Cardew)

for that purpose. The explosives were prepared from a mixture of diesel and ammonium nitrate, contained in fertiliser. The problem with this method was the availability of experts for the safe handling of the explosives. In addition waste wood that would offer additional food for the termites should be removed. Finally it is recommended that compacted soil be broken up prior to replanting.

- **Nursery:** The right species and provenance suiting the soil type and climatic conditions in the proposed area, and only high quality seed material should be used. The seedlings should be kept in the nursery until they are large and vigorous enough to be planted to the field. How long they are kept in the nursery involves a compromise of several factors. If the seedlings are kept in the nursery for a longer time, the bark will be thick enough and will be no longer a suitable source of food for grasshoppers. Furthermore the mortality rate of the seedlings will be lower. On the other hand, the tap root will quite likely start to coil and this will encourage termite attack. Additionally, each day in the nursery costs money to carry out watering and weeding of the seedlings.

- **Planting:** Only healthy and vigorous seedlings should be used. Wider spacing should be taken into consideration since less refilling, tending and thinning has to be done. Apart from reducing the costs of these operations, a wider spacing results in faster growing trees because of less competition and a reduction in the potential damage done to the trees during each of these operations. The tubed seedlings are not supposed to be exposed to the heat of the sun but should be placed somewhere in the shade. The temperatures under the black polythene can be as hot as 80° C, enough to cook the roots of a seedling. The tube has to be removed prior to planting. A suitable plant hole has to be dug, big enough to allow all roots to fit in. The coiled taproot of the seedling should be uncoiled, otherwise it will strangle itself as it increases in diameter. Many uprooted termite-infested seedlings show a coiled and already deteriorated tap root, through which termites started the infestation. Therefore, coiling and upwards bending of the roots (**fig. 6-6 A**) should be avoided during planting, so that the root system can develop properly. Planting should be carried out in such a way that the newly planted seedlings suffer as little stress as possible. Some water and fertiliser if necessary will give the seedling the right start.

- **Tending and Pruning:** Any damage of the bark during pruning should be avoided. The branches are supposed to be pruned as close to the stem as possible, so that the bark grows over the sore immediately (**rapid occlusion**). Diversity should be allowed in a plantation rather than creating a monoculture. A diverse understorey offers attractive conditions for beneficial insects. Hygiene in the plantation is of great importance. Pest-related problems are often enhanced because waste such as pruned branches offers additional food for pests. One should consider removal or burning of any waste. Furthermore, silvicultural treatments such as tending and pruning should not be delayed but carried out as early as possible.

- **Thinning:** Damage of the bark of residual trees caused by falling trees (**figs. 6-6 E-G**) should be avoided. Only experienced chainsaw operators familiar with directional felling should carry out the operation. Vehicles like skidders should only be operated, if really necessary so that soil compaction and damage of rootlets of trees along the snig tracks (**fig. 6-6 H**) are minimised. The use of bandages, eg. made from the rubber of a worn-out conveyor belt should be considered in order to protect the base of the stem from being damaged by wheels (**fig. 6-6 D**). It is doubtful whether waste wood placed at the base of the trunk can protect the roots from being damaged by skidders. In other countries skidders are more and more being replaced by horses for hauling. Horses are much cheaper than a skidder and do less harm and damage to trees. Straight snig tracks can also contribute towards less damage of residual trees because damage often occurs in bends. It is advisable to leave a buffer of trees along the snig tracks which are felled at the end of the operation. Any gravel piled up for the construction of temporary roads has to be removed after the operations. If gravel is covering the bark of trees along the road, it will cause rot and damage of the trees in the long term. Waste materials such as timber or gravel should not be pushed downhill but disposed of thoroughly. Bigger pieces of timber or boulders can easily damage the bark of trees when rolling downhill. The right season for thinning, and also for pruning should be considered. Most wood-boring insects attack only green timber and as the timber dries, it becomes less suitable for an attack. Therefore fewer problems are experienced when thinning is carried out during the dry season, when the waste dries faster.

- **Post Logging:** The harvested timber should be removed from the forest as soon as possible to avoid infestation with wood borers resulting in timber degrade. Ideally the timber should be immediately processed after harvesting. If this is not possible, the entire log surface has to be treated with a suitable insecticide or the stems have to be continuously sprinkled with water, as shown in **fig. 8.3**. Another preventive measure that should be considered in some cases is to debark the logs in order to create conditions that are no longer suitable for insects associated with the bark and the sapwood.

Fig. 8-3: Sprinkling of logs with water to avoid infestation with wood boring Scolytidae and Platypodidae beetles (reproduced from Barbosa, P. and Wagner, M.R., 1989)

- **Regular Visits:** During regular visits of the plantation, any signs of an insect attack should be thoroughly monitored. The earlier an out-break is detected, the more successfully remedial measures can be taken and the smaller the economic loss will be.

- **Other Silvicultural Practices** include the diversification of single-species forests and the diversification of age classes as discussed in the previous section. The elimination of alternative or wild hosts is a further possibility to prevent insect-related problems. An example is the elimination of Lau-lau (*Syzygium spp.*), the wild host of *Agrilus spp.*, adjacent to areas where *Eucalyptus deglupta* or *Terminalia spp.* plantations are established

8.2. 2 Available Curative Measures

There is quite a variety of available curative measures. Definitely chemical methods are the most effective ones and usually work instantly, however there are many problems related to the use of pesticides so another method should always be tried first. Consideration should also be given to whether an insecticide application is really essential. For instance if there is a problem with an insect that damages the shoot tips of a tree that is grown for chip production, it might not be necessary to take any action since a straight bole is not required. If the tree however is used for timber production, action should be taken immediately because the damage to the shoot tips will result in stunted growth and a crooked stem and thus a negatively affected crop.
The following measures for the prevention and control of insect attacks are further outlined in this chapter:

- **Quarantine**
- **Plant Resistance**
- **Cultural Methods**
- **Mechanical and Physical Methods**
- **Biological Methods**
- **Chemical Methods**
- **Integrated Pest Management (IPM)**

8.3 Quarantine

Quarantine is the examination, observation and isolation of introduced organisms and products for a certain period of time to avoid the accidental introduction and spread of pests and diseases. All introduced plants and animals are subject to quarantine, even soil and parts of plants and animals such as feathers, skins, wood or seeds are restricted. The term is derived from the French word *quarantaine* which means forty days. Quarantine has gained increased importance due to increasing levels of trade and transport links between countries and continents. Quarantine is one of the most important pest management tools, especially for islands nations like PNG or Australia which usually have very strict quarantine legislation. In Papua New Guinea the functions of agricultural quarantine are mandated by the recently imposed National Agriculture Quarantine and Inspection Authority (**NAQIA**) Act (1997) to control the import and export of animal, fish, plants and their parts and to prevent the entry and spread of diseases, pests, contamination, weeds and any undesirable changes pertaining to plants, animals, and fish, and the total PNG natural environment.

8.4 Plant Resistance

The resistance of plants to insects is the result of inherited qualities. Plants possessing these qualities are less susceptible and more or less resistant to insect attack whereas other varieties lack the genetically determined resistance. Plant resistance can be due to

- **antibiosis** in which a plant produces a substance that a particular insect dislikes or that is poisonous for the insect. These plant compounds can be toxins, growth inhibitors, high concentrations of indigestible substances such as silica or lignin, and sticky exudates from glandular trichomes
- **antixenosis**, deterring an insect by means of deterrents and repellents, thick leaves with hairs or a surface of wax
- **tolerance** that allows the plant to recover from insect damage.

Increased plant resistance is often the result of plant breeding. For this purpose varieties with a high yield are interbred with varieties less susceptible to pests. The result might be a hybrid with both properties, high yield and high resistance. Most cultivated plants are derived from respective wild types that naturally occur in the forest. The wild types usually show a high degree of resistance to many pests and are thus important for the improvement of plant and seed material. Therefore the *in situ* **conservation** of these **plant genetic resources** in their natural habitats or the *in vitro* **conservation** of their protoplasm in gene banks are essential so that the genetic material will be available for plant breeding in the future. There are many varieties of agricultural and forestry crops in use with increased plant resistance due to conventional breeding. An example of a tree crop with increased resistance is *Agrilus*-resistant varieties of *Eucalyptus deglupta*. Additionally, **genetic engineering** offers a powerful tool for molecular biologists inserting foreign DNA into a crop plant. The foreign genetic information in a so-called **transgenic plant** usually encodes antifeedant or insecticidal proteins that are detrimental to the biology of insect pests. However, the release and use of transgenic plant material is quite controversial and major concerns have been raised regarding environmental and human safety. Plant resistance is also influenced by several indirect factors like the time of the year, which is important in terms of plant growth. Climatic factors like drought and seasonal rains affect the plant resistance. If a plant suffers from drought or from too much water its resistance will be weakened and as a consequence insects will be invited to attack the particular plant. Furthermore an attack by one pest species usually promotes secondary infestations by other pests. Secondary insect pests are attracted by specific chemical factors that are released by unhealthy plants (**chapter 3.1.3**). The soil conditions like the type of soil, erosion, compaction and drainage are crucial for the well-being of a plant. Finally, the applied cultural methods contribute towards healthy plants and reduce the risk of insect attack.

8.5 Cultural Methods

Cultural methods have been used successfully in traditional gardening in PNG for thousands of years and are still applied in subsistence farming. Cultural methods are cheap, simple and appropriate when existing indigenous resources are used. Another crucial advantage of cultural methods over most other control methods is that pests cannot develop resistance to cultural methods. As a result these methods can be applied for a long time without losing their effectiveness and efficiency. Most cultural methods are appropriate and effective in agricultural, horticultural and agroforestry systems. Unfortunately some applications have the disadvantage of lowering the yield of the planted crop. **Silvicultural methods** applicable for forestry are outlined in **chapter 8.2.1**. Some cultural methods include:

- planting of **trap crops** in between the major crop diverts pests to the trap crop and ideally leaves the major crop more or less unaffected. The trap crop including pest insects can be removed and burnt
- **intercropping** in order to increase the diversity and, if the right combination of plants is chosen, to increase plant resistance due to synergistic interactions between the planted crops. This can be enhanced by interplanting repellent plants or plants with insecticidal properties
- **crop rotation** avoids continuous infestation with the same pest species
- **elimination of wild and alternate hosts** in order to avoid attraction and concentration of the pest on the cultivated crop
- **careful timing and placement of crop** to avoid synchrony with pests
- **promotion of hedges and other suitable habitats** for natural enemies inside or along the garden or plantation
- **fertiliser application** is one basic concept of forestry to minimise competition for nutrients and to boost the growth of the plants so that the canopy will be closed as soon as possible. As a result of the latter there will be fewer problems with defoliating insects.

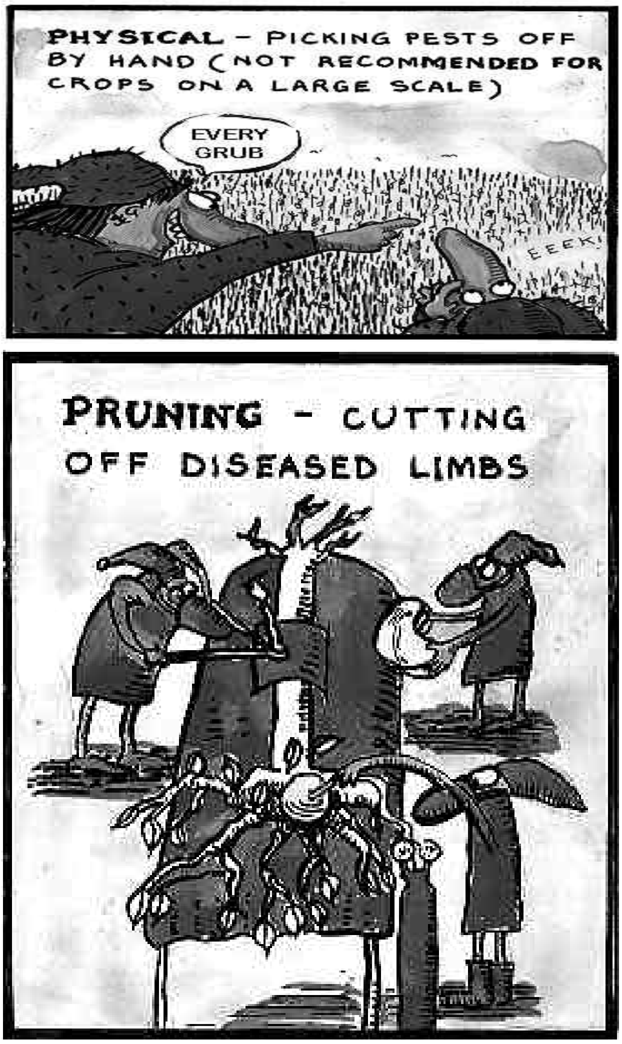


Fig. 8-4: Physical and mechanical pest control (reproduced from CRC TPM, 1992; Artist Gaynor Cardew)

8.6 Mechanical/Physical Methods

Mechanical and physical methods also offer cheap and quite effective measures for insect pest control. The following methods are available:

- **manual collection** and destruction of the pest insects. This however can be very labour intensive and time consuming and is therefore only feasible on a small scale or in particular cases like in termite control to eliminate the reproductive queens
- **modification of the pest's habitat** in a way that the conditions are no longer suitable for the pest's development, colonisation and utilisation. In agriculture ploughing is commonly done to expose pupal stages of moth and butterfly pests to the sun and thus to kill them.

