DISCOVERY LEARNING ABOUT COCOA

An inspirational guide for training facilitators

compiled & edited

by

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Copyright Statement

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PREAMBLE

The farmer participatory approach aims to build farmers' capacities to make their own crop management decisions, based on a better understanding of the agro-ecology of their own fields, and according to their own unique set of circumstances and priorities. Participatory approaches facilitate an active learning process and informed decision-making by farming communities.

An integrated crop management (ICM), or integrated pest[1] management (IPM) system, can never be a prescriptive, 'off the shelf' package. A grower must look at all the options available to him or her and make an informed decision as to which measures to take. Because each farmer's situation is different, the types of IPM measures they implement may vary between regions and often even from farm to farm.

A successful farmer participatory cocoa IPM programme depends on:

- Farmers' sound knowledge of the agro-ecosystem and how this relates to pests;
- A practical approach to manipulating the cropping system to manage pests on a cost-effective and sustainable basis;
- Willingness and ability on the part of both farmers and support systems (extension, research, others) to experiment, modify and innovate;
- Participatory training approaches in cocoa extension services;
- Promotion of cost-effective and environmentally sound methods in cocoa management.

This introductory manual aims to give some basic information on the options available towards ecologically sound cocoa production. It is aimed at agricultural extension, farmers groups, university students and others involved in farmer participatory cocoa IPM. The manual provides illustrated technical information on major cocoa pests and basic discovery learning exercises and field experiments.

The manual consists of three major parts: Part I provides a general introduction to the crop. Part II covers the technical background on the biology and management of some major key pests, linked to a set of farmer participatory exercises in Part III. Many of these exercises have been field-tested for cocoa.

An introductory manual such as this one will have global relevance, but is not intended to be comprehensive. The described cocoa pests were selected for their regional or global impact on cocoa productivity. The exercise protocols should be viewed as guidelines and sources of inspiration rather than as rigid instructions. They can and should be adapted to local conditions, depending on available materials, prevalent pest problems, local knowledge and experience within the farming community.

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1. Crop Protection Compendium, CAB International, CD-ROM / Internet
   An interactive multimedia knowledge base, containing a wide range of science-based information on all aspects of crop protection.

2. Understanding Natural Enemies. Working with Natural Enemies Series, Technical Support Group Bulletin No 1. (2001), CABI Bioscience, 74 pp.
   A training bulletin explaining the basic principles of biological control in a non-specialist way.

3. Participatory exercises adapted and compiled or designed based on various (re)sources world wide, such as:

[1] Pests = arthropods, vertebrates, pathogens, weeds or any other organisms detrimental to agricultural production

▪ Vegetable IPM exercises (1998), J.G.M. Vos, CABI Bioscience/FAO, 674 pp.
▪ West Africa STCP curriculum development workshop report (2003), STCP/CABI Bioscience, 61 pp.

4. CAB Abstracts 1973-. CAB International Wallingford UK
An extensive database of scientific literature covering a wide range of crop protection subjects.

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Further Reading

The scope of this manual is not intended to be all encompassing. We have found the resources detailed below to be an excellent source of further reading.

The following books were written in the 1970s and 80s and are still considered standard references works:

- Entwistle PF (1972) Pests of Cocoa Tropical Science Series, Longmans, London, UK, 779pp
- Thorold CA (1975) Diseases of Cocoa, Clarendon Press, Oxford, UK, 423pp
- Wood GAR & Lass RA (1985) Cocoa (4th edition), Longmans, UK, 620pp

The Crop Protection Compendium 2002 edition, CAB International is a detailed reference work on over 1850 pests and natural enemies of world-wide or regional importance, including data for more than 200 crops and 150 countries (http://www.cabi.org/compendia/cpc/index.htm).

The following websites provide extensive information on all aspects of cocoa, from low to high technology covering farming methods to end-product processing.

http://www.cabi-commodities.org/Cocoa/Cocoa.htm (with useful resource centre)
http://www.dropdata.net (useful information on spray application techniques for cocoa: click on 'cocoa' under 'tree crop issues')
http://www.icco.org/ (has useful 'Question & Answer' pages)
http://www.cocoa.com/
http://www.acri-cocoa.org/ACRI/projects.htm
http://www.candyusa.org/CocoaTree/talamanca.htm

Glossary of Technical Terms

Anamorph	Asexual or imperfect stage in the life cycle of a fungus

Basidium (pl.) basidia	Sexual produced spore of a BASIDIOMYCETE fungus
Biotroph	Organism that lives in living tissue
Cherelle	Small and immature pod
Chlorotic	Partial or complete absence of green colour in plants
Chupon	Vertical stems or shoots
Clone	Group of plants produced vegetatively from one original plant
Conidium (pl.) conidia	Spore of anamorph stage in the life cycle of a fungus
Cultivar	A variety of a cultivated plant species
Fruit body	A non-technical term for a fungus structure that contains asexual or sexual spores
Hyperplasia	Enlargement of cells through uncontrolled cell division.
Hypertrophy	Enlargement of host tissue through uncontrolled cell enlargement
Hypha (pl. hyphae)	Threads of a fungus
Instar	Development stage in insect life-cycle
Intracellular	Within the cells
Intercellular	Between the cells
Jorquette	The point at which the vertical chupon stem changes to fan growth
Larva (pl. larvae)	An insect in its first stage after hatching from the egg, the caterpillar state
Mycelium (pl. mycelia)	A mass or mat of fungal threads
Necrosis	Death of a plant part or of clearly defined area of plant tissue
Necrotroph	An organism that lives on decaying tissues
Nymph	Development stage of insect life-cycle that resembles the adult form
Pest	Any living organism causing a problem on plants
Saprobe	A microorganism living on decaying organic matter
Saprophyte	A plant living on decaying or dead plant material
Spore	Propagating structure of a fungus
Sporophore	Fungal fruiting body that produces sexual spores
Stoma (pl. stomata)	Minute openings in the surface of leaves and green stems for plant respiration
Stylet	Needle-like piercing mouth part of an insect
Systemic	(i) of a disease –occurring throughout the plant (ii) of a fungicide –absorbed into the plant through roots or foliage, then translocated throughout the plant
Teleomorph	Sexual or perfect stage in the life cycle of a fungus

