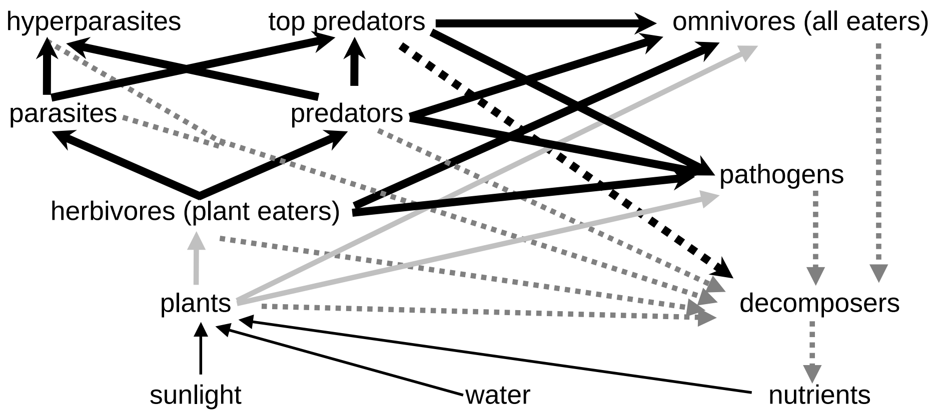
4 Pests, diseases and the agro-ecosystem

4.1 Biodiversity and food webs

If we think about the myriad of life forms in a natural forest, how do the forest creatures live? Trees and other plants absorb water and nutrients from the soil and obtain energy from the sun, and transform these into leaves, stems, roots, flowers, and fruits. Of all the forms of life on earth, only plants can produce organic matter from solar energy, water and nutrients. Because of this ability, plants are called *producers.* All other kinds of living things require organic matter as food and are called *consumers*.

Some consumers eat plant parts, such as leaves, fruits or seeds (many types of insects, for example); they are called herbivores. Some eat other animals, and depending on the way they eat (see Section 4.3); they are called predators or parasites. Birds that eat insects, lions that eat impalas, and wasps that parasitise caterpillars are examples. Other animals have a mixed diet of both plants and animals and are called omnivores. Micro-organisms that cause disease in plants and among animals are called pathogens. Finally, some life forms eat or decompose dead plants and animals. These scavengers and decomposers include birds such as vultures, insects that live on rotting plant and animals, and many types of fungi and bacteria.

Each species plays an important role to maintain the balance of the web of life. By studying natural systems like forests, which provide an enormous diversity of plants and animals, we can learn a great deal about the behaviour and relationships between different kinds of plants and animals. Even though many of them are consumers and exist by eating or parasitising others, they seldom eliminate their hosts. A balance exists between the different life forms in an undisturbed forest. The figure below shows the relationship among producers, consumers, and decomposers in a natural food chain:



In an agricultural field the food chain is much simpler than in a natural forest, since there are only a few kinds of plants (the types planted by the farmer and weeds that invade the field). This narrow diversity of plant life can only support a limited range of animals. Nevertheless, the plants and animals are still linked in a food chain, just as they are in the much more complex forest.

An ecosystem is a natural system that is formed by dynamic interactions between biotic (living) and non-biotic (non-living) elements in a defined area. Biotic elements include plants, insects (pests, natural enemies, decomposers), microbes and other living organisms, and non-biotic elements comprise weather components such as temperature, relative humidity, wind, sunshine, rain and soil. Each element has its special characteristics and role in the system that, as a function of time and place, will influence the distribution and population of living organisms. The term ecosystem also involves nutrient and energy flows within the system.

An agro-ecosystem is characterised by a much simpler composition with regard to the number of species residing in the system and the relative simplicity of energy flows than a natural, stable ecosystem. Because of this simplicity, injudicious use of pesticides can easily disturb the balance due to the killing of natural enemies and other organisms. The integrated pest and production management (IPPM) and integrated crop management (ICM) concepts find their basis in the stability of the agro-ecosystem and in economic efficiency. By maintaining the stability of the agro-ecosystem, pest populations can be kept at manageable levels. To achieve this, the following important points need to be remembered:

A. Each ecosystem is dynamic with respect to numbers, position, role and intensity of each of the elements within, which transform and develop continuously. They form a living, ever-changing system.