The storage of logs in water ponds or the sprinkling of logs with water to prevent infestation with wood-boring ambrosia beetles is shown in **fig. 8.3**

- **destruction of habitat** of the pest insect, for instance the drainage of marshes and swamps to eliminate mosquito-borne diseases. In forestry particular pest problems can be reduced or avoided by pruning and burning of *Hylurdrectonus*-infested branches, or by debarking of trees to prevent the infestation with bark beetles

- **trapping of insects** for instance by using coloured sticky traps, light traps or pheromone traps. Trapping requires knowledge of the biology and behaviour of the particular insect pest to successfully concentrate the individuals to a prescribed location where they can be destroyed. The oldest trapping method is the use of a **trap tree**. A tree is felled and sacrificed to attract bark beetles and wood borers. Once the pest insects are concentrated the trap tree and the pests are destroyed. Apart from the significance for the monitoring of insect populations, pheromone traps offer a cheap, effective and environmentally sound measure for the control of insects. **Pheromone mass traps** lure the target insect in huge numbers onto surfaces treated with adhesive (sticky traps), toxic chemicals or pathogens, or onto an electrocutor gird where the insects are killed. Pheromones are also applied for **mating disruption** or **male confusion**, outlined in the **chapters 7.2** and **3.1.3**. Methods involving pheromones are commonly used in forestry against ambrosia and bark beetles as well as against certain moths like the gypsy moth *Lymantria dispar*. In agriculture pheromone traps have been developed for the control of the pink bollworm *Pectinophora gossypiella* and the oriental fruit moth *Grapholita molesta*. One limitation of the method is the high selectivity of pheromones that are usually only effective against one particular pest species. Another possibility is the use of bait barriers (**fig. 8-19 K**) that cannot be crossed by flightless insects. Control strategies involving pheromones can also be considered as chemical or biological methods

- the **sterile male** technique is used to control the New World screw worm fly *Cochliomyia hominivorax*, a serious pest of cattle and man. Billions of flies are reared on artificial medium. The pupae are irradiated with gamma rays in order to induce the sterility of males. After the final emergence the sterile males are released. Since the female flies mate only once, control can be achieved by releasing huge numbers of sterile males. Thus the probability that the females are inseminated with the sperm of a sterile male is increased, resulting in infertile eggs.

8.7 Biological Methods

Biological control or biocontrol is the management of insect pests by using either natural enemies like entomopathogens, parasites, predators and, in a wider sense, naturally occurring substances derived from plants and animals such as toxic plant compounds, pheromones and hormone analogues. Advantages of biological methods are that the targets are selectively affected with hardly any side effects and that the methods are sometimes much cheaper than conventional chemical methods. Biological control alone will not always prevent infestations, but can markedly reduce the severity and the frequency of infestations. Unfortunately only a small number of efficient organisms are available for the control of pests.

An outstanding example for weed control in PNG is the weevil *Cyrtobagous salviniae* that was introduced for the control of the water fern *Salvinia molesta* on the middle and lower Sepik River (see **chapter 4.2.1** and **fig. 4-2**). Similar *Salvinia*-related problems occurring in other countries were also successfully tackled with the introduction of the phytophagous weevil *Cyrtobagous*, as shown in **fig. 8-5**. Currently scientists are challenged by a severe infestation of the Sepik River with the water hyacinth (see article on next page). Two weevil species that were identified as suitable biological control agents had to be introduced since they do not naturally occur in PNG. The **introduction** of organisms however, is often a critical issue and has to be carried out with the

Post-Courier, Thursday July 16, 1998

Weevils wipe out Sepik scourge

In a move that could save the environment, village economies and even human lives, CSIRO scientists have wiped out 20 square kilometres of a noxious water weed infesting the Sepik River.

Researchers from CSIRO Entomology used tiny weevils as biological control agents to control a massive outbreak of the exotic Latin American weed, water hyacinth, that was threatening the river, the villages which depend on it and the natural environment.

The project, funded by AusAID, is a fresh triumph for Australia's "six-legged ambassadors" - tiny benign insects now saving crops, family livelihoods, industries and ecosystems around the Asia Pacific region.

Water hyacinth infestations clogging up the Sepik River wetlands were causing great hardship to people using the rivers and streams to move around the country - like a road network.

According to Mr Mic Julien from CSIRO Entomology, the release of biological control agents such as weevils dramatically reduced the areas covered by the weed.

"Over the past five years, we have released 450,000 weevils and reduced infestations from 27 square kilometres to just seven," Mr Julien says.

The Sepik River system is a major waterway in PNG. Water hyacinth was first recorded in the Lower Sepik River flood plain in 1984 and spread quickly, infesting many lagoons and hundreds of kilometres of river banks.

By 1991, large water hyacinth infestations were severely disrupting the lifestyle of villagers from the Middle and Lower Sepik who could only reach gardens, markets and fishing by using the waterways.

These infestations also resulted in the deaths of several people who were unable to reach essential services in time for life-saving treatments.

The Government realised that it was neither desirable or practical to control the weed with herbicides and so alternative control methods were sought. "Firstly, we needed to locate water hyacinth outbreaks and determine the extent of the problem," says Mr Julien.

It was found to be much more widely spread than previously thought with infestations in about 250 locations.

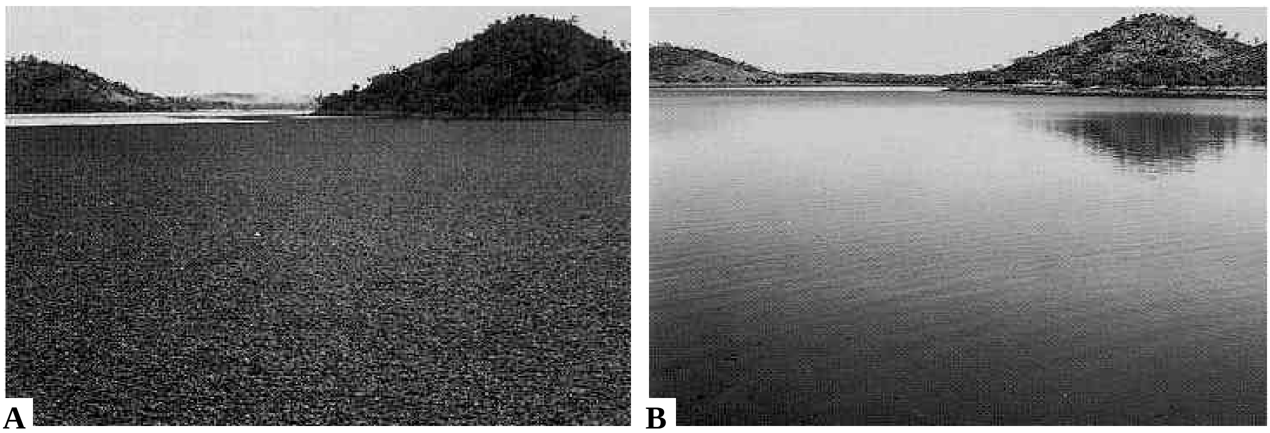
The second aspect of the project was deciding what to do at each location and then doing it.

"A combination of biological control using the weevils, *Neochetina bruchi* and *Neochetina eichhorniae*, and some manual control was used," he says.

"The weevils are reared both in Brisbane and PNG, and then either transported by air or boat to infested areas.

"You can see dramatic reductions of water hyacinth within five years of releasing the weevils. Lagoons and lakes which had been almost totally covered by the weed are now substantially cleared."

The project is led by CSIRO Entomology from its research centre in Brisbane in collaboration with Department of Agriculture and Livestock.



A B

Fig. 8-5: (A) Floating mat of the water fern *Salvinia molesta* on lake Moondarra, near Mt. Isa, Queensland; (B) the same location five months later, after the weevil *Cyrtobagous salviniae* had been released (reproduced from CSIRO, 1991[2]) greatest care. Introduced biocontrol agents can easily turn into pests themselves, firstly because they might find favourable conditions for their multiplication in the new environment and secondly because there might be no effective natural enemies to control the introduced organism. There are a number of cases where the introduction of a biological control agent resulted in the extinction of one or several endemic species. One negative example from Papua New Guinea is the introduction of the cane toad *Bufo marinus* (**Bufonidae**). Originally from South America, the frog was introduced from Hawaii to the Kerevat area, East New Britain, in 1937 by the then Department of Agriculture for the control of the Sweet Potato Moth *Hippotion celerio* (**Sphingidae**, **plate 6 B**). After the war the frog was brought to Port Moresby by the Department of Health for pregnancy testing and was released after use. *Bufo marinus* spread from there and can be encountered now throughout the country up to altitudes where the temperature does not fall below 15° C. Even though apparently successful in the control of its target, the frog has now become a severe pest. Especially in urban centres many individuals can be found next to artificial light feeding on insects that are attracted to the light. The frogs become an annoying scent cacophony when they die in large numbers. Furthermore, endemic birds and reptiles such as adders, herons and egrets are poisoned by the frog, when feeding on it. A decrease in the number of predators has already been observed in some areas. The poisonous *Bufo marinus* secretes a milky fluid from its warts that can severely irritate skin and can cause temporary blindness. Another example of an ecological disaster is the introduction of the fly *Bessa remota* (**Tachinidae**) form Malaysia to Fiji for the control of the coconut moth *Levuana iridescens* (**Zygaenidae**) that resulted in its complete extinction. Therefore, quarantine practices have to be followed strictly and the introduction and release have to be monitored carefully to avoid environmental disasters.

A safer approach to biological control uses organisms for periodic liberation that are already present or that are less persistent but will be effective for some time after the release. **Augmentation** aims at an increase in the natural enemy's population to an effective level of control and can be achieved in two ways. **Inoculation** is the periodic release of a natural enemy that is unable to survive in the area in the long term. The control depends on the next generation(s) of the natural enemy, whereas **inundation** has an instant and short-term effect like an insecticide since the control is achieved by the released organisms.

A further strategy of biological control is the **conservation** and the subsequent enhancement of natural enemies. This approach encourages management techniques that reduce harmful effects on the natural enemies and improve their living conditions, usually by means of habitat diversification (see **chapter 8.1**). Similar positive effects on the environmental conditions suiting the natural enemies can be gained by **environmental manipulation** or **habitat modification**, outlined in **chapter 8.6**.

Learning about the pest and its predators and parasites is most important and a basic requirement for the development of biological control strategies. Ideally a potential biocontrol agent should have the following qualities:

- ecological compatibility to avoid disasters
- synchronisation of the life cycles of the pest and the natural enemy to increase efficiency
- high searching ability for the host or prey
- high dispersal abilities to avoid repeated liberation
- absence of hyperparasites and secondary enemies of the control agent
- culturability to allow the cultivation or mass rearing of the control agent if necessary.

Biological control generally does not aim at the complete eradication and elimination of the pest but in the suppression of the pest population in order to reduce the damage to a tolerable threshold level. Successful biological control results in the natural balance and coexistence of both the pest and the control organism as shown in **fig. 4-26**. Some organisms used for biological control in Papua New Guinea are listed in **box 8-1**.

BIOCONTROL AGENT	USED AGAINST		SUCCESS
Cyrtobagous salviniae (Salvinia weevil)*	weed	*Salvinia molesta* (Water Fern)*	very successful
Heteropsylla spinulosa (Psyllidae)*	weed	*Mimosa invisa* (Giant Sensitive Plant)	successful
Microlarinus lypritornus (Stem Weevil)*	weed	*Tribulus cistoides* (Calthrop Puncture Vine)	unsuccessful
Bufo marinus (Cane Toad)*	insect	*Hippotion celerio* (Sweet Potato Moth)	ecological disaster
Anoplolepis longipes (Crazy Ant)	insect	*Pantorhytes* weevil	ecological disaster
Trichogramma sp. (egg parastic Wasp)	insect	*Ostrinia furnacalis* (Asian Corn Stem Borer)	± successful
Scolia rufucornus (Scoliidae Wasp)*	insect	*Oryctes rhinoceros* (Rhinoceros Beetle)*	unsuccessful
Pachylister chinensis (Histeridae Beetle)*	insect	*Oryctes rhinoceros* (Rhinoceros Beetle)*	unsuccessful
Neochryopus savagei (Carabidae Beetle)*	insect	*Oryctes rhinoceros* (Rhinoceros Beetle)*	unsuccessful
Platymerus laevicollis (Assassin Bug)*	insect	*Oryctes rhinoceros* (Rhinoceros Beetle)*	unsuccessful
Apanteles priscus (Braconidae Wasp)*	insect	*Tiracola priscus* (Cacao Army Worm)	unsuccessful
different Lady Bird Beetles*	insect	various insect pests	± successful
Gambusia affinis (Mosquito Fish)*	insect	*Anopheles sp.* (Mosquito, vector of malaria)	unsuccessful
Selasius unicolor (Drilidae Beetle)*	snail	*Achantina fulica* (Giant African Snail)*	unsuccessful
Tefflus planifrons (Carabidae Beetle)*	snail	*Achantina fulica* (Giant African Snail)*	unsuccessful

Box 8-1: Organisms used for biological control in PNG (* asterisks indicate introduced species)

8.7.1 Entomopathogens

Entomopathogens are microorganisms that have the potential to kill their insect host. Most pathogens are host-specific affecting insects of a particular genus or family only. An insect is either infected through the cuticle, wounds, the anus or spiracles by nematodes and fungi, via the mouth by bacteria or during the egg stage by viruses and nematodes. A long-term storage for many pathogens is soil, where the infectious particles can survive for several years. Humid conditions in the environment as well as a high density of the insect host enhance the virulence and rate of infection.

A large number of microorganisms is already in use for the biological control of a wide range of insect and other arthropod pests. These control agents have several advantages for instance being selective, non-toxic and usually having no effect on non-targets. Some disadvantages are the higher costs of production compared with insecticides and low stability in the environment due to the inactivation of the pathogen by the ultraviolet (UV) light of the sun, and desiccation. Furthermore, insects can develop resistance to particular pathogens upon repeated exposure.

The task of insect pathologists is to isolate pathogens from diseased or dead insects and then screen them for their virulence. Once a potential pathogen has been identified, scientists try to multiply it, for instance in liquid fermenters. The pathogen is finally formulated with stabilisers and other additives, before it is suitable for spraying. If commercial pathogens are unavailable, it is recommended that diseased insect pests be collected and brought to other areas in order to accelerate the chain of infection and to disperse the disease. It is also worthwhile trying to prepare aqueous extracts of infected and dead insects and to spray these extracts in order to disperse the pathogen. The symptoms of an infection depend amongst many others on the pathogen. The colour of a fungus-infected grasshopper might turn to red, fungal conidiophores might become visible growing from the spiracles or on the intersegmental membranes (see **fig. 8-6**) and the animal might be of softer consistency. Caterpillars and grubs that are infected with bacteria usually become soft and amorphous and their colour changes to brown or black.

The following entomopathogens in use:

Bacteria

The spore-forming bacteria are the most promising microbial control agents. The endospores of these bacteria can persist in a dormant stage in the environment for quite a long time. Most entomophathogenic bacteria are from the genus *Bacillus* like *B. popilliae* used for the control of scarab beetles (**Scarabaeidae**), *B. sphaericus* used against mosquito larvae and the famous *Bacillus thuringiensis* (**Bt**). About 40 different Bt subspecies are widely used for the control of larval Lepidoptera, Coleoptera and aquatic Diptera like mosquitoes. Bt-spores contain a crystal-like protein that is, once incorporated by the target insect, responsible for the perforation of the digestive tube resulting in the insect's death. Each subspecies affects selectively only a narrow range of particular insect species, leaving other organisms unharmed, a property that is highly desirable. The subspecies *B. t. israeliensis* is successfully used in mosquito control programmes. Commercially manufactured Bt-products available on the market are **Thuricide HP** ®, **Biobit** ®, **Delfin** ® and **Dipel** ®.