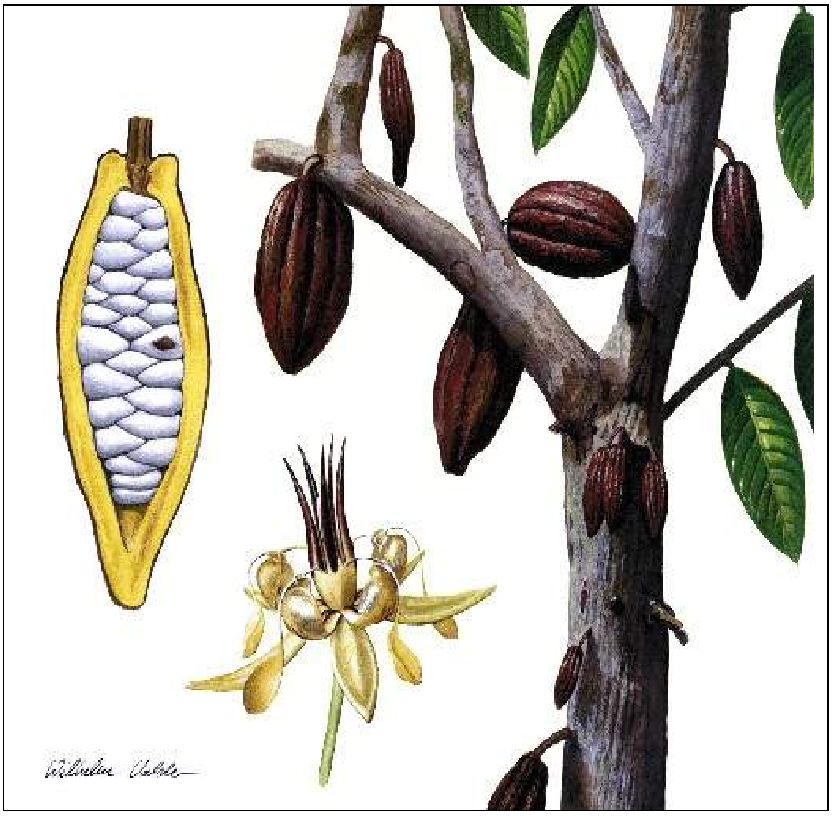
PART I

GENERAL INTRODUCTION

Healthy cocoa tree, Cameroon.
Photo J. Vos © CABI Bioscience

INTRODUCTION TO THE COCOA CROP

THE COCOA COMMODITY



Drawing of Theobroma cacao © W. Valder

Cocoa was widely cultivated by the Maya-speaking peoples of tropical Central America before the Spanish Conquest of the 16th century. The Maya Indians found at least 1000 years ago that, when roasted, the seeds (or beans) of the cocoa tree produced an aroma so divine, they believed the tree was a gift from the god Quetzacoatl. From the roasted beans, they made a drink, often used in ceremonies and rituals, called *xocolatl*, from which the word 'chocolate' is derived. The cocoa grown by the Mayas presumably ultimately originated from the wild cocoa in the forests of the Amazon Basin.

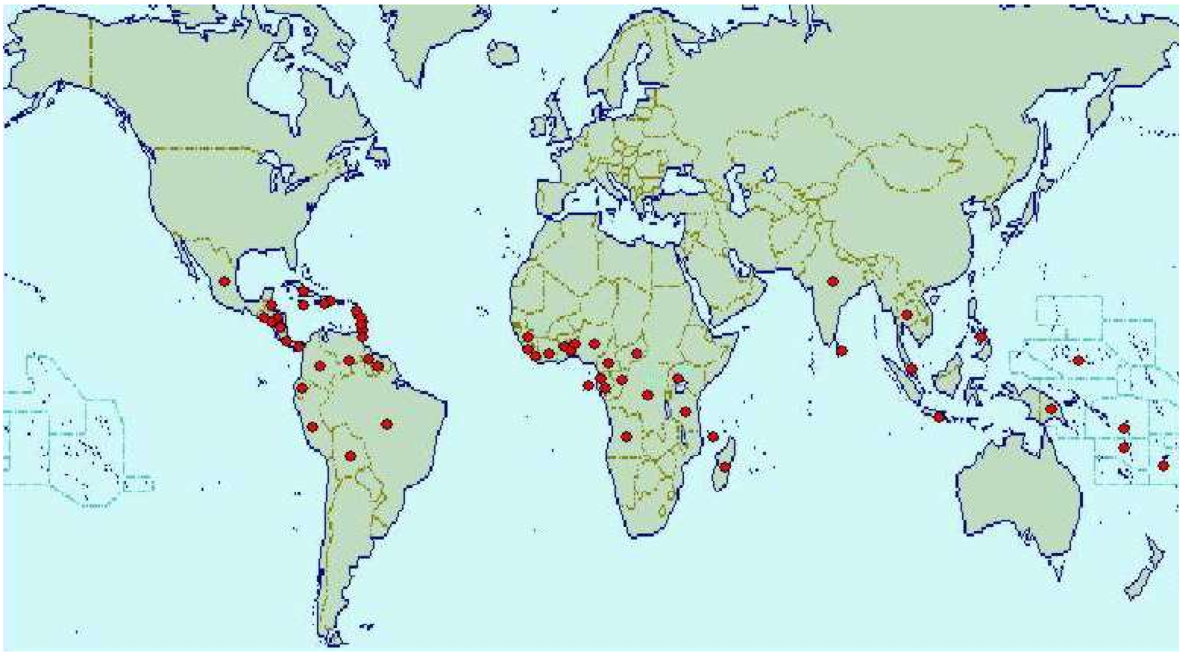
In the 17^{th} century, markets in Europe were rapidly expanding and cocoa spread to most islands in the Caribbean and subsequently to mainland Venezuela and Colombia. In the same century, the Spanish succeeded in transferring a few live plants to Manila in the Philippines. Cocoa cultivation gradually spread southward through the East Indies, and ultimately also to Sri Lanka in the 19th century. Apart from this, early in the 20th century a series of introductions were made by the British into Sri Lanka from Trinidad, by the Dutch to Java and by the Germans to Papua New Guinea from various parts of Latin America. This gave rise to the cocoa industries of Papua New Guinea and Indonesia. Quite independently, Ecuador and the Province of Bahia in Brazil developed major cocoa areas in the 19th century, although the first planting in Bahia had been made in the mid 18^{th} century. From Bahia, cocoa found its way to West Africa, where vast cocoa areas developed in the 20th century in Cameroon, Nigeria, Ghana and Cote d'Ivoire.

More than a millennium after its discovery, chocolate is now a big business. The USA alone, the world's biggest consumer, consumes between 1 and 1.4 million tonnes of chocolate every year, and the global trade in confectionery, of which chocolate has the lion's share, is estimated at about US$ 80 billion per year. Cocoa has become a vital export crop for many countries, particularly in West Africa, which produces over 65% of the world's cocoa. It is also a major foreign exchange earner for some Central and South American countries and for South and Southeast Asia.

Over 80% of all cocoa is produced by smallholder farmers. Cocoa provides employment in many rural communities and pays for school fees of farmers' children. Smallholder cocoa is grown mostly under shade trees and either inter-cropped or grown in a semi-natural agro-forestry setting and hence, is a particularly rich and stable habitat for many species (biodiversity).

COCOA PRODUCTION

Cocoa is grown all over the humid tropical zones of the world:



Cocoa distribution map (source: Crop Protection Compendium 2002, CAB International)

CONSTRAINTS TO COCOA PRODUCTION

Being an exotic in many cocoa producing locations, cocoa has contracted a number of serious 'new encounter diseases', which originate from the indigenous flora but to which exotics have no co-evolved defence mechanism(s). It has been suggested that when cocoa is in its natural habitat, in the upper reaches of the Amazon rain forest, it is to some extent protected from infection by a range of co-evolved natural beneficials. Exceptions to this rule of thumb are the serious disease threats in Central and South America in the form of Witches' Broom and Frosty Pod. Nonetheless, wherever cocoa is introduced, the crop is becoming increasingly susceptible to a wide range of diseases with which it has only recently come into contact. For example, in West Africa, cocoa farmers need to deal with a range of pest organisms, such as Black Pod, Mirids, Stem Borer, Mistletoe, Termites, Weeds and Cocoa Swollen Shoot Virus. Furthermore, through increasing global movement of plant material, there is a looming threat of introduction of Witches' Broom and Frosty Pod diseases from South America.