B. Each ecosystem contains a hierarchical structure. For example: plants are producers of vegetable food, which can be used to feed herbivores. The herbivores (including pests) eat the plants using various modes of attack. The herbivores, in turn, serve as food for the predators and parasites (often known as natural enemies when the herbivore is a pest), which again may be eaten by other predators or parasites. Finally, all organisms serve as food for the decomposers. If no natural enemies exist within the agro-ecosystem, the pests will multiply unlimitedly and destroy the crop. But if the crop is finished, the pests will die of starvation. Many natural enemies are not choosy about their food and will eat other organisms, perhaps even decomposers, when there are no pests.

C. All elements of the agro-ecosystem are strongly linked and disturbance of one element disturbs the whole balance. Therefore, the task of farmers is to maintain the balance amongst elements in the agro-ecosystem, ensuring a good environment for the crop to grow well.

A well-balanced agro-ecosystem needs to become as close as possible to a natural ecosystem and therefore to have a high degree of diversity, both with regard to number of species and to genetic diversity among individuals within one population. In practice, it means that we can see various kinds of plants and animals. Some beneficial animals include earthworms that help increase soil fertility, and natural enemies such as spiders, beetles, ants, frogs and lizards that help suppress insect pest populations. If we do not find many of these beneficials in an agro-ecosystem, there is a problem caused by one of the following reasons:

- Too many pesticides are being used that killed the beneficials.

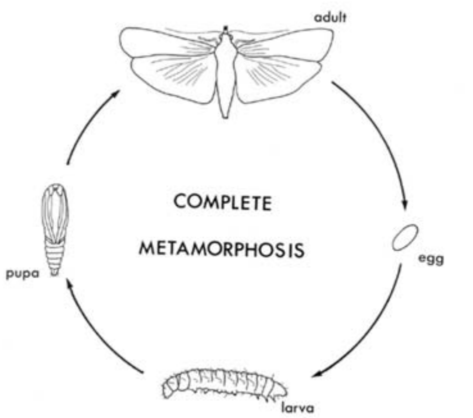
- Not enough food for the beneficials. The larval stages of most natural enemies eat other animals such as caterpillars and leafhoppers, whereas the adults may live on honey or pollen produced by wild plants in the environment. The adults need adequate food to be able to produce eggs and, thus, the next generation. Therefore, a variety of plants are needed to maintain the populations of these natural enemies. The more diverse the vegetation in an agro-ecosystem, the more diverse also the natural enemy populations, hence the more likely that pest populations will be controlled naturally.

- Soil composition or texture does not support the life of earthworms and soil insects. Unfavourable conditions for the soil inhabitants are often caused by low organic matter content or prolonged inundation of a field. The soil becomes hard and/or short of oxygen. The disappearance of the soil organisms will cause further deterioration of the soil.