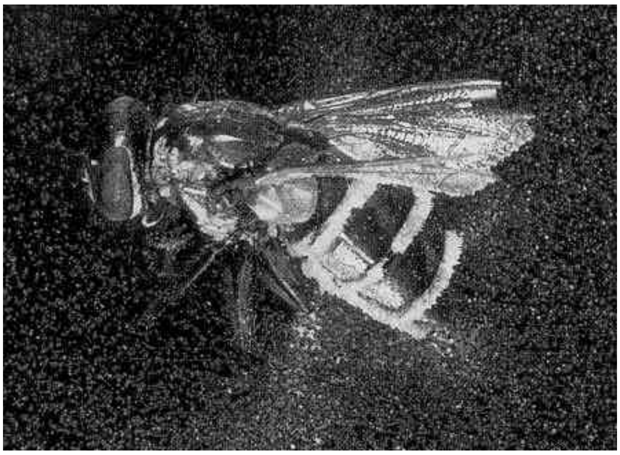


Fig. 8-6: A fly killed by the pathogenic fungus *Entomophthora muscae*; conidiophores are visible protruding through the intersegmental membranes (reproduced from CSIRO, 1991[2])

Fungi

Fungi are the most common cause of diseases in insects of all developmental stages. More than 750 species of 35 genera are known as entomopathogens. Different from bacterial infections that start after the ingestion of the spores, fungal diseases usually occur when spores enter an insect body via wounds of the cuticle or via the spiracles. From the germinating spore hyphae penetrate the cuticle of the insect and invade its body. Death is caused by released fungal toxins or is due to a disruption of vital body functions of the insect. The fungus then sporulates and releases spores from its conidiophores, as shown in **fig. 8-6**. The spores spread the disease throughout the insect population. The spread of the spores requires warm and moist conditions and the virulence is often markedly reduced in low humidity - unfortunately conditions that are most suitable for insect outbreaks. This fact is a limitation on the use of fungi as biocontrol agents even though the formulation of the spores in oil can improve the virulence. Another problem is the fact that it is difficult to mass produce fungi for commercial purposes. There are only a few species of fungi that are used in agriculture, for instance *Nosema*; *Entomophthora* for the control of aphids; the white muscardine *Beauveria* such as *B. bassiana* (**Naturalis-L** ®) and *B. brongniartii*; the green muscardine *Metarhizium* such as *M. anisopliae* (**BioGreen** ®, **BioBlast** ®, **BioPath** ®), the latter two genera for the control of soil-borne pests such as termites and beetle grubs and *M. flavoviridae* effective against locusts; *Verticillium lecanii* (**Vertalec** ®) against aphids and scales; *Hirsutella thompsonii*; *Nomuraea*.

Viruses

A large number of viruses have the potential to kill insects, however only a few viral groups are host-specific and thus safe for biological control since these leave beneficial insects and vertebrates unaffected. The three useful groups of entomopathogenic viruses, all having proteinaceous inclusion bodies that enclose the virions, belong to the

- **Baculoviruses** (Baculoviridae): the nuclear polyhedrosis viruses (**NPV**) and the granulosis viruses (**GV**). The baculoviruses mostly affect the midgut of endopterygote insects such as moth and beetle larvae after ingestion of the inclusion bodies. These viruses have DNA genomes and replicate in the cytoplasm of their host cells. Baculoviruses are very stable and can persist in the soil for many years. Some baculoviruses are host-specific like the *Helicoverpa* NPV affecting only one particular target genus. The importance of a specific NPV for the control of *Lymantria ninayi* and other defoliators of *Pinus spp.* is outlined in **chapter 6.2.6**.

- **Cytoplasmic Polyhedrosis Viruses** (**CPV**) (Retroviridae) like the *Cypovirus* have RNA genomes and were found in more than 200 mainly lepidopteran and dipteran species. These viruses are less persistent in the environment than NPVs.

- **Entomopoxviruses** (**EPV**) (Poxviridae: Entomopoxvirinae) are generally host-specific viruses with a large DNA genome and affect a wide range of insects like Orthoptera, Lepidoptera, Diptera and Coleoptera.

Viruses seem to be ideal biocontrol agents, however there are a number of problems that currently restrict their availability. The virulence usually rapidly decreases when the virus particles are exposed to the ultraviolet (UV) light of the sun and remains unchanged for some time only when the virus is protected from UV, for instance in the soil. Furthermore, viruses can be multiplied only *in vivo*, ie. in their natural host which is difficult and expensive. Lastly, the virulence of cultivated viruses is often decreased.

Protozoa

Protozoa are unicellular eucaryotic animals. Four phyla of the protozoa were found as parasites of insects, the **Sarcomastigophora**, **Microspora**, **Apicomplexa** and **Chilophora**. However, most of these pathogens particularly the Chilophora are characterised by their low pathogenicity. Promising seem to be the Amoebae (Sarcomastigophora) such as *Malamoeba locustae* for the control of locusts, the Neogregarines (Apicomplexa) and the Microsporidia (Microspora) such as *Vairimorpha necatrix* that particularly infect Noctuidae caterpillars. The spores of the latter group are ingested by the target insect and multiply in the cytoplasm of the gut epithelium cells, from where cells of other tissues are infected. In general, a protozoan infection results in the loss of vigour and fecundity of the target insect and causes its death after several weeks due to a chronic rather than a more ideal acute infection. Apart form these disadvantages, protozoans are difficult to multiply on a large scale and therefore their use as biocontrol agents is restricted to inoculative augmentation or to a use in conjunction with other biological or chemical agents.

Nematodes

Four families of entomophagous roundworms, eelworms or threadworms are benign and potential biocontrol agents, the **Mermithidae**, **Heterorhabditidae**, **Steinernematidae** and **Neotylenchidae**. In general, Nematodes kill their host in a relatively short time, are easy and cheap to mass produce and actively search for their hosts. These properties make Nematodes suitable tools for the control of soil-borne and plant-boring pests. In use is *Deladenus siricidicola* (Neotylenchidae) for the control of the wood-boring wasp *Sirex noctilio*, a serious pest of *Pinus radiata* plantations in Australia.

8.7 2 Predators and Parasites

The original idea of biocontrol was to use natural enemies such as predators and parasites for the regulation of a pest population. Therefore, a predator or parasite is introduced into a pest-infested area by means of mass release. Suitable conditions for the predator or parasite have to be created and maintained so that the introduced organism is able to temporarily or permanently establish itself in the area. Ideally the natural enemy keeps the pest population at a low level so that no further control measures have to be applied. Suitable conditions for beneficial insects, release techniques and possible problems regarding the use of foreign biological control agents are discussed at the beginning of **chapter 8.7**. Furthermore, general aspects of predation and parasitism are outlined in the **chapters 4.3**, **4.7.4** and **4.7.5**. The identification of suitable organisms for biological control is often not an easy task, but the knowledge of the type of defence strategy used by a particular pest species can give an indication of where to look for a suitable control agent. If the pest uses aposematic coloration for its defence, then it is in general effectively protected from day-time predators. Therefore, the use of a predator as a biocontrol agent is quite likely to fail. Since warning coloration is not effective against parasitoids, it is definitely more promising to search amongst parasitoids for a suitable

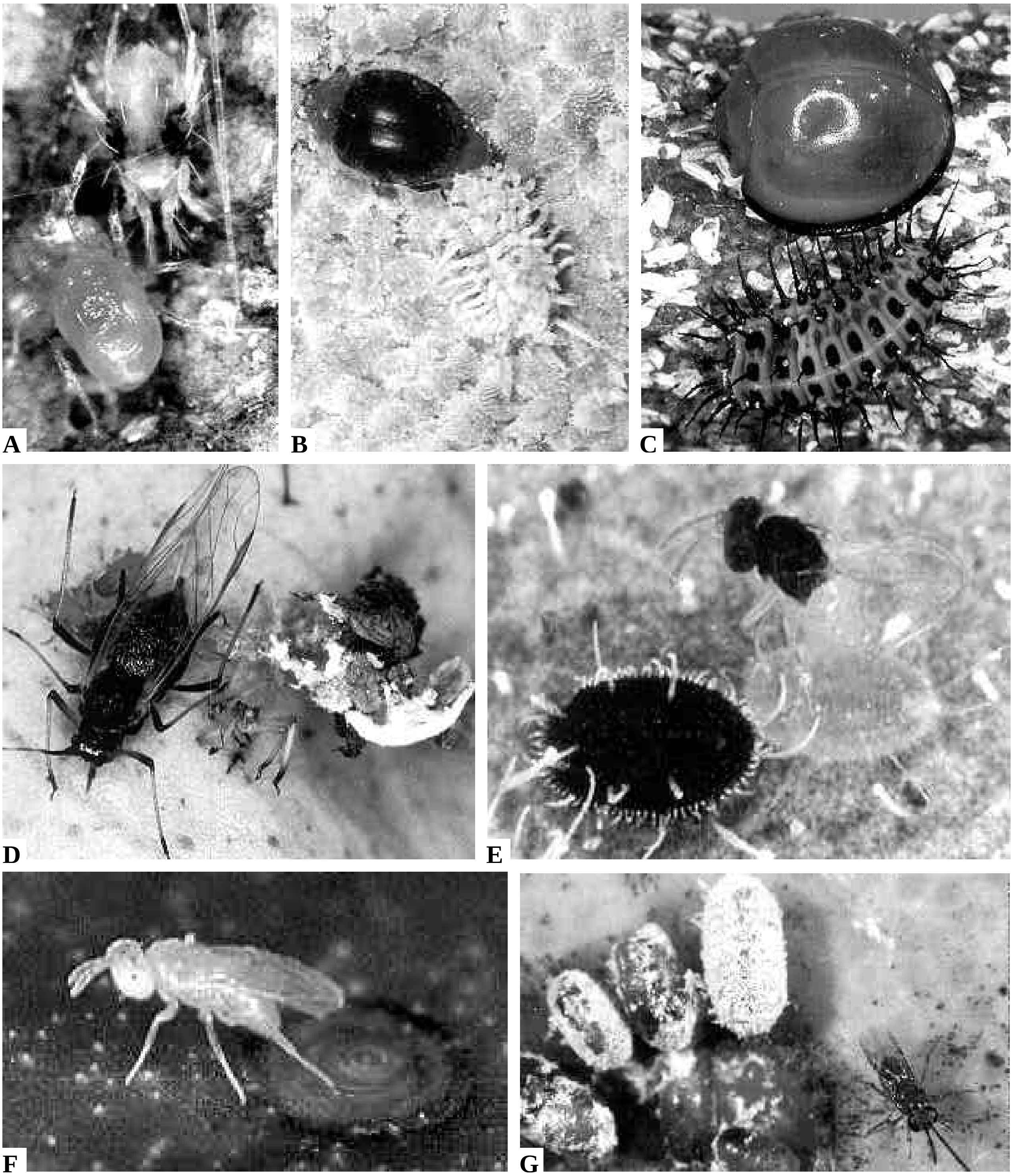


Fig. 8-7: Useful Predators and Parasites: (A) predatory mite *Phytoseiulus persimilis* (Phytoseiidae) feeding on the twospotted mite *Tetranychus urticae* (Tetranychidae); (B) larval and adult ladybird *Cryptolaemus montrouzieri* (Coccinellidae) feeding on citrus mealybugs *Planococcus citri* (Pseudococcidae); (C) larval and adult ladybird *Chilocorus circumdatus* (Coccinellidae) feeding on white louse scales *Unaspis citri* (Diaspididae); (D) the camouflaged green lacewing larva *Mallada signata* (Chrysopidae) attacking a winged adult aphid (Aphididae); (E) the parasitic wasp *Encarsia formosa* (Chalcidoidea: Aphelinidae) laying eggs inside a whitefly nymph (Aleyrodidae); the black scale is already parasitized and a new wasp will soon emerge; (F) the parasitic wasp *Aphytis sp.* (Chalcidoidea: Aphelinidae) laying eggs in the red scale *Aonidiella aurantii* (Diaspididae); (G) the parasitic wasp *Leptomastix dactylopii* (Chalcidoidea: Encyrtidae) with 'mummies' of parasitized citrus mealybugs (reproduced from Papacek, D. et al., 1995)

biocontrol agent. This concept can save a lot of time and money required to carry out lengthy sets of predation experiments.
Suitable natural enemies of arthropod pests shown in **figs. 5-57** and **8-7** belong to the following groups:

Insectivorous Vertebrates
Many insectivorous vertebrates are important for the natural control of insect pests, however vertebrates play only a minor role as biological control agents, which is mainly due to their unspecific predation. The unsuccessful introduction of the amphibian cane toad *Bufo marinus* (**Bufonidae**) for the control of the sweet potato moth is outlined at the beginning of **chapter 8.7**. Likewise, the introduction of the mosquito fish *Gambusia affinis* for the control of the mosquito *Anopheles sp.* apparently failed to be successful. Many insectivorous mammals such as echidnas (*Zaglossus bruijni* and *Tachyglossus aculeatus*) occur only in very small numbers which restricts their efficiency as biocontrol agents. However, rainbow lorikeets *Trichoglossus haematodus* (**Psittacidae**) are reported to feed on large numbers of *Lymantria ninayi* caterpillars and thus are of a certain importance for the control of this defoliator of *Pinus patula*.

Predacious Non-Insect Arthropods
Important predators of insects and other arthropod pests are the spider-like animals (Arachnida). Predatory mites of the families **Phytoseiidae** (**fig. 8-7 A**) and **Stigmaeidae** are commercially mass reared and are suitable for the control of pestiferous spider mites (**Tetranychidae**), scale insects (**Coccidae**) and many other homopteran pests. The true spiders (**Araneae**) and harvest men (**Opiliones**) also have a great potential as efficient biocontrol agents, particularly in tropical ecosystems. These animals are unsuitable for mass rearing, therefore integrated pest management (**IPM**) aims at conservation techniques and the modification of habitats in order to enhance existing spider populations. However, due to their unspecific feeding habits, the use of spiders is unfortunately restrictive.