In addition to problems with crop health, farmers face a volatile world market, labour constraints, constraining land tenure systems, high costs of farm inputs and lack of credit facilities. **Exercise 1** will help you to identify some of the problems that smallholder cocoa farmers face in the area you are working, and to understand farmers' perceptions of those constraints.

GROWING SUSTAINABLE COCOA

There are no 'silver bullets' or simple solutions to these diverse and complex problems that currently plague the cocoa industry. This manual focuses on growing a healthy crop in a sustainable way, utilising management methods that are cheap, practical and sustainable for the small farmer, and reducing dependence on costly inputs such as pesticides and fertiliser.

GROWING A HEALTHY CROP

A healthy crop is a more productive crop. Growth is more vigorous, yields are generally higher and the plant is better able to resist or compensate for pest attack. In this section, we will look at some of the approaches we can take to improve and maintain the all round vigour of the cocoa tree. **Exercise 2** explains the value of monitoring cocoa fields, while **Exercise 3** facilitates regular observation of cocoa fields using agro-ecosystem analysis (AESA).

COCOA RAISING AND REHABILITATION

Cocoa is normally raised from seed as it is the easiest and cheapest. A cocoa nursery usually has a simple structure as a roof with e.g. palm leaves as cover for shading and is usually situated close to a source of water for irrigation. Cocoa beans are collected from healthy ripe pods and planted into nursery bags filled with clean topsoil – care should be taken not to introduce seed- or soil-borne diseases through seedlings. After 4 – 5 months, the seedlings are ready for transplanting. Vegetative propagation can be done through cuttings or marcotting. Tree cuttings are taken with between two and five leaves and one or two buds. The leaves are cut in half and the cutting placed in a pot under polythene until roots begin to grow. When marcotting, a strip of bark is removed from a branch and the area covered in sawdust and a polythene sheet. The area will produce roots and the branch can then be chopped off and planted.

Grafting cocoa, Costa Rica. Photo © R. Mack

There are various methods of rejuvenating existing cocoa farms. Clear felling or complete replanting is expensive, but appropriate in conditions with high pest pressure. Planting under old cocoa trees, the 'Turrialba method', provides farmers with continuous revenues, but has the disadvantage of maintenance of pest populations. Alternative practices are making use of chupon regrowth, either through encouraging vigorous basal chupons to grow and subsequently chopping off the old tree, or through coppicing, which is chopping the main stem of a tree and allowing regrowth through chupons.

When budding, a bud is cut from a tree and placed under a flap of bark on another tree. The budding patch is then bound with raffia, waxed tape of clear plastic to prevent moisture loss. When the bud is growing the old tree above it is cut off. Such rejuvenating practices can't be used when old trees are infected with systemic diseases, such as Cocoa Swollen Shoot Virus (CSSV). Top grafting is common in Papua New Guinea. In Brazil, farmers have started to rejuvenate Witches' Broom infected farms through grafting with productive and/or disease resistant clones. Infected mature trees are cut down after which a bud-stick of a healthy resistant stem is grafted onto the main trunk of the mature tree. Using the mature tree's root system, the resistant stock will produce its first cocoa pods within two years. **Exercise 4** explains grafting mature trees. In recent years, tissue culture methods for cocoa have also been devised for cocoa and projects are ongoing for distribution to farmers in some cocoa growing regions.

Pruning and shade management

Pruning and shade management are essential elements of cocoa management. Pruning involves thinning of branches and removal of old or dead stems, whilst shade management involves leaving forest trees and/or planting shade trees to optimise the light intensity in the cocoa grove.

Pruning serves many purposes, including:

- ***It determines the shape of the tree***. It is important that the tree is shaped to facilitate local management practices. For example, you may want to prevent the tree from growing too tall to make tasks such as harvesting, sanitation and spraying easier.

- ***It maximises the nutrient distribution towards pods***. By cutting away new and unproductive chupons on mature trees, you encourage the growth of good size pods.

Pruning of cocoa, Cameroon. Photo J. Vos © CABI Bioscience

- ***It helps prevent some pest problems***. Pruning of Mistletoe infected branches is one of the best management practices to reduce local impact and spread. In addition, thinning the cocoa canopy causes more light to filter to the centre of the tree, and more air circulation, whereby Black Pod disease can be prevented or reduced. One has to consider however that holes in the cocoa canopy attract cocoa Mirids, which thrive in sunny conditions and form another important pest problem in West Africa.

Exercise 5 explains about pruning methods.

Being an under-storey forest tree, cocoa can be most readily sustained in partial shaded conditions. During establishment, food crops such as bananas and plantains, and herbaceous plants and shrubs can provide the necessary temporary shade for cocoa seedlings. In mature cocoa groves, light shading can be provided by a range of other crops such as coconuts or by e.g. 10 large or 15 medium forest trees per hectare. From an environmental viewpoint, forest trees left in the field after the initial clearing of land, also have a very important role to play in the conservation of the forest and associated fauna and in the reduction of soil erosion. In Latin America, shade trees are called ‘neighbour trees’ and, as in many parts of the cocoa growing world, are kept in the cocoa grove for the production of by-products such as fruits, for medicinal use or timber. As discussed under pruning, shade management is an element of pest management as light shading can reduce the impact of pests such as Mirids and weeds, whereas too heavy shading is likely to increase disease problems.

Exercise 6 will create an understanding of the impact of shading on relative humidity in the cocoa farm.

Soil nutrient management

Soil nutrient management is critical to the general health of the tree, particularly where cocoa is grown on poor soils with low nutrient levels. The fertility of soils under cocoa plantations with complete canopy formation can be maintained or sustained for a fairly long time due to the ability of cocoa to recycle nutrients back into the soil through leaf fall and decomposition of leaf litter. However, continuous harvesting will eventually result in loss of soil nutrients.

Light shade and gap replanting in 20 year-old farm, Cameroon. Photo J. Gockowski © IITA

Fertiliser verification trials in farmers’ groves in Ghana have generated a good deal of farmers’ interest. The trials demonstrated significant increases in yield. Rehabilitation studies in Nigeria showed that NPK fertiliser applications had a positive impact on growth and development of cocoa seedlings and chupons, regardless of the rehabilitation technique used.

Continuous use of inorganic fertilisers has a number of problems associated with it, including the depletion of soil organic matter, the deterioration of soil structure, and the acidification of the soil. The use of organic fertilisers can address many of these problems, and is important for maintaining healthy soils. Organic fertilisers can come from a number of sources including farmyard (cattle, goat, chicken) manure, composts and 'plant teas', which can act as liquid manures. **Exercise 7** covers the production and application of compost, while **Exercise 8** looks into impact of fertilisation.

Pest management

Globally, about 500 insect species have been recorded on cocoa, however, only a tiny fraction of these are economically damaging. **Exercises 9, 10 and 11** 'Cocoa insect zoos' will help you recognise some of the cocoa insect pests and their natural enemies, and learn about their basic biology. **Exercises 12, 13, 14 and 15** will help you learn more about disease symptom development and ecology.