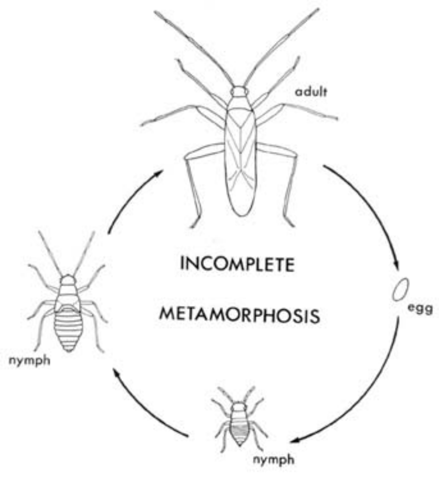
4.2 Life cycles

4.2.1 Insect life cycles

During the course of their lives, insects pass through a number of stages. The adult stage is responsible for reproduction and may or may not actually feed. The male adult transfers sperm to the female who may store it and so be able to fertilise eggs over long periods of time. In most species the female possesses a specialised structure, the ovipositor, used for depositing the eggs in selected places. After hatching from eggs, immature insects feed and grow to become adults. In the case of many insects, the form of the immature stage differs greatly from that of the adult and is called a larva e.g. butterfly and beetle species. The larva hatches from an egg and is very small. It begins to feed and grow immediately but the larval skin is unable to stretch sufficiently to allow room for growth. In order to complete its growth the larva must shed its outer skin, a process called moulting. Before moulting, a new soft skin is formed beneath the old and, when the old one is shed, the new one is stretched and hardens rapidly leaving space for further growth of the larva. Moulting occurs several times and on each occasion the larva is said to enter a new stage of growth, or instar. When the larva is full-grown, the final moult produces an immobile stage, which is known as a pupa. Although the pupa is unable to move about, internally a lot of activities are occurring as its tissues are re-organised so that when it emerges from the pupal skin as an adult it has changed (metamorphosised) often very dramatically. The type of metamorphosis that involves a larva and a pupa is known as 'complete metamorphosis'. Beetles and moths are good examples of sweetpotato insect pests that undergo this type of development.



Another type of development called 'incomplete metamorphosis' is shown by other insects e.g. aphids and grasshoppers. In this case the immature stages resemble the adult, and are called nymphs, not larvae. Although they are similar to their adults, nymphs lack certain adult features such as sexual organs and wings. Nymphs grow through a series of moults, and during the later stages adult features begin to develop. The most obvious feature is the development of wing 'buds' that eventually develop into complete wings (in species that have wings). The adult features become mature and functioning only after the final moult.

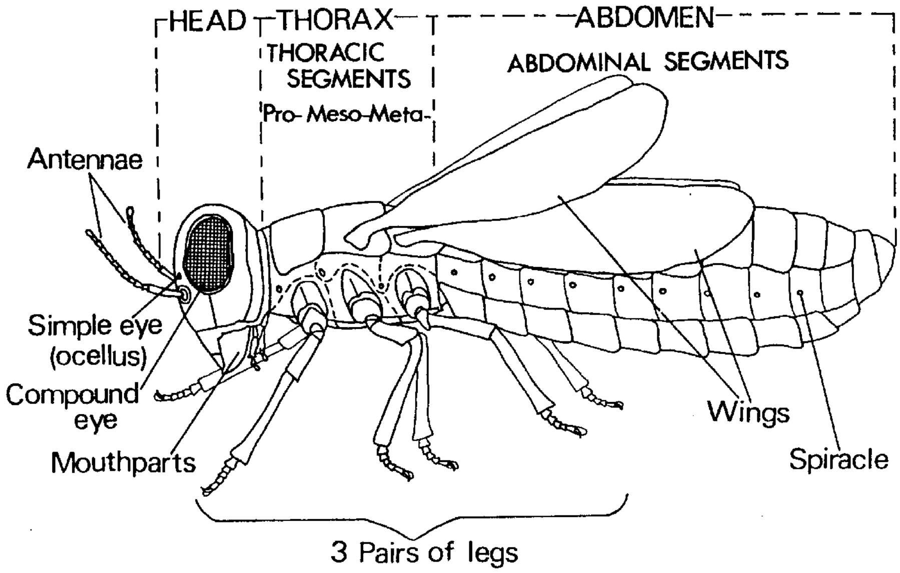


The time taken for an insect to complete its lifecycle (from egg to adult) varies between different insect species. The environmental conditions such as temperature, food sources etc. also affect the speed of development of the different life stages of the insect. Most insects have a faster lifecycle at warmer temperatures. Many insects can use several different plants as host plants during their development; we refer to these different plants as alternative hosts. Insects can survive on alternative host plants when their preferred food plant is not in the field.

Because insects have relatively short lifecycles high populations can often build up over very short periods of time. For example if one female sweetpotato weevil adult lays 100 eggs that hatch and develop into larvae, pupae and then adults (50% of which are female), over 1 month. This will mean that one month later there are 50 female sweetpotato weevil adults, if these 50 then mate and each lay 100 eggs that develop into adults, one month later there will be 2500 female sweetpotato weevil adults to feed and lay eggs on the developing sweetpotato crop. The table below demonstrates just how quickly insect populations can develop if natural enemies and other pest management strategies do not reduce them.