Predacious and Parasitic Insects
Predacious and parasitic insects are, apart from entomopathogenic microorganisms, the most important and effective biocontrol agents. Suitable insects for biological control are recruited from 16 insect orders and from more than 200 families. Most common predators, parasites and parasitoids are wasps and ants (**Hymenoptera**), beetles (**Coleoptera**), flies (**Diptera**), lace wings and their larvae, the antlions (**Neuroptera**), bugs (**Hemiptera**), and damsel- and dragonflies (**Odonata**). Beetles, wasps and flies are usually host-specific monophages living on particular species or genera whereas lacewings, bugs, damsel- and dragonflies are polyphagous general predators that feed on a wider range of prey. Some beneficial insects are shown in **fig. 8-7** and are further outlined below. The biology of insect predators and parasites is outlined in the **chapters 4.3**, **4.7.4** and **4.7.5**.

- Amongst the mainly host-specific beetles notably the two families **Coccinellidae** (ladybirds) and **Carabidae** (ground beetles) are successfully in use as predators against many agricultural pests like aphids (**Aphididae**), scales (**Coccidae**), many other hemipteran pests, sawflies (**symphytan Hymenoptera**) and caterpillars of moths and butterflies (**Lepidoptera**). Less specific predators are the rove beetles (**Staphylinidae**). In forestry the aphid *Pineus pini* (**Adelgidae**), a pest of *Pinus* is controlled by the ladybird beetle *Cryptolaemus montrouzieri* (**fig. 8-7 B**)
- In the family **Hymenoptera** there are numerous less specific predators and the mono- or oligophagous parasites and parasitoids. About 25% of the hymenopteran families, mainly the social ants and wasps are strictly predacious. **Vespidae** and **Sphecidae** wasps are important general predators that collect various prey insects for raising their brood (**fig. 5-58**). Other important predators are ants (**Formicidae**) such as ants of the genera *Pheidole* and the meat ants *Iridomyrmex* that are used for the control of various pests. Native crazy ants *Anoplolepis longipes* were introduced to certain areas in Papua New Guinea to control the *Pantorhytes* weevil. The success of the

crazy ants (see **chapter 5.6.3.30**) regarding their work as biocontrol agents is doubtful but definitely the ants turned into a nuisance spreading into villages and molesting humans. My own endeavour to search for organisms suitable for the control of the termite *Copto-termes elisae* lead to an ant of the genus *Pheidole*. Initially, these animals seemed to be the perfect candidates due to their large numbers that could cope with the large number of termites in a colony. Furthermore, the small size of the ant that allowed them to intrude into the termite galleries and additionally the ants' greed in grabbing termites were very promising to successfully control *Coptotermes*. After some days the ants eventually stopped killing any more termites probably because the termite stock in the ant nest was already filled up. Interesting however was the method of trap-ping the ants so that the whole colony could be carried to a termite-infested area. A hollow banana 'stem' was baited with sugar as shown in **fig. 8-8** and closed at both sides with fine gauze to prevent other insects like cockroaches stealing the sugar. The trap was then placed next to where the ants had established their colony and covered with leaves to create moist conditions suiting the ants. After some days the whole ant colony had moved into the trap and was ready for transport.

Of greater significance for biological control are parasitic wasps that are recruited mainly from the superfamilies **Platygasteroidea**, **Ich-neumonoidea** and **Chalcidoidea**. The latter group contains approximately 100,000 species in 20 families that are benign parasitoids for the control of various insect pests. Egg parasitoids of the family **Trichogrammatidae** and **Mymaridae** and ecto- and endoparasites such as **Aphelinidae** and **Encyritidae** (**figs. 8-7 E-G**) are commonly used against aphids, mealybugs, scale insects, whiteflies and a large number of pestiferous caterpillars. The most famous biocontrol agents are wasps of the genus *Trichogramma* (**fig. 5-57**) that are for instance used in the Markham valley in Papua New Guinea for the control of the Asian corn stem borer *Ostrinia furnacalis* (**Lepidoptera: Pyralidae**). The egg parasitoid *Trichogramma plasseyensis* is mass reared at the Bubia Agricultural Research Centre on the rice moth *Corcyra cephalonica* (**Pyralidae**), a close relative of the Asian corn stem borer. The host itself is reared on an artificial diet made from corn, wheat or rice and is inoculated with *Trichogramma*. The wasp then parasitizes the eggs of its host and eventually about two wasps hatch per egg of the rice moth. Prior to hatching, approximately 1,300 parasitized eggs of the host are glued on small pieces of cardboard, the so-called '**Tricho cards**'. For the mass release of the wasp about 75 Tricho cards are distributed per hectare of corn. After the final emergence, the adult *Trichogramma* wasps search for eggs of their host, the Asian corn stem borer for parasitzation. A problem is the synchronisation of the life cycles of the host and the parasitoid. The parasitoid has to be released at the right time, ie. when the female *Ostrinia* have laid their eggs, so that the emerged wasps are able to parasitize the eggs of the host. Tricho cards suitable for use against various pests can be obtained commercially.

Fig. 8-8: Ant trap baited with sugar; see text for further details (photo Schneider, M.F.)

Other important parasitoids are **Braconidae** and **Ichneumonidae** wasps, both from the superfamily Ichneumonoidea, which are very often host specific and the **Platygasteridae** and **Scelionidae**, both Platygasteroidea, that are parasitoids of spiders, insect eggs and larvae.

• An important family of parasitic flies (**Diptera**) are the **Tachinidae** that are commonly used as biocontrol agents against various pest species. The habits of the tachina flies vary considerably: some attach their eggs to their host, whereas species that ‘give birth’ to larvae deposit the maggot either on the body of the host or ‘inject’ the maggot into the host by means of a ‘larvidepositor’.

- Adult lace wings and their larval antlions (**Neuroptera**) are important general predators used as biological control agents against a wide range of homopteran pests. Mainly green lacewings (**Chrysopidae**, **fig. 8-7 D**) and brown lacewings (**Hemerobiidae**) are commercially mass reared and available for the agriculturalist’s convenience. In forestry the felted scale *Eriococcus spp.* (**Eriococcidae**) occurring on Hoop pine is controlled by a green lacewing.
- Praying mantids (**Mantodea**) are general predators that are important for the natural control of insect population. However these insects are insignificant as biocontrol agents.
- As beneficial general predators dragon- and damselflies (**Odonata**) are of no significance as biocontrol agents.
- Only a few **Orthoptera** with seizing forelegs are known to be predacious.
- A number of **Hemiptera** like assassin bugs (**Reduviidae**) and cicadas (**Cicadidae**) are useful general predators of other insects, however, these predators lack host specifity and are therefore less suitable biocontrol agents. Certain **Psyllidae** are useful for weed control, for instance *Heteropsyla spinulosa* which is used in PNG for the control of the giant sensitive plant *Mimosa invisa*.

8.7.3 Plant-derived Insecticides

Plant-derived insecticides definitely have great potential for the natural control of insect pests, particularly in tropical countries like Papua New Guinea. Currently more than 860 plant species with insecticidal properties, mostly originated from the Tropical rain forest, have been identified, as well as 150 plant species with compounds effective against nematodes, rodents, mites and molluscs. The significance of these plant genetic resources as potential insecticides becomes evident when looking at the perspective of an increasing number of insects showing resistance against chemical insecticides. It can be assumed that only a minority of the potentially useful plants have been assessed so far. A race against time has begun to save these plant genetic resources, before the last patch of tropical rain forest has vanished. Usually the active compounds can be easily extracted from the respective plants without any sophisticated devices, costing only labour. Finally, the use of local genetic resources for the manufacture of plant-derived insecticides could make a developing country like Papua New Guinea more independent of pesticide imports and furthermore be of potential economic value. Plant-derived insecticides are certainly able to replace chemical insecticides to a greater extent in small-scale agricultural and agroforestry systems, however their use is yet to be proven for large-scale agricultural and forestry plantations.

Plant-derived insecticides contain natural insecticides, deterrents or repellents that belong to various groups of chemicals such as alkaloids, rotenoids and pyrethrins. Some of these compounds are shown in **fig. 8-9**. Since many plant-derived insecticides are as toxic and harmful as chemical insecticides, they have to be handled and used carefully and withholding periods have to be allowed as in the case of chemical insecticides. Plants containing repellents can be interplanted between the crops, or parts of these plants can be used for mulching. In general the preparation of aqueous extracts, as shown in **box 8-2**, is the most common and appropriate method gaining the best results in terms of pest control.

Some effective insecticides can be prepared from the following plants occurring in PNG:

- **Meliaceae** like Neem (*Azadirachta indica*) and the Persian Lilac *Melia azedarach* and *M. composita*
- *Crotalaria spp.*
- **tobacco** (*Nicotiana tabacum*)
- **lemon grass** or **citronella** (*Cymbopogon citratus*)
- **pyrethrum** (*Tanacetum cinerariaefolium*, formerly *Pyrethrum*, then *Chrysantemum*)
- **derris** (*Derris elliptica*, *Derris spp.*)
- **chilli** (*Capsicum frutescens*)
- **garlic** (*Alium sativa*)

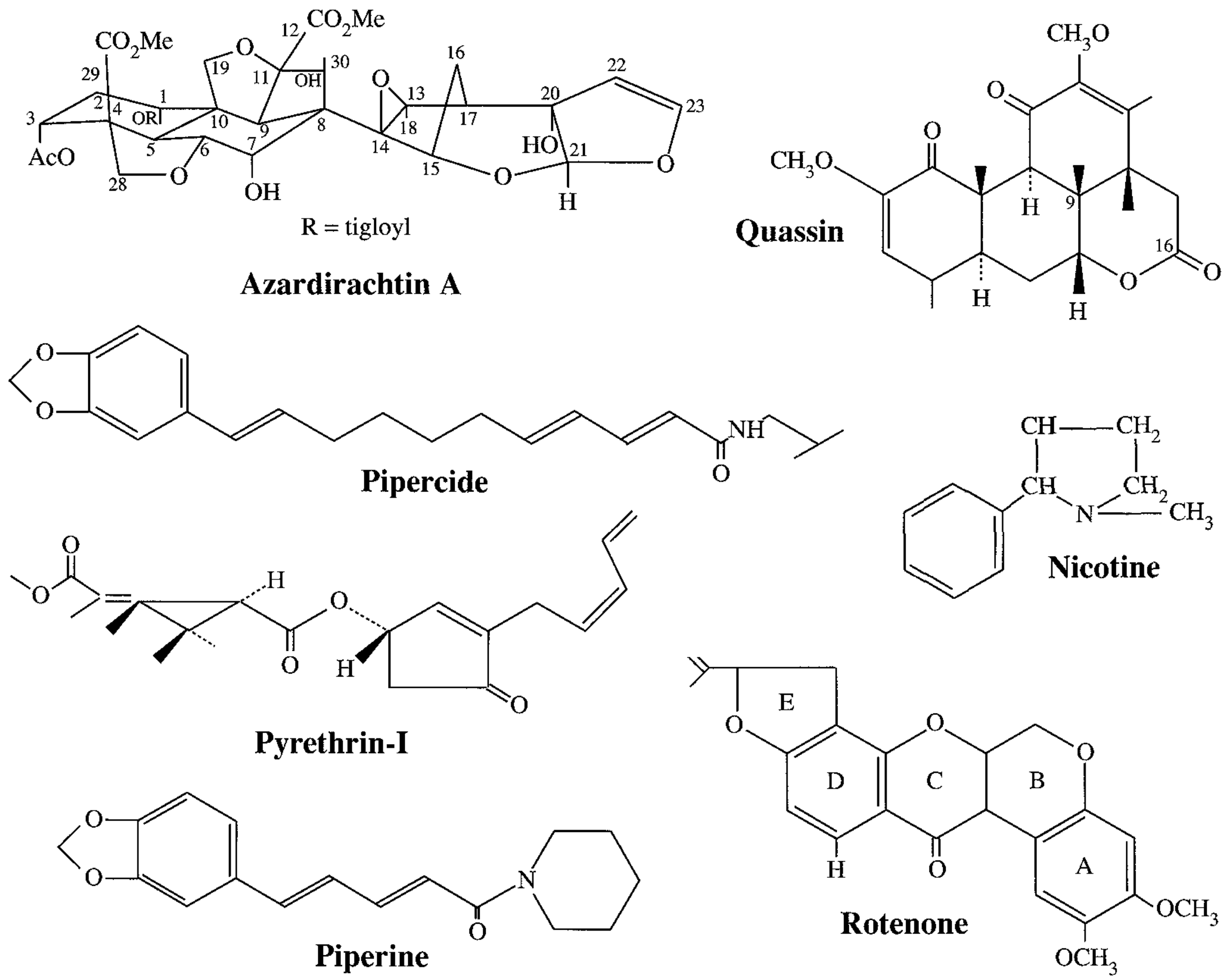


Fig. 8-9: Secondary plant compounds of selected plants (reproduced from Prakash, A. & Rao, J., 1997)

A famous example is the **Neem** tree *Azadirachta indica*, a **Meliaceae** originating from the Indian subcontinent. The plant was used traditionally for thousands of years as insecticide, repellent and medicinal plant. Soap made from Neem oil was used to cure various skin disorders, furthermore the oil has antiseptic and antihelminthic properties and was even used for the treatment of malaria. Additionally this fast growing and nitrogen fixing multi-purpose tree was planted as an ornamental and shade tree and provides good fire wood. Neem flowers release a perfume-like scent and bees make delicious honey from the nectar. The Neem tree was introduced to PNG during the colonial days and can be found now in the Markham Valley, Lae and Port Moresby as a road-side tree. The antifeedant properties of Neem became known to science in the 1950's during an outbreak of plague locusts. It was observed that these insects only roosted on Neem trees without feeding on the leaves. A large number of secondary plant compounds have been isolated from various parts of the tree. The highest concentrations of the main constituent, **Azadirachtin A** (**fig. 8-9**) and other triterpenoids can be found in the oil of Neem kernels (**fig. 8-10 G**). Azadirachtin A has antifeedant effects, disrupts egg and larval development and metamorphosis, affects the behavioural system and can result in oviposition deterrence. Pest species that are affected by Neem products are from the orders Lepidoptera, Diptera, Coleoptera, Orthoptera and Hemiptera. Neem products like **Neem Azal T/S** ® are commercially manufactured and available on the market, however the active ingredients of Neem can be easily extracted with water from dried seeds or kernels, as shown in **box 8-2**.