Making the most of natural control mechanisms

In the cocoa agro-ecosystem, there is a large complex of natural enemies, including predators, parasites, insect diseases, nematodes and other beneficials, attacking cocoa pests. One of the most fundamental ways in which farmers can reduce their reliance on chemical pesticides is to make the most of the natural enemies already present in the field: **conservation** of beneficials is a key cornerstone of IPM / ecological production systems.

Perhaps the most important way in which you can conserve natural enemies is to minimise the number of pesticide applications you make. The decision whether or not to apply pesticides should always be based on the findings of detailed observations of the crop, taking into account pest and natural enemy levels and the general health of the crop (see **Exercise 3**). To learn about side-effects of spraying, **Exercise 16** is recommended, while **Exercise 17** looks into pesticide specificity.

When pesticide applications are justified, there are a number of approaches to minimise the impact they have on natural enemies. Some insecticides are intrinsically less harmful to natural enemies than others. As a rule of thumb, one can consider biopesticides (such as *Trichoderma stromaticum*, a biocontrol agent used in Brazil against Witches' Broom) safer to natural enemies than synthetic chemicals. Chemical control methods can also be made to act more selectively by the way in which they are applied. A good example of this is local stem treatment of cocoa against Stem Borers, where in Ghana research is focusing on inserting a chemical paste into the borer hole of the tree trunk.

Inoculating soil with biocontrol agent for cocoa seedbed, Costa Rica. Photo U. Krauss © CABI Bioscience

Adding more beneficials

Sometimes, even when you have tried to conserve natural enemies, they are still not effective enough to prevent economic damage. In this situation it is sometimes possible to boost the populations of natural enemies that are already in the ecosystem, by mass rearing them in laboratories or rearing units and then disseminating them into the field. This approach to biocontrol is being investigated in West Africa in relation to the potential management of Black Pod (using fungi and bacteria) and Mirids (using insect pathogens).

Introducing new beneficials

Sometimes there simply are no beneficials that are effective against a pest in a particular system. This situation usually arises when exotic pests have been introduced to a new region leaving their natural enemies behind and as a result their numbers increase rapidly. One approach is to go back to the area where the pest originated, find natural enemies attacking the pest, and import them into the new region to redress the balance. This classical biocontrol principle is being applied in Frosty Pod management research in South America.

Cultural methods

Growing a healthy crop can help the plant resist or compensate for pest attack. Cultural methods manage pests by changing the way in which one grows the crop.

Maintaining crop hygiene, i.e. removal and destruction of infected plant material, is probably the single most important method for managing many key cocoa pests. In West Africa, regular removal and destruction of diseased pods can suppress Black Pod caused by *Phytophthora palmivora*. In Indonesia, the practice of regular complete harvesting reduces levels of cocoa Pod Borer in the subsequent season. In South America, close monitoring and removal of Frosty Pod infected pods is likely to be an effective method to manage the problem, although early detection is the key. In Ghana, cutting out CSSV affected trees and their neighbours and replanting with resistant varieties can be an effective management method.

Cocoa pod residues in cocoa farm as a potential infection source, Ghana. Photo J. Vos © CABI Bioscience

Pest Resistant Cocoa Varieties

The use of pest resistant varieties is also a very valuable IPM strategy. **Exercise 18** shows you how rehabilitation using resistant material can help slow down disease epidemics. Germplasm collections are currently maintained in many cocoa-producing countries. Efforts in West Africa have been focused on Black Pod and CSSV resistance. The focus in Latin America is on finding resistance against Witches' Broom and Frosty Pod. It is advisable to contact your local cocoa research institute to find out about available resistant materials in your location.

Weed Control

A number of weed control strategies are available to smallholders. Cultural and mechanical controls include use of shade (both by the cocoa canopy and its shade trees), weed slashing using a machete, and maintaining leaf litter on the soil to function as a mulch.

Weeding ("brushing") cocoa, Ghana.
Photo J. Vos © CABI Bioscience

Mulch can consist of naturally occurring leaf litter in cocoa plantations with a complete canopy, which has an add-on benefit of replenishing soil nutrients to some extent. In addition, cocoa leaf litter harbours saprophytes that can reduce pathogen populations on infected cocoa pods, branches or leaves that drop-off or are removed from the trees. In Papua New Guinea for example, it was found that in leaf litter, Black Pod caused by *Phytophthora palmivora* was reduced faster to base levels than in cocoa with grass as a live ground cover. Mulches and cover crops also help to smother weeds and reduce leaching of nutrients. Leguminous cover crops can also add nutrients to the soil.

Selective weeding practices are directed at the most problematic weed types such as vines, grasses and tall broad leaved weeds, while less damaging species are left to provide ground cover, while not having a significant effect on the yield of cocoa. The problem weeds may be controlled either by slashing or by spot application of a herbicide. Use of broad-spectrum products and blanket application techniques is not advised for many environmental and health reasons.

Use of pesticides

Pesticides, and particularly insecticides, are not as widely used on cocoa compared to other high value crops. This is partly because many pesticides are not particularly effective for certain key pests, but also because up until recently returns on cocoa were so low that many small farmers couldn't afford them. The adverse side-effects of some longstanding, broad-spectrum, cocoa pesticides, including the destruction of non-target beneficials, make these chemicals undesirable and there are moves to replace the most toxic among them. **Exercise 19** uses a role-play to better understand the development of pesticide resistance. Recognising the cost and environmental and other impacts, rational pesticide use strategies are being developed for cocoa. These strategies focus on minimised use of lower toxicity pesticides through optimised application techniques. An example is the use of chemical elicitors of induced resistance through stem injection, which is being field-tested in West Africa for Black Pod control.

Application techniques for cocoa

A critical component of rational pesticide use is skilful application. It is rarely appreciated just how inefficient normal existing pesticide application practices are. For example, it has been argued that with sprays to cocoa Mirid bugs, only about 0.02% of the active ingredient put in the sprayer tank reaches the biological target. Most of it falls back onto the ground as "run-off" and is wasted: contaminating both the operator and the environment.

From a practical standpoint, there are essentially two types of equipment commonly used for spraying cocoa trees: motorised knapsack mist-blowers (or air blast sprayers) and manual (hydraulic) sprayers. Other techniques have been used, including thermal foggers and trunk injectors for systemic pesticides, but are not currently in common practice by smallholders.

Motorised mist-blowers have many uses, but they were originally developed for obtaining good droplet coverage for control of Mirids in the tall cocoa trees of West African plantations. However, they are out of the price-range for many smallholder farmers. The lower-cost alternative is to use manual (hydraulic) sprayers, which are the mainstay of smallholder pesticide application. Many locally available sprayers are fitted with variable cone nozzles that produce a variable range of droplet size spectra and flow rates.

Research in cocoa is ongoing to improve the efficiency of knapsack spraying, e.g. through optimising nozzles. Cone nozzles are usually considered most appropriate for applying insecticides and fungicides to complex surfaces such as cocoa trees, and work is being carried out to optimise their performance with cocoa fungicides.