Month	Population of females	Total number of eggs laid (100 per female)	Number of adults emerging	Number of female adults emerging, ready to mate and lay eggs
1st	1	100	100	50
2nd	50	5,000	5,000	2,500
3rd	2,500	250,000	250,000	125,000
4th	125,000	12,500,000	12,500,000	6,250,000
5th	6,250,000	625,000,000	625,000,000	312,500,000

The insect's body has three main regions, the head, the thorax and the abdomen, which are generally recognisable in all stages of insect development after the emergence from the egg. All insects have a protective, relatively tough outer skin, called the cuticle. This outer skin is often hardened in parts, especially in adult insects, to serve as an external skeleton for the attachment and support of muscles and other internal structures. It is relatively inflexible except at joints between the various cuticular plates enclosing the body and between the tubular sections which form the jointed legs and other appendages.



The head. The head has a number of important structures as follows:

Eyes. Adult insects usually have two quite large light-sensitive organs, the compound eyes, which consist of many small units each with an individual lens. The adults of some insects also have one or more additional light sensitive organs, the ocelli, located between the compound eyes at the front or the top of the head. Larvae have ocelli at each side of the head, but do not have compound eyes.

Antennae. These highly mobile structures are conspicuous in most adult insects. Some can detect smells, while others are sensitive to touch or vibrations. Many insects use their antennae to help find their way around during darkness.

Mouthparts. These structures are used to take in food. They serve as sensors and for handling food. In those insects that bite or cut their food there are mandibles for cutting and grinding the food and maxillae for examining the food chemically. In other insects some or all of the mouthparts are modified to form a piercing or sucking tube like a straw.

The thorax. In adult insects this is usually a robust-box like structure housing many large muscles. It bears three pairs of legs and often also one or two pairs of wings.

Legs. The adult leg has five main parts. The immature stages of most insects also have three pairs of legs but they are usually less well developed, and in some larvae they are absent or greatly reduced.

Wings. These are also attached to the thorax. Not all insects have two pairs of fully functional wings, in some species one or both pairs may be absent or modified. All beetles have one pair of hard wing-covers (elytra) which protect the other set of wings underneath which are folded away when the beetle is not in flight.

The abdomen. Is composed of eleven segments. In some adult insects there are external genital organs at or near the end of the abdomen, but in others such as the beetles these are normally incorporated within the abdomen except when protruded for mating or egg-laying. The paired openings (spiracles) of the internal respiratory tubes can often be seen along the abdomen.

4.2.2 Life cycles of fungi, bacteria and viruses

Although crop diseases often appear "as if out of nowhere", they also have lifecycles and these may be quite varied and complex. However, the key factor is that plant diseases, just like insects, always derive from previous infections. This previous infection is also always of the same disease, so a previous infection of *Alternaria* can only generate a new *Alternaria* infection. Fungal and bacterial diseases usually have special resting stages in which the disease organism can survive for long periods of time, often in leaf litter, and may be blown in the wind onto young, previously unaffected crops. These resting stages, when they arrive on a new host plant, can germinate and penetrate into the new host. With fungal diseases, you can often see their resting stages or spores as a fine dot at the tip of a mat of fine hairs protruding from the surface of a diseased leaf. Occasionally, as with smuts, these fruiting bodies can be quite massive and the spores form a very obvious fine dust. Common ways by which plants get infected by fungal and bacterial diseases are:

- by spores blown about in the wind from older diseased crops;
- by spores splashed up by heavy rain from leaf litter;
- from diseased planting material, especially if the crop is propagated vegetatively as sweetpotato is.

Virus diseases are unusual in that they do not have a form that by itself can penetrate the skin of a new host so as to infect it. Instead, they rely on another organism, often a plant-sucking insect such as a whitefly, leafhopper or aphid that feeds on the crop, to carry the virus from one plant and to insert it into another plant. Thus, just as the mosquito has first to feed on a human with malaria in order to transmit the disease to another healthy human, so the aphid or whitefly has first to feed on a diseased plant in order to transmit the disease to a healthy plant. In this way, the insect acts in much the same way as mosquitoes act in transmitting malaria in humans. So, if we can stop such insects feeding and moving from an old diseased crop to a new crop, this can prevent plants in the new crop becoming diseased. Also, just as only Anopheline mosquito species can transmit malaria, so only one type of insect can transmit a particular virus. Thus, only whiteflies can transmit cassava mosaic disease or *sweetpotato chlorotic stunt virus* whereas only aphids can transmit *sweetpotato feathery mottle virus*. Virus diseases also generally spread quickly through the whole of an infected plant: this means that cuttings taken from even a healthy-looking part of a newly-diseased plant are probably infected.