To prepare aqueous Neem seed extracts

1. grind 200 g Neem seeds
2. soak over night in 10 litres water
3. a bit of detergent, OMO or soap can be added to aid wetting of the wax-covered surface of the leaves
4. strain the solution, if a knapsack sprayer is used for the application,
5. otherwise use twigs with leaves dipped into the solution for spreading the insecticide
6. do not spray when the sun is very hot but preferably apply the extract during the late afternoon

Alternatively the following extracts are also quite effective against a wide range of insect pests. Several ingredients like chillies, derris and tobacco can be used together:

- 200 g crushed *Melia* seeds per 10 litres water
- 1 kg pulverised tobacco leaves or cigarette butts per 15 litres water
- 100 g finely ground chillies per 5 litres water
- 100 g derris powder and 50 grams soap per 10 litres water
- 200 g finely chopped garlic, 20 g soap and four tea spoons engine oil per 1 litre water
- 20 g pyrethrum powder per 10 litres water

Care should be taken when handling chillies and derris. Rubber gloves are recommended

Box 8-2: Recipes for the preparation of natural insecticides (recommended by Stoll, G., 1995[3])

The Persian lilac or Chinaberry tree *Melia azedarach*, another Meliaceae similar to Neem, has also been introduced to PNG. Neem performs better in the lowlands whereas *Melia* can be grown at higher altitudes like at Bulolo and Wau. Both species bear fruits after a few years, yielding up to 50 kg per mature tree. Fruiting of Neem occurs in the Port Moresby area between August and October and in Morobe Province between December and February, depending on the rainy season. The two species can be distinguished easily, according to **fig. 8-10**. Neem leaves are pinnate whereas those of *Melia* are bipinnate. The Neem seeds contain two kernels whereas the very hard *Melia* seeds usually enclose five kernels. The major chemical compounds found in *Melia* kernels are the triterpenoids **meliantriol** and **melianone**. *Melia* is very poisonous and about ten seeds can be fatal to a human being. Own research has revealed high mortality of eggs and first larval instars of *Eurema blanda* (**Lepidoptera: Pieridae**) after the treatment of the eggs with aqueous Neem and *Melia* seed extracts. Even concentrations far below the recommended concentration resulted in 100% mortality of the treated eggs and caterpillars after three to four days. Furthermore it could be shown that *Melia* was more effective than Neem.

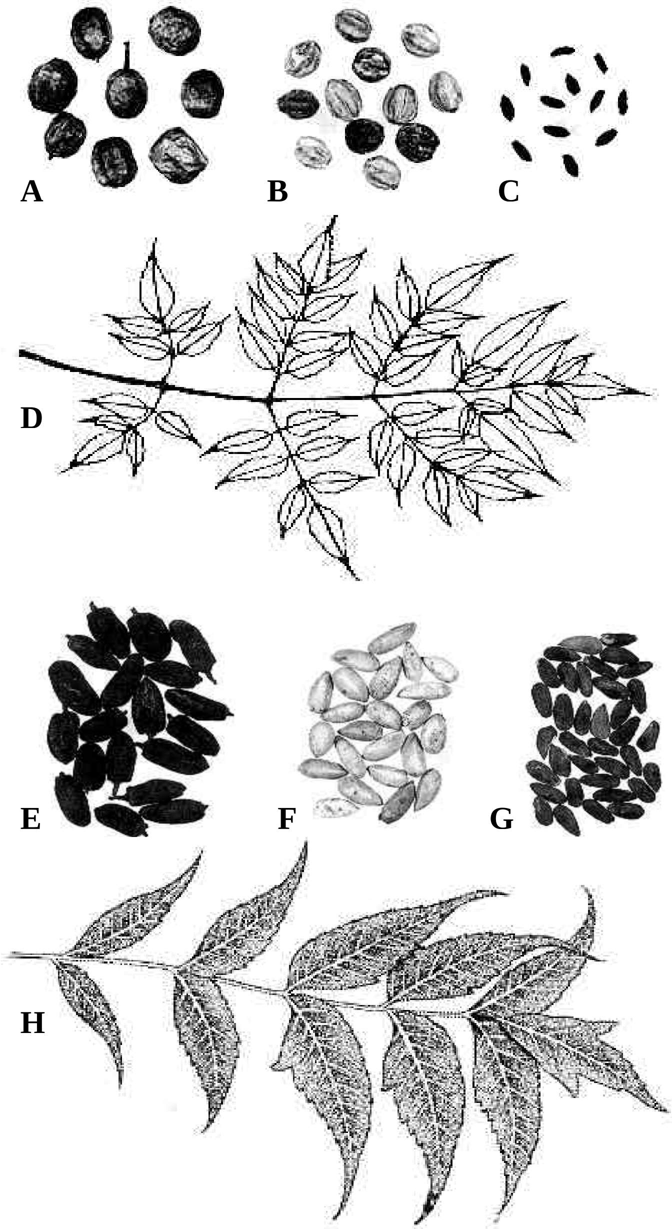


Fig. 8-10: *Melia azedarach* (A): dried fruits; (B) dried seeds; (C) dried kernels; (D) bipinnate leaf; *Azadirachta indica*: (E) dried fruits; (F) dried seeds; (G) dried kernels; (H) pinnate leaf (reproduced from Schmutterer, H. 1995)

8.8 Chemical Methods

Chemical methods are (still) the most widespread remedies for pest control since conventional chemicals are cheap, easy to use and almost spontaneous in their effect. Chemical methods use poisonous pesticides to control pests. The term pesticide is the overall term for any agent suitable for the control of pests. In particular there are insecticides, weedicides, acaricides for the control of mites, fungicides molluscicides, bactericides, rodenticides, etc., however this section only focuses on insecticides. The chemicals contained in an insecticide prevent, destroy, repel or mitigate insect pests. Insect populations are usually modified by insecticides within a short period of time. However chemical measures are in most cases temporary remedies and often require repeated applications which bear certain risks, for instance the development of a resistance to the chemicals used (see **chapter 8.8.2**). Ideally, an insecticide should be toxic to the target insect; should not affect the current and next crop; should not be poisonous to man and other non-targets; should be selective; should be stable to protect the crop for a long time but should also break down fast into harmless substances in order not to contaminate food crops or the environment; should not accumulate in food chains; should not be mobile in the environment and the target insect should not develop resistance when the insecticide is applied repeatedly. Insecticides are incorporated by their targets in different ways, depending on the chemical:

- **stomach poisons** become effective when eaten by an insect and absorbed via its digestive tract (**oral entry**)
- **contact poisons** are incorporated via the legs of the insect that come into contact with the treated surfaces (**dermal entry**)
- **fumigants** are volatile chemicals that enter the body of an insect through inhalation
- **systemic poisons** are incorporated by plants through leaves and are then translocated for instance to other parts of the plant. Insects acquire the insecticide by feeding on poisoned parts of the plant. The advantage of a systemic insecticide is that the target insect can be poisoned even though it cannot be reached directly by means of spraying, eg. a wood-boring insect hidden in the stem. The translocation depends on the physicochemical properties of the insecticide and the plant species. The chemical might be translocated for only a short distance in the parenchyma or for longer distances via the plant's vascular system, ie. the xylem and/or phloem
- **physical poisons** are applied to suffocate the target insects by means of dust or to disrupt the cuticle by using petroleum oil, detergents or organic solvents.

8.8.1 Insecticide Classes

Inorganic Insecticides

Inorganic insecticides were the first insecticides ever used and usually act as stomach poisons. Examples of inorganic compounds are arsenic trioxide and pentoxide, copper, lead, and calcium arsenate, or chemicals used for the treatment of timber composed of copper, arsenic and chromium, or fumigants like aluminium phosphide (Fumitoxin®). Most of these compounds are quite cheap and were commonly used in forestry but have now been replaced by other insecticides that are less persistent and damaging to the environment.

Organochlorines

Organochlorines or chlorinated hydrocarbons were the first group of synthetic organic insecticides. Even though the mode of action of these chemicals is not fully understood, they interfere with the central nervous system of the insect and affect the transmission of nervous signals. Some of their properties are:

- low acute toxicity
- low selectivity
- high persistence
- no longer effective due to the development of resistance
- accumulation in fatty tissues
- their use is restricted in many countries
- cause cancer in man
- are now only allowed for the treatment of soil-borne pests like termites

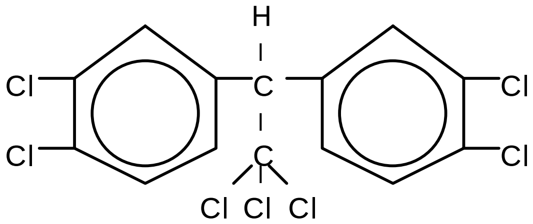


Fig. 8-11: Chemical Formula of DDT (2,2-di-[4-chlorophenyl] 1,1,1-trichloro-ethane)

Some common organochlorines are **Lindane**, **Aldrin**, **Dieldrin**, **Endrine**, **Endosulfan**, **DDT** (**fig. 8-11**), **Hexachloride** (**BHC**), **Heptachlor**, **Dicofol**, **Benzene** and **Chlordane**.

Organophosphates

Organophosphates are esters of phosphoric acid or phosphorothionic acid with methoxy or ethoxy groups. Organophosphates are nerve poisons and kill the target by inhibiting the action of the enzyme **acetylcholine esterase** that plays a key role in the signal transduction in nerve cells (**chapter 2.2.4**). The chemicals act as contact poisons, stomach poisons and as fumigants. Organophosphates are the most important and most commonly used class of insecticides. Common products are **Malathion** (**box 8-4**), **Coumaphos**, **Tepp**, **Azodrin**, **Meta-Systox R**, **Chlopopyrifos**, **Diazinon**, **Parathion**, **Methylparathion**, **Fenthion**, **Disulfoton**, **Fenitrothion**, **Actellic**, **Imidan**, **Dichlorvos**, **Chlorophos**, etc. Similar chemicals were and are still used in warfare as binary chemical weapons even though they are banned. Some features of organophosphates are:

- range from very toxic to relatively harmless
- the target is killed within minutes after contact. Symptoms are excessive flow of saliva, nausea, convulsions, paralysis of the 'respiratory' muscles and eventually death
- some have systemic properties
- are usually degraded rapidly, however the metabolites might be very stable and toxic
- unlike organochlorines, organophosphates are not accumulated in fatty tissues.

Carbamates

Carbamates are a relatively new class of insecticides. They contain esters of carbamic acid and resemble organophosphates in their biological action. Some of these chemicals are persistent. Available are **Aldicarb**, **Landrin**, **Carbaryl**, **Methomyl**, **Carbofuran**, **Propoxur**.

Synthetic Pyrethroids

These chemicals are analogues of natural pyrethrins, originally prepared from the daisy *Tanacetum cinerariefolium*. Pyrethroids affect the signal transduction in nerve cells, therefore they show high biological activity against insects but also high toxicity in non-targets such as fish and man. Pyrethroids are usually rapidly broken down and eliminated from the environment. Commercial products are **Decis**, **Allethrin**, **Bioallethrin**, **Karate**, **Supershield**, **Mavrik** and **Pyrethrum**, etc. Pyrethroids are one of the active ingredients of **Mortein** ®.

Insect Growth Regulators (IGR)

Those chemicals are chemical control agents but can be considered as biocontrol agents, too. Insect hormone analogues like the **Juvenile Hormone Analogue** (**JHA**) **Fenoxycarb** interfere with the larval and adult development of insects and do not kill the target instantly. JHAs seem to have the advantage of being more or less specific affecting only particular groups of insects. Natural JHAs also occur in some plants such as *Cyprus* and *Podocarpus*. The wood of the latter contains natural Crustecdysone, a hormone that is usually found in Crustaceans. This compound protects the tree from being infested by wood-borers because their development is disrupted by the hormone. The **Benzoylphenyl Ureas** (**BPU**) like **Atabron**, **Nomolt**, **Alsystin** and **Teflubenzuron** are chitin synthesis inhibitors that disrupt the moulting process of insects. These substances are less toxic for non-target organisms, are rapidly eliminated from the environment and act specifically on particular insects only. More precisely, the term for this group of insecticides should be 'growth dys-regulators'.

Plant-derived Insecticides

Plant-derived insecticides such as alkaloids and pyrethrins, also considered as biocontrol agents, are outlined in **chapter 8.7.3**. Some of these compounds are shown in **fig. 8-9**.

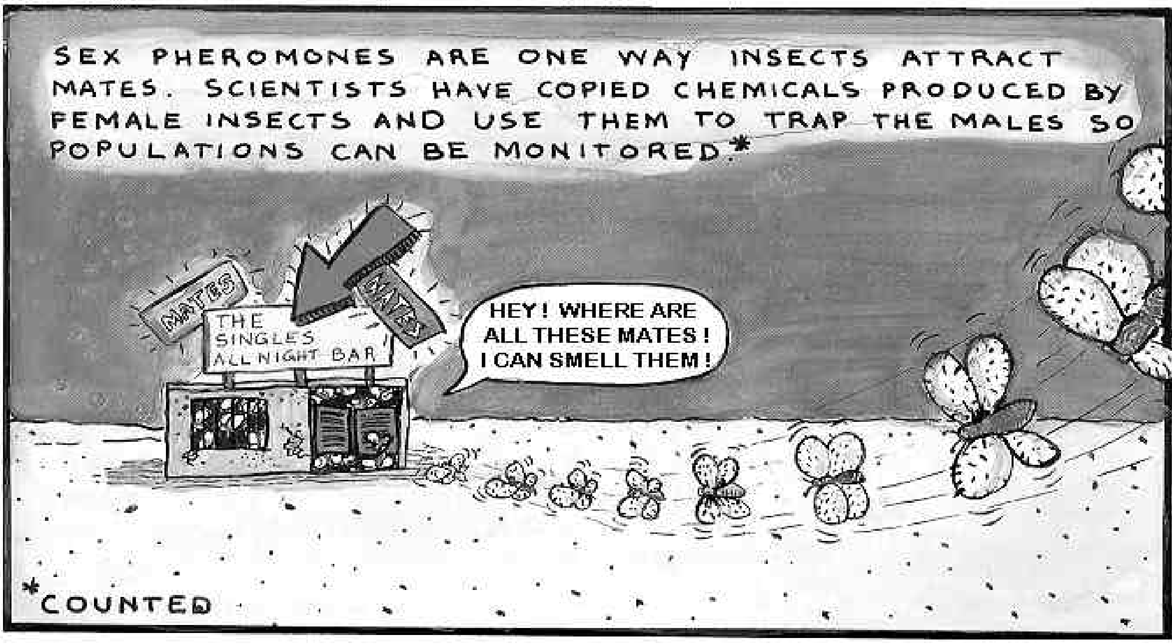


Fig. 8-12: Pest control by the uses of sex pheromones (reprod. from CRC TPM, 1992; Artist Gaynor Cardew)

Pheromones and other Semiochemicals
The perspectives of pheromones and other semiochemicals, eg. for mating disruption are outlined in **chapters 3.1.3**, **7.2** and **8.6**. These chemicals are also considered as mechanical/ physical or biological control agents.