POST HARVEST HANDLING

There is an interesting variation in post harvest handling of cocoa produced by smallholders, depending on location and season. Generally speaking, cocoa pods are collected at a central location, where pods are broken, husks removed and the white-yellowish seed masses are heaped together for fermentation. Fermentation takes about 5 to 7 days, depending on the season and temperature. Farmers sometimes mix the heap on the 2^{nd} or 3^{rd} day, to allow for aeration and a more uniform fermentation. During fermentation the cocoa flavour develops and the beans turn brown. After fermentation, beans are transferred to drying tables or mats or other surfaces depending on the method (sun drying or artificial drying using fire). During drying, the fermentation process is completed. Drying takes about one week in the sun and brings the bean moisture down to about 7.5 %. Dried beans are sold in jute bags.

Farmer-to-farmer exchange of information on cocoa qualities, Panama. Photo © R. Mack

Cocoa quality depends on various factors, but primarily on the cocoa variety and the post-harvest handling. Generally speaking, fine or flavour cocoa beans are produced from *Criollo* or *Trinitario* varieties, while bulk cocoa beans come from *Forastero* trees. Poor post-harvest handling can cause cocoa beans to be mouldy and/or germinated which reduces or diminishes the cocoa quality. Mouldy cocoa beans should be rejected on two counts, namely the tainting and off-flavours to the beans and possible contamination by mycotoxins (including ochratoxin).

ECONOMICAL COCOA PRODUCTION

Many farmers perceive cocoa farming as a risky enterprise. Price fluctuations on the product side are a major factor in profitability. At the same time farmers are often unaware of the importance of other factors that determine their profits. Many farmers use local units for area, volume and weight that do not have a fixed conversion to standard units. **Exercise 20** will create an understanding why we need to make use of standard units. To determine how farmers' expenditures relate to income, **Exercise 21** shows a simple economic analysis of the cocoa growing enterprise to give better insights into which factors could improve their profit margins. Farmers who are united in co-operatives can benefit from an improved market position as well as other advantages such as information sharing and strategic use of resources, such as expensive, but more efficient spray equipment. **Exercise 22** demonstrates a group dynamic to show the importance of co-operation.

PART II

PEST DATASHEETS

Black Pod infected pods, Cameroon. Photo J. Vos © CABI Bioscience

Black Pod
Phytophthora species

IMPORTANCE

Of all cocoa diseases world-wide, Black Pod or *Phytophthora* pod rot causes the largest loss of production. Seven fungi have been identified as causing Black Pod disease of cocoa, but two are of major importance (see pages 16-17 for distribution):

Phytophthora palmivora: has a world-wide distribution, being found in tropical and sub-tropical regions. It infects over 200 other plant species, as well as cocoa.

P. palmivora on cocoa pod, Panama.
Photo H. Evans © CABI Bioscience

***Phytophthora megakarya*:** only present in Central and West Africa. It is thought to have moved from a local forest tree host onto cocoa and has been identified on the fruits of *Cola* and *Irvingia* species. The distribution map was produced from published literature references up until May 1999; since that time the fungus has been found in Côte d'Ivoire.

P. megakarya on cocoa pod, Cameroon.
Photo H. Evans © CABI Bioscience

Of less importance, although locally significant are:

P. capsici: found in many tropical and sub-tropical regions infecting many plant species, especially solanaceous crops, as well as cocoa.

P. citrophthora: widespread in tropical and sub-tropical regions with primary host citrus, but involved in the cocoa Black Pod complex in Brazil and Indonesia.

Other *Phytophthora* species recorded as causing black pod disease of cocoa, but considered to be of minor importance are:

P. heveae: primarily infects rubber, Brazil nuts, avocadoes, mangoes and guavas, but is found on cocoa in Malaysia, where in Sabah the economic significance was considered to be slight.

P. katsurae: primarily infects coconuts but has been reported from cocoa in Côte d' Ivoire.

P. megasperma: this fungus is found in temperate and sub-tropical regions but is only recorded on cocoa in Venezuela.

DESCRIPTION

Symptoms on cocoa pods caused by the various fungal species are all very similar. The disease begins with the appearance of a small translucent spot, about two days after infection. The spot turns a chocolate brown colour, then darkens and expands rapidly until the whole pod is covered.

The pod becomes completely black, in about 14 days and internal tissues, including the beans, shrivel to form a mummified pod. Mummified pods are major sources of infection in *P. palmivora*, whereas in contrast *P. megakarya's* main source of primary infection is the soil. A strong fish-like smell is associated with the infected cocoa pod. Sporulation on the pod surface appears as a diffuse yellow/white covering, which may become denser as the disease progresses. Spores are released from the surface of the pod by rain splashing onto the surface and these infect other parts of the cocoa tree.

Besides pods, the pathogen also infects the stem, flower cushions and chupons. Infection produces cankers, which may girdle the trunk and cause 'sudden death'. These cankers are seen as slightly sunken patches of bark, sometimes with a red ooze through the bark cracks. Removal of the bark reveals a discrete, spreading, reddish lesion in the vein tissue that usually does not penetrate deep into the wood.

Stem canker caused by Phytophthora, Philippines. Photo H. Evans © CABI Bioscience

The significance of *Phytophthora* stem canker is probably underestimated. Canker reduces tree vigour and 'carrying capacity', hence yield. Cankers are often associated with stem or bark borer attack as these appear to be attracted to cankers.
Phytophthora species can also cause seedling and leaf blight.

The only way to distinguish between the seven fungal species is by laboratory examination. If the type of pod infection looks different to that normally observed/seen locally, it may be a new strain or species of the fungus. This should be reported to the local Ministry of Agriculture immediately. It should be noted though that pod rot symptoms can also be caused by other diseases, such as Frosty Pod rot (see Frosty Pod Datasheet).

ECOLOGY

Pods are susceptible at all stages of development and infection can occur on any part of the pod surface. Under humid conditions, a single infected pod can probably produce up to 4 million spore-producing structures. Water is required for these fungi to spread from the source of infection, be it soil, roots, pods or stem cankers. Very humid conditions cause the disease to develop and spread more rapidly. *P. palmivora* can survive in mummified pods and in cankers, *P. megakarya* spreads mainly with soil that is rain-splashed up into the tree or carried by ants. Once in the canopy, *P. megakarya* can survive in stem cankers. *P. megakarya* remains viable in infected debris for at least 18 months, whereas *P. palmivora* can survive in this way for less than 10 months, depending on the ground cover (see **Weed control in Part I**).

Rodents, such as rats and squirrels can also carry the fungal spores around the cocoa trees. Rapid, long distance dispersal of the fungi is primarily by man, often on contaminated harvesting and pruning tools and in contaminated soil on shoes (see **Exercise 14** to better understand the role of soil in disease spread).

PEST MANAGEMENT

There are four basic strategies for controlling the fungi that cause Black Pod disease: cultural, chemical methods, the use of resistant cocoa material and biological control, although this is in the experimental stage.

Cultural control

Cultural methods work by making it more difficult for the fungi to spread through the crop.

Field inspections should begin at the start of the rainy season (see Agro-Ecosystem Analysis in **Exercise 3**). After 2-3 days of continuous rainfall, check for and remove primary infections on pods. Infected plant material needs to be disposed of carefully, composting is an effective method but it must be done properly otherwise it could be a future source of infection (see **Exercise 7** on compost preparation). Burning of infected material should only be used as a last resort, due to its damaging effects on the environment. Regularly harvest ripe, healthy pods to prevent post-harvest losses, as even minor infections can cause spoilage.