4.3 Natural enemies

In agricultural fields we can find many types of creatures that live on the plants. But are all of these really pests? Or could some of these be beneficial insects or natural enemies?

A natural enemy is a living organism that kills, injures or causes disease in other living organisms. There are three kinds of natural enemies:

- Predators
- Parasites
- Pathogens

4.3.1 Predators

Predators are animals that hunt and eat other animals. Examples include: lions, snakes, spiders, and ladybird beetles. Predators often have to consume many prey individuals in order to fulfil their daily dietary requirements. The bodies of predators are designed to hunt, catch, kill and eat prey. Predators generally have strong teeth or mouthparts, sharp vision and strong legs. The behaviour of different insects can be observed either in the field or by setting up insect zoos and confining different insects together in order to observe their behaviour.

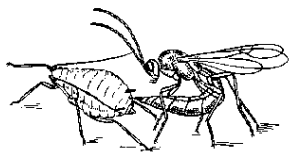
4.3.2 Parasites

Parasites also consume other organisms but by entering the body of their victims and obtaining nourishment from their fluids and tissues, which weakens or even kills them. We call the victim a “host". The parasites that attack insects are usually species of wasps or flies. The winged adult is able to search for a host and then lays eggs in or on the host’s body. Insect parasites can be classified as follows:

- Egg parasites lay their eggs in the eggs of other insects.
- Larval parasites lay their eggs in or on the larval stage of other insects.
- Pupal parasites lay their eggs in or on/and develop in the pupal stage of other insects.
- Some parasites develop in the nymphal or adult stage of their hosts.

egg parasite

pupal parasite



parasite of aphid nymph

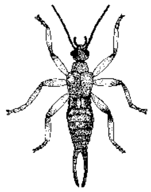
The developing larva of the parasitic insect lives in or on the egg or body of the host, slowly weakening the host insect which, thus, cannot complete its development. The parasite larva, however, is able to enter the pupal stage before killing the host completely. Some pupae are formed within the body of the host, while other parasites pupate on or near the body of the host. The adult parasite emerging from the pupa usually lives on nectar or pollen. Weed flowers are a main source of food for adult parasites.

4.3.3 Pathogens

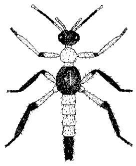
Pathogens are micro-organisms that cause disease. They enter the body of their host, living and multiplying within, and hence weakening and finally killing the host. Some pathogens require more than one kind of host in order to complete their life cycle. Bacteria, fungi and viruses are kinds of pathogens. Insects attacked by pathogens are usually swollen, exhibit colour changes, move slowly, often stop eating and may be covered with a powdery substance. There is a bacterium *Bacillus thuringiensis*, often called, Bt, for short, that is produced and used as a biological pesticide. Bt kills several kinds of pests but does not affect most natural enemies.

4.3.4 Common natural enemies in sweetpotato fields

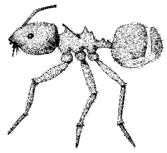
The pictures below show some predators commonly found in sweetpotato fields:



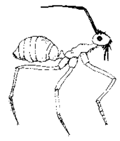
Earwig



Rove beetle

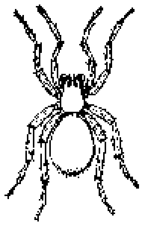


Big-headed ant (*Pheidole*)

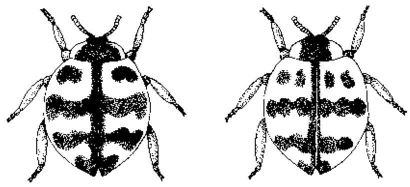


Long-legged ant (*Anoplolepis*)

Ground beetle



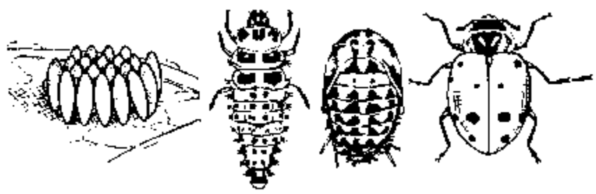
Spider



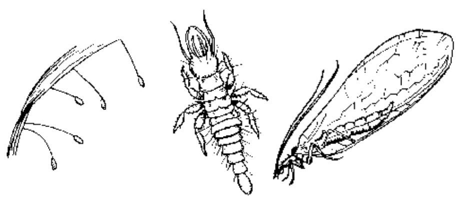
Two common types of ladybird beetles

The life stages of the ladybird beetle: (a) egg, (b) larva, (c) pupa, (d) adult:

(a) (b) (c) (d)



Both the larva and adult of the ladybird beetle are predacious. The ladybird beetle is an important predator of aphids. Generally the wings of the adult beetle are red, but some species have yellow wings. Black markings are usually present on the wing. The eggs are easily distinguished by their upright, oblong, grouped arrangement. They are usually yellow or orange.

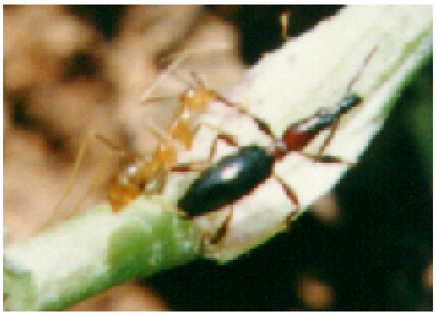


Lacewing egg, nymph and adult

Flower fly

Other important predators of aphids are the lacewing and the flower fly (syrphid). The lacewing has only three stages in its life cycle: egg, nymph and adult. Adult lacewings are light green. The wings have a netlike appearance. The egg is on the edge of a long stalk. The nymph is the predacious stage.

The flower fly is often found hovering around flowers. Both the larva and the adult are predacious. The larva moves slowly, but eats a great deal. During its development, a single larva can consume a few hundred aphids. Some more examples of predators are shown in the colour pictures below.



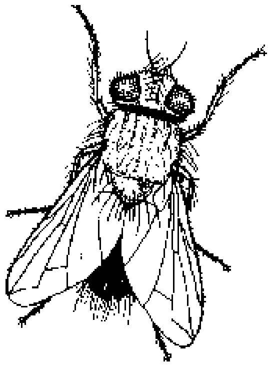
Predatory ants attacking weevils

A predatory ant of sweetpotato weevil eggs

The ladybird beetle larva is an aggressive predator

The predatory flower fly

Common parasites of sweetpotato pests include several kinds of wasps and flies that attack foliage and stemborer eggs and larvae. The parasitic wasps are normally very small and difficult to identify. The picture on the left shows the pupae of a parasitic wasp on the surface of a larval host. The picture on the right shows a parasitic fly.



Common pathogens of sweetpotato pests include the fungus *Beauveria bassiana*, which is commercially available in some countries, and various viruses, such as the one shown in the picture below.

A sweetpotato weevil killed by the fungus Beauveria bassiana

A hornworm killed by a virus. The way the worm is hanging indicates that the death was caused by a virus infection

To maintain their life cycles, natural enemies must have some food source. This means that we have to accept the existence of at least a small number of pests in agricultural fields, otherwise natural enemies, especially those that eat only one type of food, cannot survive. If they starve, their disappearance will lead to an explosion in pest numbers.

4.4 Natural enemies and pesticides

4.4.1 What are pesticides?

In many local languages words that mean "remedy" or "medicine" are often used to refer to pesticides. Nevertheless, pesticides are not remedies or medicines, but poisons that kill. This becomes clear when we look at the formal names and the actual meaning of different kinds of pesticides:

- Insecticide = kills insects.
- Rodenticide = kills rats.
- Fungicide = kills fungi.
- Bactericide = kills bacteria.
- Herbicide = kills weeds.
- Nematicide = kills nematodes (microscopic worms that cause cracking of sweetpotato roots).

Some pesticides interfere with breathing or digestion. Others kill indirectly by interfering with development or reproduction. Whatever the mechanism, the result is the same: the pest is killed. But not only the pest! Other insects, including natural enemies, and even animals and humans can become sick or be killed from exposure to pesticides.

We should avoid referring to pesticides as medicines or remedies and call them what they are: poisons. When we do this we are reminding ourselves and others that pesticides are dangerous and should be avoided whenever possible. If it is absolutely necessary to use pesticides, they should be used very carefully, because they present dangers to environmental and human health.