8.8.2 Some Important Facts about Chemical Insecticides

Conventional insecticides have the advantage of being relatively cheap, simple to use and very fast and effective in killing insects. However there are also many disadvantages that should be thoroughly taken into consideration prior to using chemical insecticides:

Persistence of Insecticides
Many chemicals, in particular the organochlorines, remain unaltered in the environment for a very long period of time. For instance DDT can still be found in unchanged quantities fifty years after the application. A certain persistence of two to three weeks is desired in order to avoid repeated applications. The persistence depends on the chemical, the soil type, the crop species and the climate since high temperatures and ultraviolet radiation (UV) help to break down the chemicals faster.

Important in this context is the **withholding period**. This is the recommended period of time that has to be allowed between the last application of an insecticide and the harvest of a crop, so that residues of the insecticide are eliminated from the crop. The withholding period depends on the crop species, the insecticide used, the temperature and the intensity of the sunlight and varies between several days and several weeks. The withholding periods for selected insecticides and crops for the Highlands region of Papua New Guinea are:

Orthene:	tomato	3 days
	cabbage	7 days
	aibika	7 days
	snake bean	7 days
Karate:	tomato	3 days
	cabbage	3 days
Carbaryl:	aibika	1 day
Atabron:	cabbage	10 days

Effects on Non-Targets (Selectivity)
Chemicals are often not very specific in their action against their target organisms, ie. they have the potential to kill any living creature, including the person who applies the insecticide. The selectivity of an insecticide depends on the ability of the target to detoxify the chemical; on the structure of the receptor on the target system; and on the ability to

Fig. 8-13: Effects of chemical insecticides on non-target organisms (reproduced with permission from CRC TPM, 1992; Artist Gaynor Cardew)

accumulate the insecticide within particular cells of the target organism. Insecticides can affect organisms that are far away from where the insecticide has been applied. Spray droplets evaporate, are carried away by the wind for several kilometres and residual insecticides are leached out of the soil. Eventually insecticides might end up in rivers and might poison animals living there or affect humans fetching their water from there. Usually only a tiny fraction of the spray reaches the target, the rest is 'wasted', ending up in the environment.

Resistance to Insecticides

Due to the frequent and increasing use of insecticides, target organisms can sooner or later develop resistance to the insecticide that the organism is exposed to. Once resistance to a particular insecticide has been acquired, it is no longer effective against the pest and should no longer be used. Resistance is usually genetically determined. The change in the sensitivity to an insecticide is due to mutations in the genome of a target organism and the result of the subsequent natural selection of the advantaged individuals. Broad-spectrum insecticides interfere with several or many biochemical and physiological processes of the target. The resistance to this kind of insecticide requires the mutation of several or many genes, an event that is less likely than the mutation of one particular gene in the case of a monogenic resistance to narrow-spectrum insecticides. Currently over 500 pest species have developed resistance to one or several insecticides. Resistance monitoring has become an integral part of pest management. Since the development of new and more powerful insecticides is very costly, the problem of resistance can be overcome by developing alternative control strategies such as biological control and integrated pest management.

Accumulation in the Food Chain

Since most of the pesticides are lipophilic substances that dissolve in oils, fats or organic solvents rather than in water, they tend to be accumulated in fatty tissues under the skin and around the guts of animals or humans. The insecticide deposits can remain there unaltered

Fig. 8-14: Resistance to chemical insecticides (reproduced from CRC TPM, 1992; Artist Gaynor Cardew)

Fig. 8-15: An ill wind
A cloud of the insecticide DDT billows over the beach and beachgoers in 1945 as part of a mosquito-control program at New York's Jones Beach State Park. Used in Europe to ward off bug-borne disease during World War II, DDT was once hailed as a miracle product. This photograph was published in the October 1945 GEOGRAPHIC article "Your New World of Tomorrow". But by the time "tomorrow" came, evidence showed that birds from sprayed areas accumulated high levels of DDT, damaging their ability to reproduce. Other research pointed to the chemical as a human carcinogen. Use of DDT was banned in the United States in 1972 (reproduced from National Geographic, 2/1996)

for a very long time and can cause chronic diseases. If contaminated animals or plants are consumed, the accumulated insecticide is incorporated by and deposited in the consumer. The more consumers are involved, the higher the insecticide will be concentrated at the end of the food chain (**biomagnification**). Since residues of insecticides can be found in almost any food stuff regular controls of food are necessary. For certain food an **acceptable daily input** (**ADI**) is recommended by the **World Health Organisation** (**WHO**) in order to avoid health hazards due to continuous exposure to contaminated food. Milk, especially mother's milk, can be very rich in insecticide residues. Particularly organochlorines like **DDT** accumulate well in the food chain.

Toxicity of Insecticides

Basically there are two types of toxicity. The **short term** or **acute toxicity** becomes evident minutes up to several days after the incorporation of a single poison dose whereas the **long term toxicity** is the result of the continuous exposure to small poison doses and might show after years, eg. causing cancer or damage to unborn life. Insecticides like organochlorines have a low short term toxicity but are mutagenic, cancerogenic and teratogenic in the long term, whereas organophosphates typically are characterised by a high short term and low long term toxicity. The long term toxicity depends on whether the contamination is of the **oral** (via the mouth), the **dermal** (via the skin) or the **respiratory** (via the lungs) type and whether there is a **single** or **chronic** exposure to the chemical. Scientists test newly developed pesticides for their toxicity by using test animals, usually rats, fish, etc. The toxicity is expressed as **LD_{50}-value** (**L**ethal **D**ose) which is the concentration that kills 50% of the test animals. However, the toxicity of a certain chemical to a rat does not necessarily mean that the toxicity will be the same for humans. The **World Health Organisation** (**WHO**) suggests hazard classes for insecticides and other pesticides depending on their **LD_{50}-value**, as shown in **box 8-3**.

HAZARD CLASS		estimated lethal oral dose for a human being	LD_{50}-value for rats (mg/kg body weight) oral solids	oral liquids	dermal solids	dermal liquids
I A	extremely hazardous	a few drops, a grain	≤ 5	≤ 20	≤ 10	≤ 40
I B	highly hazardous	one teaspoon (5 ml)	5 - 50	20 - 200	10 - 100	40 - 400
II	moderately hazardous	two tablespoons or less	50 - 500	200 - 2000	10 - 1000	400 - 4000
III	slightly hazardous	two tablespoons to 0.5 l	> 500	> 2000	> 1000	> 4000

Box 8-3: Pesticide Hazard Classes as recommended by the World Health Organisation (**WHO**)

8.8.3 Safe Use of Pesticides

When using insecticides, it is very important to follow certain safety precautions in order to reduce the risk of health hazards and to minimise the contamination of the environment. Insecticides should always be used with the greatest care and are **not** to be used for any purpose, or in any manner contrary to the information provided on the label. For the safe use of pesticides the following guide-lines should be followed strictly. These guide-lines also apply to the use of biological insecticides.

- Transport pesticides carefully so that the containers are not damaged or fall over. Put the container in an upright position and secure it properly.
- Avoid the spilling of pesticides. Cover spilled insecticides with absorbent material.
- Never transport and store insecticides together with food items.
- Store insecticides in a suitable, well ventilated shed that should be kept locked at all times. Do not expose insecticides to the sun.
- Store insecticides out of the reach of children and unauthorised persons.
- Never store insecticides in empty soft drink or beer bottles since they might be mistakenly consumed.
- Prior to the use of insecticides get advice on which insecticide and concentration to use, how often to spray and whether the particular pest is resistant to the used pesticide.
- Read the instructions on the label of the container carefully.
- Calculate the exact amount of insecticide you will need. Only apply the dosage indicated in the instructions for use. Remember: **more doesn't help more**.
- Only prepare the amount of insecticide that you will need for the treatment for one day. Once mixed, the active ingredient is broken down rapidly by microbial action.
- When preparing and applying insecticides use protective clothing and other safety gear. Wear rubber gloves, rubber boots, an overall or at least a pair of long trousers and a shirt with long sleeves in order to cover all parts of the skin during spraying, as shown in **fig. 8-16**.
- Additionally wear goggles and a mask when preparing the spray solution.
- When handling pesticides do not smoke, eat and drink. Do not chew *buai*.
- Do not inhale the vapour of insecticides.
- Don't spray if it is raining, very windy or very hot and sunny. Preferably spray in the early morning hours or in the late afternoon to minimise 'sunburn' of the sprayed plant and degradation of the active ingredients by ultraviolet (UV) radiation.
- Mind the direction of the wind, as shown in **fig. 8-17**. Always spray with the wind, so that the insecticide is drifted away from you and other knapsack operators.
- If the wind is too strong, you should not spray since the wind might carry the spray droplets a long distance away from the target.
- If the nozzle of the sprayer is clogged never try to blow it free with your mouth.
- After spraying clean and rinse the sprayer thoroughly and dry the device.
- Properly dispose of the excess insecticide as well as the cleaning and rinsing solution.
- Avoid spilling and disposing of insecticides next to wells, creeks, rivers etc.
- Destroy or burn empty insecticide containers so that they cannot be used any more. The chemical cannot be removed completely from the containers even if rinsed a thousand times.
- Wash your hands thoroughly with soap after having finished spraying and cleaning.
- In case you come into contact with the insecticide immediately undress and wash the

Fig. 8-16: Always use protective clothing when spraying insecticides (photo Schneider, M.F.)

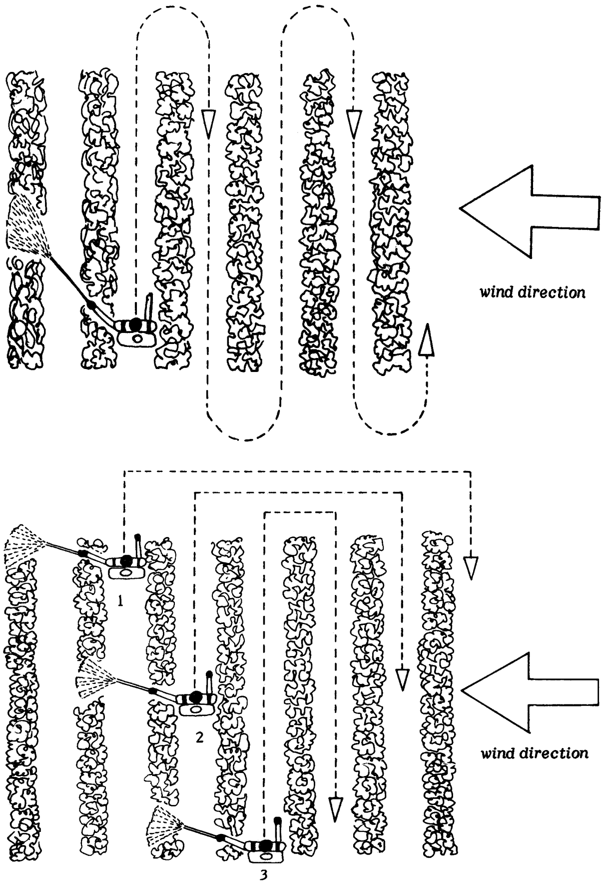


Fig. 8-17: Mind the direction of the wind in order to avoid contamination of yourself and other knapsack operators (reprod. from DAL, 1986)

exposed skin carefully with soap. In case your eyes came into contact with insecticide rinse with excess water and seek medical advice.

- In case of an intoxication with an insecticide rush the patient to the nearest hospital or physician immediately. Show the container of the insecticide or at least the label to the doctor so that he/she will be able to use the right antidote against the insecticide.
- If somebody swallows an insecticide try to induce vomiting by giving the person an emetic for instance salt water to drink. Do so only if the person in not unconscious.
- If you use organophosphates make sure that the antidote Atropine Sulphate (i.v.) is available at the nearest hospital. Intoxications with organophosphates require immediate medical care, since they can cause death within a few minutes.
- Mind the 'Withholding Period', the time between the last spraying and harvesting as indicated on the insecticide label.

8.8.4 Calculation of Concentration

In order to correctly calculate the concentration of an insecticide in a diluent, firstly convert all measures to the same unit, eg. to grams or millilitres, then calculate the concentration in % as follows:

$$\% = \frac{\textbf{amount of insecticide (in grammes or ml) x 100}}{\textbf{amount of diluent (in grammes or ml)}}$$

Example: 20 ml of an insecticide were poured into a knapsack sprayer containing 12 litres water. To calculate the concentration, firstly convert all measures into the same unit, eg. in millilitres, ie. 12 litres = 12,000 ml. The concentration of the mixture is calculated:

20 ml x 100/12,000 ml = 0.167%

To work out how much of a chemical has to be dissolved in a particular amount of diluent in order to get a desired concentration, firstly convert all measures to the same unit, eg. to grams or millilitres, then calculate the required amount of insecticide as follows:

$$\frac{\textbf{desired concentration in \% x amount of diluent}}{\textbf{100}}$$

Example: You need 400 litres spray solution of an insecticide at a concentration of 0.05%. How much of the insecticide will you have to mix with 400 litres of water? The amount of the required insecticide is calculated:

0.05% x 400 l/ 100 = 0.2 litres (or 200 ml)

Units, measures and conversion tables can be found at the end of this book.

8.8.5 Pesticide Legislation

Insecticides and other pesticides generally are under governmental control. The chemicals have to be registered, their use has to be approved and customs control the import of those chemicals. In PNG the **Department of Environment and Conservation** is in charge of matters related to insecticides. Even though there is quite a variety of imposed laws regulating the use of pesticides, the import, transport, use, disposal, etc. is often not carried out in accordance with those regulations due to a lack of funds, manpower or simply due to negligence and ignorance.