Attached pods showing symptoms of Black Pod, Brazil. Photo H. Evans © CABI Bioscience

To improve air-flow and reduce humidity (and disease incidence), seedlings should be planted well apart and in well-drained sites. See **Exercises 12 and 13** to learn about the impact of humidity on Black Pod development. Reduced humidity reduces the chances of water being available for spore spread. (See **Exercise 6** to investigate the impact of shading on the humidity in a cocoa farm.) Thin the cocoa tree canopy – but take care not to make gaps in the canopy as this could aggravate Mirid infestations in some areas (see **Mirid Datasheet** and **Exercise 5** for pruning methods). It should be noted that cultural control alone can be very effective against *P. palmivora* if conducted properly, but for very severe Black Pod caused by *P. megakarya*, additional chemical control is at present still needed.

Weed regularly, particularly at the beginning and during the wet season to increase air-flow and reduce humidity in the cocoa farm. Remove soil tunnels on the surface of cocoa trunk built by ants. This removes two sources of infection: spores carried in infested soil and those carried by the ants (see **Exercise 14** to learn about the role of soil in disease spread). When establishing new cocoa farms, try to avoid areas that are known to have Black Pod infested soil.

Mulches may also reduce splash borne inoculum from the soil onto pods borne low down on the trunk.

Chemical control

Using fungicides has shown some success; these are best used in combination with cultural methods in an integrated approach. Copper compounds (copper oxide or copper sulphate – WHO[1] Class II) either singly or in combination with metalaxyl (WHO Class III) are commonly applied as sprays using knapsack sprayers. Care has to be taken with many copper derivative fungicides, because of their human toxicity. **Exercise 16** creates an understanding of the risks involved in spraying hazardous pesticides. In cocoa grown for the organic market, copper fungicides are currently only allowed on a restricted basis but will be phased out because of their persistence and impact on beneficial micro-organisms in the soil.

Alternative (or rational) application techniques have been tried using copper impregnated pads, wrapped around branch points so that slow leaching of the copper created a film around the main stem and protected the trees against spores distributed by rain splash and crawling insects (e.g. ants). This method is however highly hazardous to mammals and small children that might touch or eat the pads. Metalaxyl can also be painted onto branch and stem cankers. Another alternative application method is painting pods with Metalaxyl and/or copper compounds. Safer, and more environmentally sound, is the method of trunk injection with phosphonic acid. This method is used on a commercial basis in Papua New Guinea and is being field tested in West Africa with some success. Internal scorching is seen and care must be taken with the dosage used

Biological control

Methods using fungi and bacteria have been researched in the laboratory and field trials, but as yet these organisms are not available commercially. However, conserving natural beneficials by maintaining leaf litter mulch to cover the soil does contribute to the break-down of Black Pod-infected crop debris and reduces the level of inoculum at soil level.

Host Resistance

Breeding for resistance offers the best long term management strategy. Many cocoa selections derived from Scavina 6, Scavina 12 and Pound 7

[1] World Health Organisation (WHO) classification of pesticides according to acute toxicity, ranging from I (highly to extremely hazardous) to III (slightly hazardous) in addition to U (unlikely to present acute hazard in normal use). IPM programmes should avoid use of WHO Class I and II pesticides. Note that formulation can move active ingredients to a lower hazard classification.

material show resistance to the Black Pod pathogens. Many cocoa research institutes have established breeding programmes selecting material under local conditions that includes the local strains and species of *Phytophthora*. IMC 47 and SNK 413 are reported to be resistant to *P. megakarya* and *P. palmivora* in West Africa. Selecting for resistance is dependent on rapid, reliable screening techniques to identify possible resistance clones and hybrids. Artificial screening methods have included detached or attached pods, leaf discs and seedlings. All these methods have advantages and disadvantages and sometimes resistance to pod rot does not correlate with resistance to canker. Despite these problems, global projects involving breeding programmes in several research centres have been very successful in producing resistant material under local conditions.

Other recent approaches seek out healthy individual trees on farms under high natural disease pressure. Once validated, such resistant individual trees can be used to provide budwood for grafting which can be used for farm regeneration and inclusion in breeding programmes.

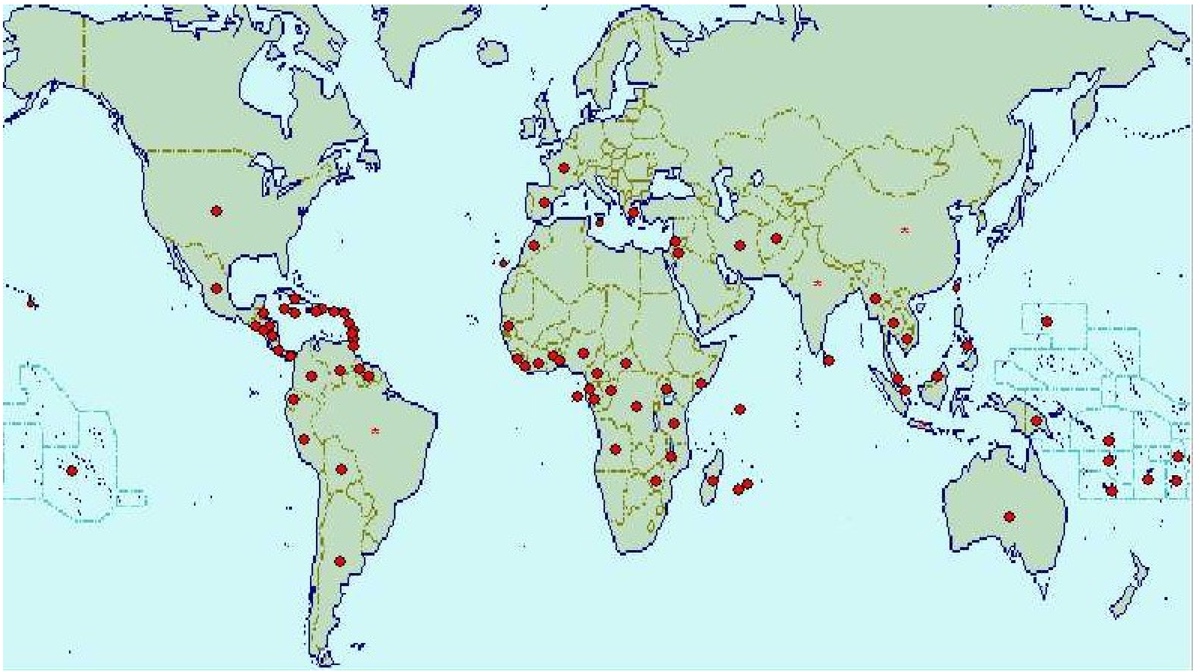
Contact your local cocoa research institute and find out about their resistant varieties. **Exercise 4** explains how you can introduce resistant varieties into established cocoa through grafting onto mature trees. **Exercise 18** creates an understanding of the impact of introducing resistant material into a susceptible cocoa farm.