Insecticides are divided into two main groups based on the way they act. One type is absorbed directly by the insect when it comes in contact with the pesticide; this is called a contact insecticide. The other type must be taken into the body of the insect through food and will poison the insect when it passes through its gut. This is called a systemic insecticide. Systemic insecticides are absorbed by the plants. They are taken in by insects as they feed on leaves. Generally, contact insecticides are sprayed onto plants. Insects come in contact with them as they move around on the plant. Both types of insecticides are toxic to natural enemies. Pesticides are hardly ever applied to sweetpotato in East Africa, but farmers may be using them on other crops.

Note that there has been no mention of viricides. This is because plant viruses are so closely involved with the life processes of the host plant that it has been very difficult to devise chemicals that kill the virus and not the plant.

4.4.2 Pesticides, natural enemies and pests

Generally natural enemies are more susceptible to pesticides than their prey or hosts. Many pests and diseases have become resistant to chemical pesticides. In the case of insect pests, this occurs because insecticides never kill all the insects in the crop. Those that survive pass on their resistance to their offspring. Insecticide use acts to select the most resistant insects, since only these survive each time an application is made. Natural enemies can be killed directly by pesticides. Alternatively they may die because they have eaten prey or have developed in hosts that have absorbed or consumed pesticides. Natural enemies usually have longer life cycles and produce fewer offspring than plant-eating insects, which makes them more vulnerable to the effects of pesticides. Because they are fewer in number they take longer to recover from exposure to pesticides. In the absence of natural enemies, the expansion in the number of pests proceeds very rapidly, producing what is known as a population outbreak.

Most farmers have observed that the problem with pests such as aphids, and others of small size, have begun to occur since they began to use insecticides. There are two reasons for this:

A. Insecticides never kill all of the pest individuals in the field. The insects that survive are generally more resistant to the pesticide than those that died. The surviving insects are the ones that reproduce and they pass on their resistant characteristics to the next generation. If the insecticide is applied frequently and at high concentrations, the selection of resistant insects will occur rapidly. Insects like aphids that have short life cycles can develop resistance to insecticides very quickly.

B. Pesticides kill natural enemies. Natural enemies are more susceptible to pesticides than pests are, partly because the life cycles of most natural enemies are longer than that of most pests so resistance takes longer to evolve. Also, this means that it will take a long time for natural enemies to recover their numbers after a pesticide application. Without natural enemies to limit their numbers, pest insects can multiply very fast, which is why applying pesticides can sometimes make pest populations even worse than when pesticides are not applied.

4.4.3 Pesticides and human health

The effect of pesticides on human health can be acute or chronic. When acute poisoning has occurred there are symptoms such as dizziness, nausea, vomiting, blurry vision and trembling. When there is repeated use of pesticides over a long period of time, chronic illnesses can occur. The symptoms include blood pressure changes, heart disease, skin problems, nerve problems and cancer. Pesticides can kill human beings. The World Health Organization of the United Nations has reported that about a million people are poisoned by pesticides every year, 20,000 of which die.

4.5 Sweetpotato pests damaging roots in the field

Pests are living creatures that we normally consider harmful because they attack our crops, livestock or other human property.

Pests that attack or damage crops can do so in a number of ways: they may be animals that chew or suck plant parts, weeds, pathogens or parasites. Each pest has natural enemies (see section 4.3), including predators, parasites and pathogens, that keep its numbers in balance. If the pest is a weed, it will have herbivores that reduce its growth, whereas a leaf-eating insect, for instance, will have a range of predators and parasites attacking it. The presence of natural enemies ensures that pests rarely destroy the entire crop that serves as their food source.

We should not call an insect a pest unless we can show that it causes an important loss. In a sweetpotato field, insects that eat the leaves will rarely consume so much that they cause a reduction in the yield of roots. However, if the leaves were to be consumed or sold as vegetables or livestock feed and the leaf damage has reduced their utilisation or value then a leaf-feeding insect would be considered a pest. In determining whether an insect or other animal eating plant parts is a pest there are many factors to consider. These include:

- How many pest individuals appear?
- At what stage of crop development they damage the plant, and to what extent can the plant overcome the damage?
- What part of the plant they attack relative to the value of that part (e.g. insects that consume sweetpotato roots are much more likely to be pests than those that feed on the leaves)?