The international community has banned the use of certain pesticides, mainly the organochlorines like DDT due to their adverse impacts on the environment, due to health hazards or because the chemicals are no longer effective against resistant pests. The twelve most dangerous pesticides are also referred to as the '**dirty dozen**'. However, some of the banned chemicals are still produced by 'Western' countries and sold to 'Third World' countries. In order to overcome these double standards, the governments of 'Third World' countries, international organisations like FAO, UNDP, OESO and EEC as well as environmental organisations like PAN appealed for protective legislation and finally, an 'Intergovernmental Negotiating Committee' (**INC**) ratified the **Prior Informed Consent** (PIC)-**Convention**. PIC is the principle that the governments of pesticide exporting countries ask importing countries for an approval of the import of the chemicals. Insecticides subject to the PIC-Convention are: Aldrin, Chlordane, Dieldrin, DDT, Dinoseb, 1,2-Dibromethane, Fluoroacetamide, Hexachlorocyclohexane (CHC), PBB, PCB, PCT, Heptachlor, Lindane, Pentachlorophenole and Tris(2,3Dibromoprophy)phosphate. Apart form the PIC-Convention, the 'Code of Conduct on the Distribution and Use of Pesticides', developed by the **Food and Agriculture Organisation** (**FAO**) tackles problems arising from inadequate pesticide legislation in the 'Third World'. Besides the non-mandatory international legislation, individual countries have more or less strict and effective national pesticide legislation:

Papua New Guinea

- Environmental Contaminants Act (1978)
- Pesticide Regulation (1986)
- Pesticide Guidelines (1986)
- Environmental Planning Act (1978)
- Public Health Act
- The Poisonous and Dangerous Substances Act (1952)
- The Industrial Safety, Health and Welfare Act (1961)
- Water Resources Act (1982)
- Quarantine Act, Chapter 234
- Customs Act, Chapter 234

Vanuatu (no own legislation)

Solomon Islands

- The Safety at Work Act, Pesticide Regulations (1982)
- The Pharmacy and Poisons Act (1964)
- The Agricultural Quarantine Act (198?)

Fiji

- Pesticide Act (1971, 1976), Chapter 157 (1978)
- Pesticide Regulations (1971, 1972)
- Pharmacy and Poisons Act, Chapter 115

Western Samoa

- Forests Act (1967)
- The Poisons Act (1986)
- Poisons Regulations (1969)
- Agriculture, Forests and Fisheries Ordinance (1959)

Tonga

- The Pesticides Act (1975), amended 1981

Pesticides usually have a **common name**, eg. Aldicarb; a **chemical name** derived from the chemical structure of the pesticide, eg. 2- methyl- 2- (methylthio)- propionaldehyde O-(methylcarbamoyl) oxime; and a **trade name**, eg. Temik. The legislation requires that certain information has to be stated on the label of the pesticide container such as the trade name, composition, common or chemical name, type of formulation, net contents, name and address of the manufacturer, registration number, signal words like **DANGER**, **WARNING**, **TOXIC**, **CAUTION**, **POISON**, **HARMFUL**, **KEEP OUT OF REACH OF CHILDREN**, health and environmental hazards, directions for use, application method, preparation and dilution of pesticide, warranty, guide-lines for storage and disposal, withholding period, expiry date, first aid measures, and pictograms, as shown in **fig. 8-18**. These and further information can also be found in technical papers and datasheets, as shown in **box 8-4** for Malathion.

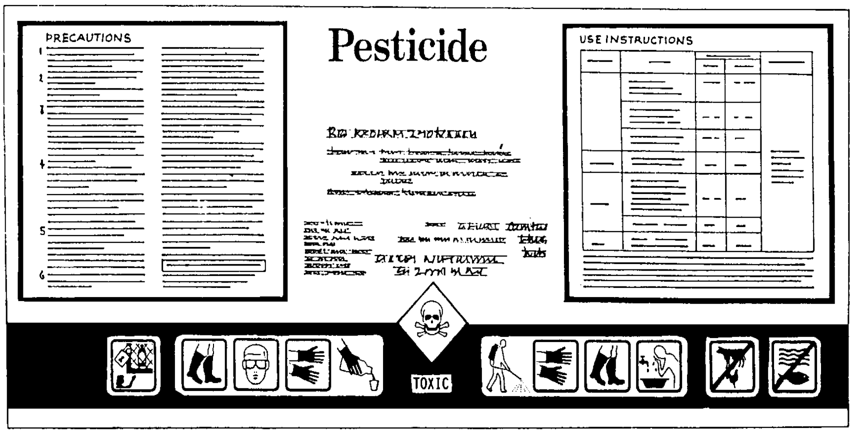


Fig. 8-18: Proposed label by FAO (reprod. from Arendse, W. et al., 1995[3])

MALATHION

Chemical Group: Organophosphate
Chemical Name: Diethyl (dimethoxyphosphorylthio) sucinate
CAS Number: 121-75-5

Some Trade Names:
Calmathion, Aldison, Kypfos, Cythion, Malamar, Detmol MA 96 %, Malaphele, Emmatos, Mercaptothion, Carbofos, Malaspray, Emmatos, Extra, Malathion, Exterm M, Malathiozol, Fomadol, Malathion 95%, Kop-Thion, Spray, For-Mal, Malathiozoo, Fyfanon, MLT, Gisonthion, Prentox, Harcros, Sumitox, Karbofos, Zithiol

WHO Recommended Classification By Hazard:
Liquid: Class III: Slightly Hazardous

Toxicity:
Lethal Dose For Rats By Oral Route: LD_{50}: 290 mg/kg
Lethal Dose For Rats By Dermal Route: LD_{50}: 4444 mg/kg
Note: The LD_{50} for malathion varies according to impurities (WHO)

Hazards:
General: see **Organophosphates**
Specific:
- Acute: harmful by swallowing, inhalation or skin contact. (FCH)
- Chronic: possible reproductive toxicity (PA). Nerve poison; cases of long-lasting polyneuropathy and sensory damage have been reported in humans, as well as behavioural changes. Debate on whether malathion is carcinogenic continues. (PAY)

Environmental Effects:
Highly toxic to bees, aquatic and to non-target species, such as freshwater fish and moderately toxic to birds. (PAY)

Main Use: Insecticide

Specific/Other Uses:
It is an active stomach and contact poison. It is effective on a wide range of insects. Dusting powder (1% a.i.) is used for controlling lice. Residual spraying of malathion is carried out against mosquitoes and houseflies.

Remarks:
WHO Expert Committee on Vector Biology and Control recommended that the limit of isomalathion (impurity) in water-dispersible powder should not exceed 1.8 percent. (IRPTC 1/79)
Isomalathion, an impurity in some powder formulations causes increased toxicity. Certain inert diluents and the surfactants in the formulation change malathion to the more toxic isomalathion (also known as maloxon). (WHO Chronicle)
In 1976, in Pakistan, 2,800 of the 7,500 field workers involved in malarial control operations were poisoned whilst applying malathion water-dispersible powder. Five of them died. This was caused by isomalathion, present as impurities in malathion. (IRPTC 1/79)
Instead of malathion, community mosquito and blackfly control programmes could use *Bacillus thuringiensis var. israeliensis* (BTI) which is toxic only to a very narrow range of organisms. (PAY)

Regulatory Control in many Countries

References:
CLP3: Consolidated List of Products Whose Consumption and/or Sale have been Banned, Withdrawn, Severely Restricted or Not Approved by Governments. 3rd. issue, United Nations, New York, 1989
FCH: Farm Chemicals Handbook, Meister, Wiloughby, Ohio, 1989
IRPTC 3/88: International Register of Potentially Toxic Chemicals, IRPTC Legal File, March, 1988
IRPTC 1/79: International Register of Potentially Toxic Chemicals, IRPTC Bulletin Vol. 2, no. 1, January, 1979
PA: Mott, L. and Snyder, K., Pesticide Alert: A Guide to Pesticides in Fruits and Vegetables- Natural Resource Defence Council, Sierra Club Books, San Francisco, 1988
PAY: “Malathion”, Chemical WATCH Factsheet, reprinted from Pesticides and You, Vol. 8, No. 2, June, 1988
Pres 86: Improvement of Control of Brown Planthopper, An Insect Pest of Rice, Presidential Instruction No. 3/1986, Jakarta, Indonesia, dated 5 November, 1986
WHO: The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification 1990-1991. International Programme on Chemical Safety, Geneva, 1990
WHO Chronicle: Vol. 32, no. 9, World Health Organisation, Geneva, September, 1978.

Box 8-4: Pesticide datasheet for Malathion (Rengam, S. and Snyder, K., 1991[3])

8.8.6 Application of Insecticides

Insecticides are purposely applied to modify the population of a pest insect to a desired level using the least amount of insecticide necessary. The success of an insecticide application depends on the phase of the pest's life cycle, on the climatic conditions, on the insecticide used and application devices and on the accuracy in delivering the right amount of insecticide to the target insect. Furthermore, an efficient application method takes into consideration the costs involved in the application as well as suitable safety precautions to minimise impacts of the insecticide on human health and the environment. One has to bear in mind that almost any application method 'wastes' most of the insecticide since only a tiny fraction of the insecticide reaches its target. Therefore, unnecessary and inappropriate spraying should be avoided for economic and ecological reasons. This section describes methods for the delivery of insecticides, that can be either biological or chemical control agents.

Broad spectrum insecticides are applied as a **curative** or **eradicant measure** to eradicate a pest population that is already established on a crop. **Protectant measures** are applied before a predicted infestation of crops. **Prophylactic measures** are continuously applied for the prevention of an outbreak. **Economic threshold programmes** are applied when the pest density reaches a predefined economic threshold level, as outlined in **chapter 8.9**.

Insecticide Formulations

An insecticide formulation is the proportion and number of additional substance that accompany an insecticide when it is prepared for the application. Insecticide formulations contain the **active ingredient** (**a.i.**) together with a number of non-active ingredients such as a carrier or an organic solvent, stabilisers, wetters or surfactants, emulsifiers, adjuvants and other additives. The amount of the active ingredient is usually expressed as % weight a.i. per weight of the formulation (**w/w**) or as % weight a.i. per volume of the formulation (**w/v**). Stabilisers are added for instance to protect the active ingredient from degradation by ultraviolet (UV) radiation. Adjuvants are additives that enhance the toxicity of the active ingredient. Emulsifiers have to be added since most insecticides are lipophilic and thus dissolve only in oils and lipids. The active ingredient needs to be emulsified with detergent-like chemicals in order to disperse properly in water. Wetters, surfactants or spreaders are surface active ingredients that lower the surface tension of water so that the spread of the active ingredient is enhanced. A simple experiment can be carried out in order to illustrate the effects of wetters: if water is dripped on the wax-covered surface of a leaf, it will run off rather than wetting the leaf. If soap is added, the water will disperse on the leaf. The following formulations are available:

- **dry formulations** are usually used undiluted. **Dusts** are the mixture of the active ingredient with a carrier such as finely ground clay or volcanic ash. The dust is spread with a perforated container, propelled by hand or by an engine driven duster. In **granules** the active ingredient is mixed with larger particles and applied by hand or a granular applicator. Granules are less hazardous than dusts since granules are not drifted by the wind. A **wettable powder** is the emulsifiable concentrate of an active ingredient that has to be mixed with water prior to the application and can be sprayed either with a lever-operated knapsack, a mist blower or a hydraulic sprayer

- **liquid formulations** are the main type of insecticides. In **emulsifiable concentrates** the active ingredient plus the emulsifier is dissolved in an organic solvent and has to be mixed with water prior to spraying. This type of formulation can be sprayed with lever-operated knapsacks, mist blowers or hydraulic sprayers. Usually undiluted liquid formulations can be sprayed with ultra low volume applicators (**ULVA**)

- **poisonous baits** are the mixture of an active ingredient with a suitable bait like cereals and are applied as bait barrier

- **fumigants** are volatile insecticides that are applied in an enclosure; eg. the treatment of nursery soil under a polythene cover.

Devices for the Application of Insecticides

Most of the devices shown in **fig. 8-16** are suitable for the delivery of one or more pesticide formulations, depending on the physical properties of the formulation. Most devices allow the dispersal of defined and exact amounts of an insecticide per area, provided that the device is calibrated prior to the application. The devices are either hand-held or mounted on a suitable vehicle like a tractor, trailer or aircraft. During the application the wind speed, wind direction, precipitation and appropriate safety measures have to be considered. The kind of application device also depends on the accessibility of the area to be sprayed. Forestry plantations in PNG, for instance are hardly accessible for vehicles to carry out spraying. In many cases man-held and man-operated devices are the only alternative to aerial spraying.