Collection of "cut-out" infected pods, Cameroon. Photo J. Vos © CABI Bioscience

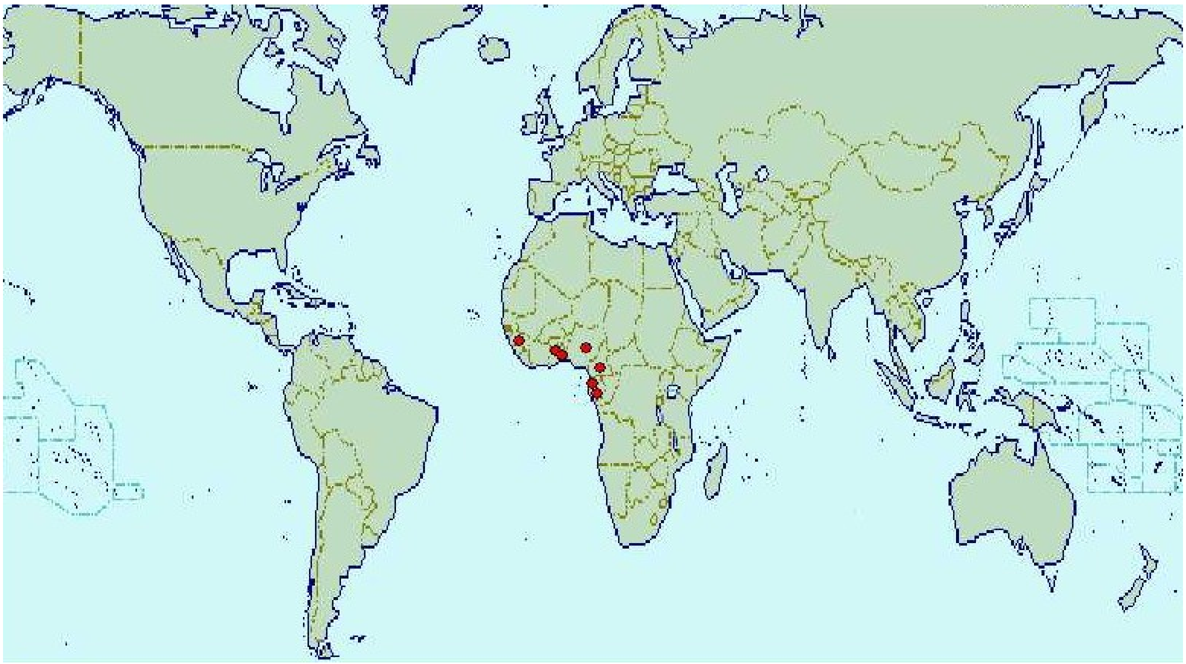
Removal of infected pods from high up in the tree, Cameroon. Photo J. Vos © CABI Bioscience

Integrated Pest Management

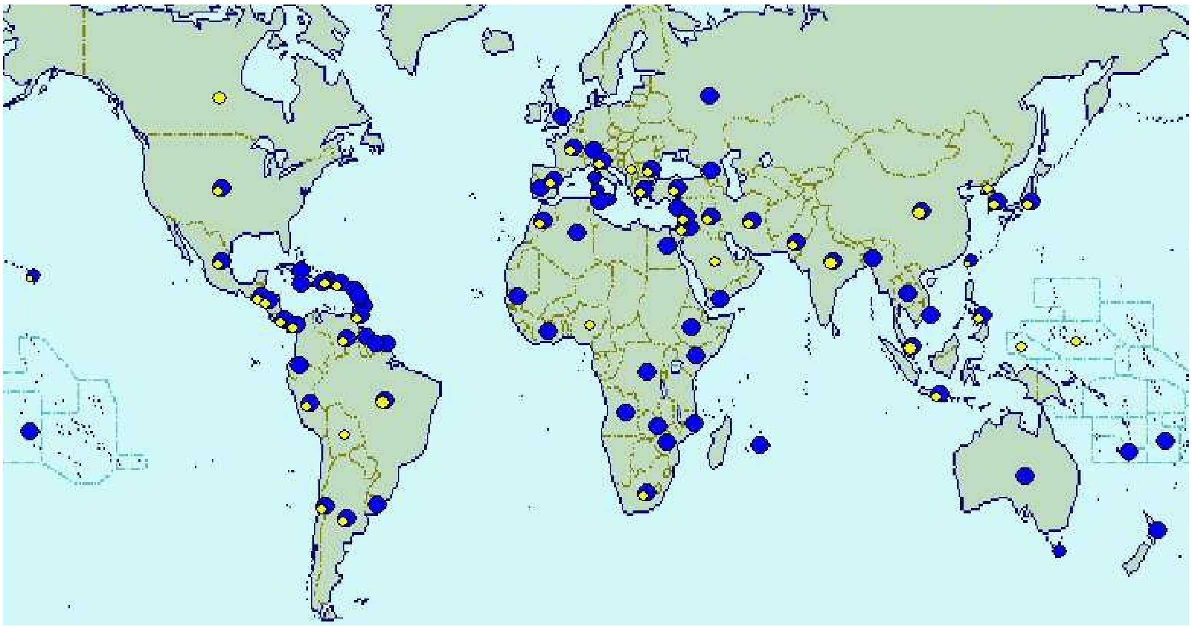
Control of Black Pod is complex and requires the integration of many approaches given above. Soil health and general good crop management are essential. 'Healthy soils' are characterised by high organic matter and plant nutrient contents, diverse and abundant microbial activity, good drainage and physical structure and low levels of pathogens. It should be noted that cultural control alone can be very effective against *P. palmivora* if conducted properly, but for very severe Black Pod caused by *P. megakarya*, additional chemical control is at present still needed.



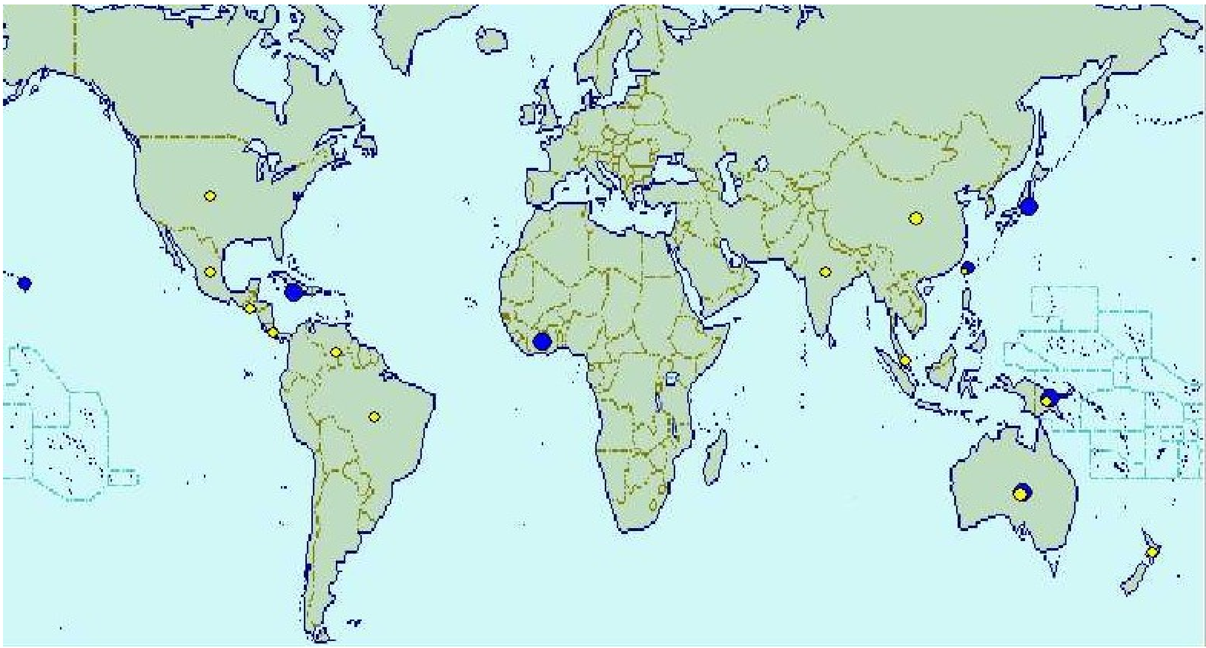
In-country presence of Phytophthora palmivora (source: Crop Protection Compendium 2002, CAB International)