- conventional **boom sprayers** allow the application of insecticides on a large scale and are used in nurseries and for crops of low height. The device can be mounted onto a suitable vehicle such as a tractor.
- **controlled droplet applicators** (**CDA**, **figs. 8-19 E**, **F**) like **ultra low volume applicators** (**ULVA**) (**fig. 8-19 A**), '**foggers**' and **aerosol-generators** are devices that neither use water nor air to propel the insecticide. Usually a highly concentrated insecticide formulation is 'atomised' by dripping it on a revolving disk as in ULVAs. ULVAs produce very small uniform droplets of a few manometers in diameter. These devices are very light, require only a relatively small storage container for the insecticide and are therefore suitable for aerial insecticide applications or for the application in arid areas where water as carrier is limited. The required amount of insecticide is usually five litres per hectare or less. Disadvantages of the small droplets are that these can remain air-borne for a considerable length of time so that they might be drifted away by the wind or that the volatile active ingredient might evaporate
- **aerial spraying** is certainly the most effective approach for treating large, inaccessible areas with insecticides but is also the most costly exercise. The advantages of helicopters (**fig. 8-19 I**) are that they can hover at very low speed at low altitudes above the area to be treated, whereas aeroplanes (**fig. 8-19 G**) have to travel at high speed at higher altitudes, especially in rugged areas. Aerial spraying by means of a fixed wing aircraft is cheaper but less effective in tropical countries than the use of a helicopter. This is because thermal winds usually carry the spray droplets away so that these hardly reach their target. Furthermore, most of the atomised spray droplets evaporate due to high temperatures before reaching the target
- **motorised knapsacks** (**fig. 8-19 D**) and **lever-operated knapsacks** (**fig. 8-19 C**) are the most common devices used for insecticide treatments in nurseries, smaller areas or on individual plants. They are relatively cheap and easy to maintain, however the devices are quite heavy, particularly when filled with insecticide, and require frequent and lengthy resting periods for the knapsack operators, especially when used in heavy terrain
- **air-blast sprayers** (**fig. 8-19 B**) or **mist blowers** (**fig. 8-19 H**) use a stream of air instead of large volumes of water to disperse the insecticide. The insecticide is forced through small nozzles into a stream of air produced by a powerful fan that carries the spray to the target
- **dusters** are devices for the application of an insecticide impregnated onto a dust-like carrier. The dust is propelled by the use of air
- **granular-insecticide applicators** are used to dispense insecticides impregnated onto a granular carrier
- **hydraulic sprayers** (**fig. 8-19 J**) utilise a mixture of insecticide and usually water that is forced through a spraying system at high pressure. There is a variety of modifications for many agricultural and forestry purposes such as low-pressure-low-volume sprayers and high-pressure-high-volume sprayers
- **dipping** in insecticide is commonly done with nursery stock or timber products
- **soil applicators** (**fig. 8-19 L**) are used for instance in nurseries and forestry plantations for the injection of insecticides against soil-borne insect pests

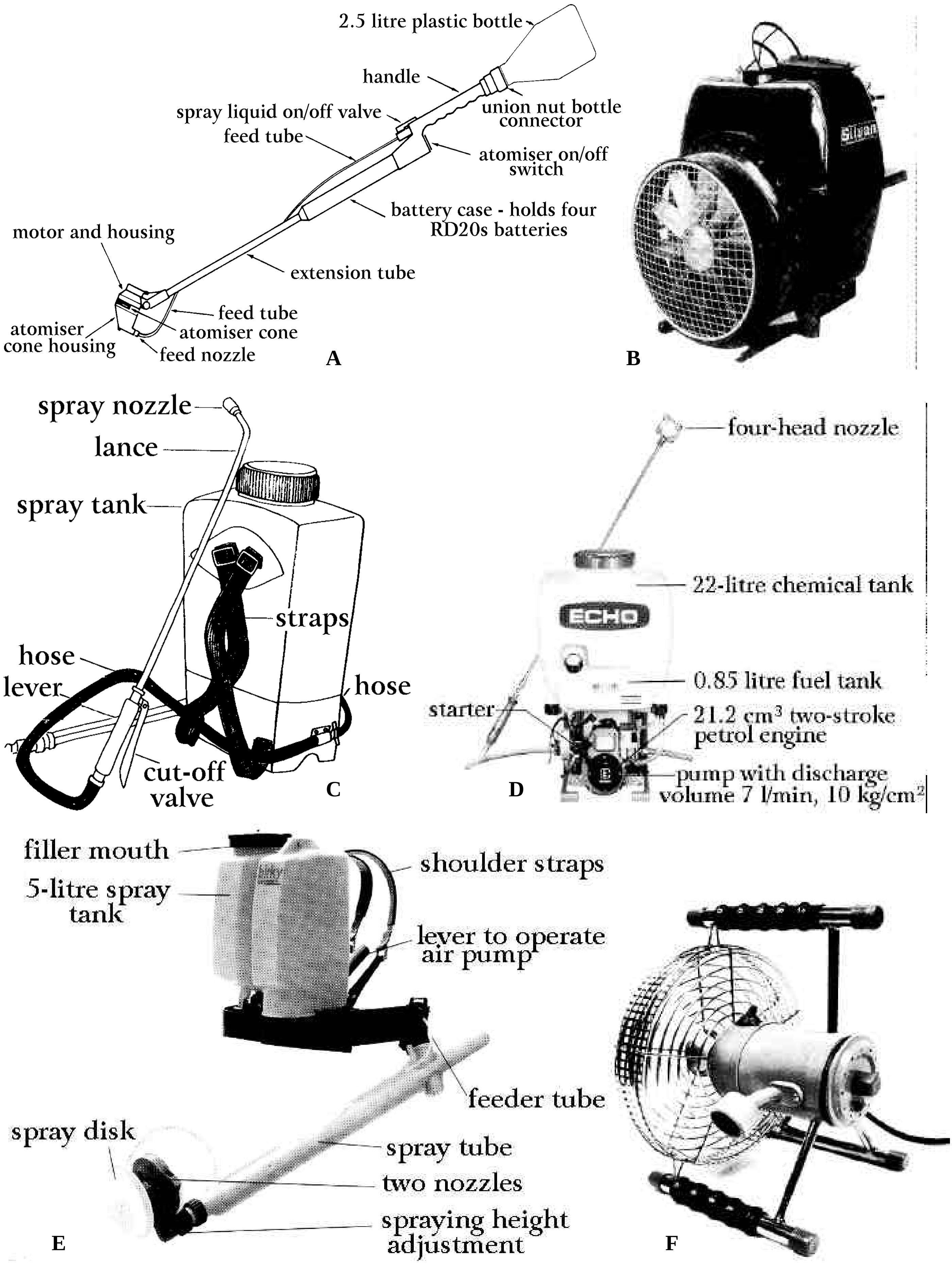

2.5 litre plastic bottle
handle
union nut bottle connector
spray liquid on/off valve
feed tube
atomiser on/off switch
battery case - holds four RD20s batteries
motor and housing
extension tube
feed tube
atomiser cone
atomiser cone housing
feed nozzle
A
Silvan
B
spray nozzle
lance
spray tank
straps
hose
lever
hose
cut-off valve
C
four-head nozzle
22-litre chemical tank
ECHO
0.85 litre fuel tank
starter
21.2 cm³ two-stroke petrol engine
pump with discharge volume 7 l/min, 10 kg/cm²
D
filler mouth
5-litre spray tank
shoulder straps
lever to operate air pump
feeder tube
spray disk
spray tube
two nozzles
spraying height adjustment
E
F

Fig. 8-19: Pesticide Applicators: (A[‡]) ultra low volume applicator (ULVA); (B[‡]) air blast sprayer; (C[$]) lever-operated knapsack; (D[‡]) motorised hydraulic knapsack; (E[‡], F[‡]) hand-held controlled droplet applicators (CDA); (G[$$]) fixed wing aerial insecticide application; (H[‡‡]) motorised knapsack mist blower; (I[†]) aerial insecticide application using a helicopter; (J[††]) hydraulic insecticide sprayer; (K[$$]) bait barrier preventing the descent of immature stages of pests from the crown into the soil or litter; (L[†††]) soil applicator (reproduced from Queensland DPI, 1990[‡]; DAL, 1986[$]; Hill, D.S. and Waller, J.M., 1982[‡‡], Ross, H.H., 1982[$$]; Barbosa, P. and Wagner, M.R., 1989[†]; Coulson, R.N. and Witter, J.A., 1984[††]; ICI[†††])

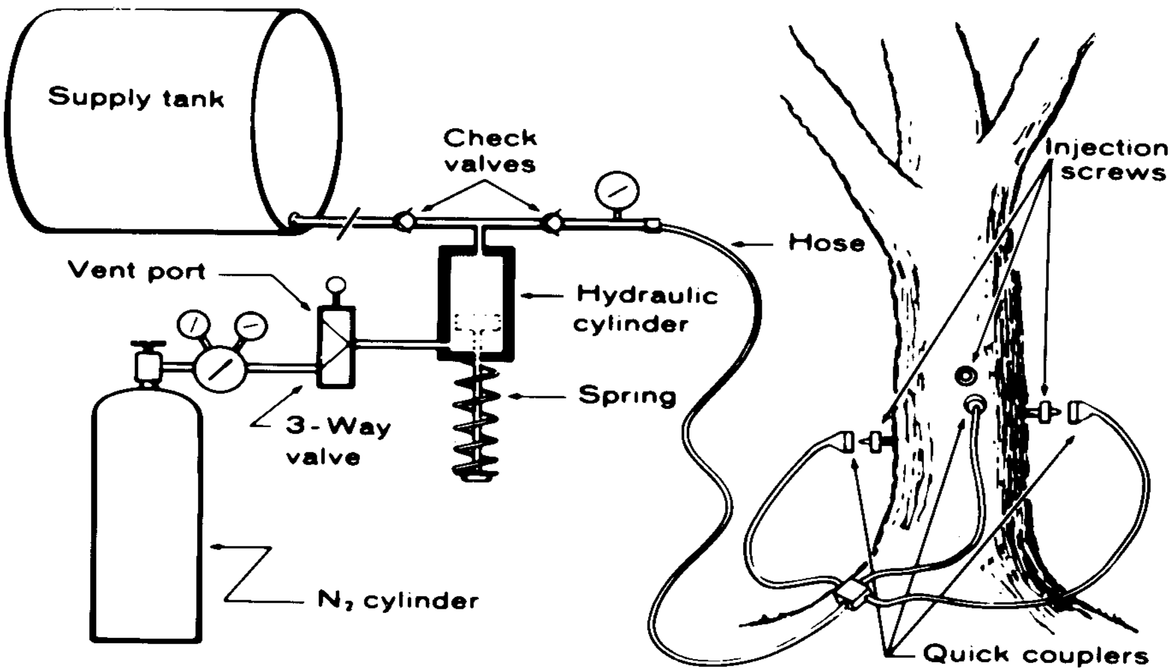


Fig. 8-20: System injector for the application of insecticides (reprod. from Barbosa, P. & Wagner, M.R., 1989)

- **system injectors** are sophisticated devices used for the application of insecticides under very high pressure, for instance into the stem of a tree, shown in **fig. 8-20**. This measure of course is not feasible on a large-scale and is used only for individual trees, eg. for valuable seed trees.

8.9 Integrated Pest Management

The overuse of chemical insecticides during the past fifty years, the resulting environmental risks such as resistance against insecticides and the problem of **biomagnification** causing hazards for the public health, demanded the development of new, more effective pest control strategies. The concept of integrated pest management (**IPM**) was developed about 40 years ago and initially involved integrated biological and chemical methods only. The concept was further developed to a complex and more sustainable approach involving ecological, sociocultural and economic principles aiming at the use of available and compatible methods for pest control. This goal is achieved by maintaining the quality and yield of crops in a cost-effective manner rather than maximising the yields. IPM is an integrated and multidisciplinary approach avoiding reliance on a single method but using various control strategies, discussed in the previous sections of this chapter and summarised in **fig. 8-21**. The basic management strategies are regular monitoring of the pest population and the application of various non-chemical methods to keep the pest population below a **threshold level**. Chemical methods are used as a last curative remedy, only if all other methods fail and the population of a pest increases above the predefined threshold level. Prognosis models for the dynamics of the pest population further support the long-term planning, and allow the exact timing, of necessary control measures. Additionally IPM aims at the conservation and modification of surrounding habitats so that these are suitable for natural enemies. Obstacles to the rapid implementation of IPM strategies are the lack of knowledge and the complexity of the biotic and abiotic factors influencing the crop and the populations of the pests as well as the natural enemies. Chemical industries are reluctant to fund applied research since IPM strategies reduce the sales of insecticides. Further obstacles are the lack of training and active participation of agriculturalists, foresters and extension officers in IPM techniques.

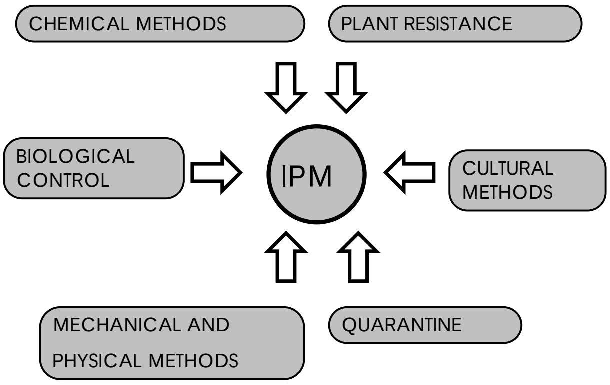


Fig. 8-21: Strategies used in Integrated Pest Management (IPM) (graphic Schneider, M.F)

The threshold concept aims at the measurement of the density of a pest insect in order to quantify the pest status of the insect associated with a particular crop. The **Economic Injury Level** (**EIL**) or damage threshold is the density of the pest population at which the costs for the application of an insecticide balance the economic loss caused by the pest. The EIL can be calculated according to:

$$\mathbf{EIL} = \frac{\mathbf{C}}{\mathbf{V} \times \mathbf{D} \times \mathbf{K}}$$, where

C = costs of control measure per unit (eg. Kina/ha)
V = market value per unit of product (eg. Kina/kg)
D = yield loss per unit number of insects (eg. kg/n)
K = proportionate reduction of insect population caused by a control measure

The calculation of the costs for spraying takes into account the purchase of the insecticide, the hire or purchase of spraying equipment, labour, transport, etc., whereas the economic loss caused by a pest depends on the crop, the costs for replanting or refilling, the costs of plant material, the costs of labour, etc. The density of the pest population at which control measures are warranted and need to be taken, before a pest population further increases and exceeds the damage threshold is called **Economic Threshold Level** (**ETL**), or warning or action threshold. This level is predictive and represents the time to apply control measures. Both levels are illustrated in **fig. 8-22**.

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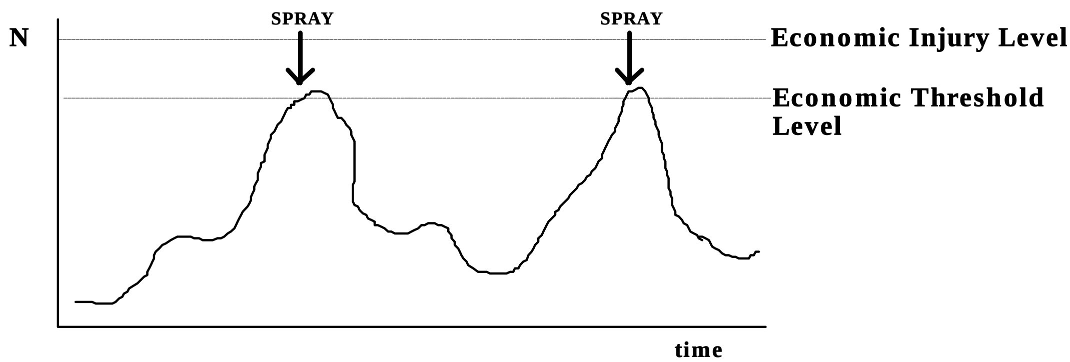

Fig. 8-22: Integrated Pest Management: Economic Injury Level (**EIL**) and Economic Threshold Level (**ETL**) (graphic Schneider, M.F.)

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