In-country presence of Phytophthora megakarya (source: Crop Protection Compendium 2002, CAB International)



In-country presence of Phytophthora capsici (yellow dots) and Phytophthora citrophthora (blue dots)
(source: Crop Protection Compendium 2002, CAB International)



In-country presence of Phytophthora heveae (yellow dots) and Phytophthora katsurae (blue dots)
(source: Crop Protection Compendium 2002, CAB International)

Cocoa Pod Borer – *Conopomorpha cramerella*

Importance

Cocoa pod borer (CPB) causes losses to cocoa by boring in the placental tissues and the wall of the pod and disrupting the development of the beans. Feeding results in pods that may ripen prematurely, with small flat beans that are often stuck together. The beans from seriously infested pods are completely unusable and in heavy infestations over half the potential crop can be lost. In light infestations there may be no economic loss but control may still be needed to prevent the development of higher infestations.

Alternative hosts include *Cola* spp and rambutan (*Nephelium lappaceum*). These are likely to be the original hosts of this insect and CPB is an example of a "new encounter disease". These fruits produce a pulp that is similar to cocoa but are seasonal and so do not provide the right conditions for permanent establishment -unlike cocoa.

Rambutan or nam-nam borers are known in Thailand, Sri Lanka and Papua New Guinea. Pod borer was already found on unnamed hosts in Western Samoa and the Northern Territory of Australia early in the 20th century. Live pod borers can travel long distances within rambutan fruit, e.g. healthy pupae were found on Thai rambutans in a supermarket at Riyadh, Saudi Arabia in 1986. See page 21 for distribution.

The most commonly used English name for this insect is cocoa pod borer, others include cocoa moth, ram-ram borer, rambutan borer, cacao moth, Javanese cocoa moth. In Spanish, *polilla javanesa del cacao*; French, *teigne javanaise du cacaoyer*; German, *Javanische Kakao-Motte*; Indonesian, *penggerek buah kakao.*

Description

Eggs

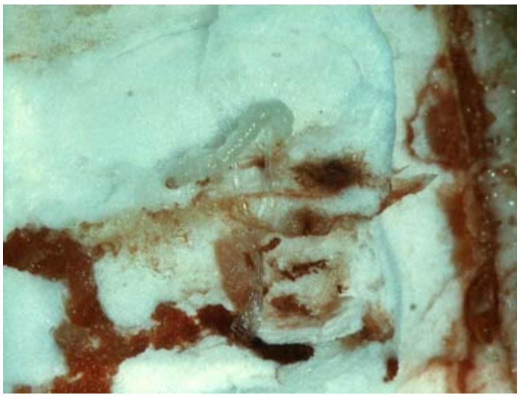
Eggs are yellow-orange, flattened and just visible to the naked eye (about 0.5 x 0.2mm) and have rectangular indentations on the egg surface. The eggs are laid singly anywhere on the surface of host-plant pods although there appears some preference for the pod furrows. On hatching (six to nine days), eggs become translucent, the shell being whitish but darkened inside by faeces.

Larvae

First larva stage (instar) is transparent white in colour and about 1 mm long. After hatching, the first-instar larva tunnels through the floor of the eggshell and, at times, tunnels along the outer woody part of the pod husk for up to several centimetres before it penetrates the husk. Once inside the pod, the larva tunnels in any direction and feeds randomly. In younger pods, early-instar larvae can penetrate the developing beans, causing malformation and undersize of affected beans.

Internal damage caused by CPB larva, Indonesia. Photo © C. Prior

Pods yellow or ripen unevenly and prematurely, causing confusion on ripeness standards for harvesting. Late larva stages are about 1 cm long and creamy coloured while still inside the pod, but greenish after they emerge to pupate. Once outside the pod, larvae crawl or lower themselves by a silk thread to a suitable site for pupation.



White CPB larva inside cocoa pod, Indonesia. Photo © C. Prior

Pupae

Pupae lie beneath a light-brown waterproof silken membrane tightly drawn over a depression on a pod surface or leaf. The pupation site could be in a furrow of the pod, or green dried leaves and other debris. Once at this site the larvae spin oval-shaped cocoons and enter a short prepupal stage before forming pupae.

CPB pupa beneath light brown waterproof silken membrane in a pod depression, Indonesia. Photo © C. Prior

Adult

The adult is a small brown moth, about 7 mm in length. It has a wingspan of about 12 mm and has bright yellow patches at the tips of the forewings. The moths have very long antennae, which are swept backwards in their natural resting position. In flight the moths look like large, slow-flying mosquitoes.

ECOLOGY

Eggs are laid on pods more than 5 cm in length. The entire larval stage takes 14-18 days to complete, with 4-6 instars. The great majority of the larvae emerge from cocoa pods after they become ripe. The larvae then tunnel out through the pod wall, leaving an easily identifiable exit hole.

The pupal stage normally takes 6-8 days to complete. The pest is therefore most likely to be transported by man to other cocoa-growing areas through movement of pods, leaves and other objects in or to which larvae and pupae are attached. **Exercises 10 and 11** show you how to study feeding patterns and life cycles.

The moths are most active at night; mating and laying of eggs being carried out at this time. A female can normally produce 50-100 eggs in her lifetime. There is no indication that the moths can fly long distances and long-distance movement of CPB must almost certainly have taken place through movement of infested pods.

During the day, adult moths normally rest underneath more or less horizontal branches of the cocoa tree, and their cryptic coloration blending with the resting place makes them difficult to spot. Adult longevity is generally about one week, but they can live up to 30 days. In total, the entire life cycle takes about 1 month to complete.

PEST MANAGEMENT

Field monitoring and decision-making tools

Research in the mid-80s showed a damage function for *C. cramerella* relating loss of yield to percentage infestation in harvested pods. The function indicated almost no yield loss with infestations up to approximately 60%, and rapidly increasing losses with higher infestations (over half the crop is lost in very heavy infestations). While this is a reasonably practical way of estimating damage, the relationship is inaccurate at higher infestation levels but for setting priorities for control action, this is probably adequate: infestations over 60% need control, while at lower infestations there is doubt about the immediate need for control. However, in addition to the fairly simple task of monitoring percentage infestations, the age of pods should also be monitored, which is not as easy. A climate-driven, pod-age-dependent computer model for cocoa pod borer has been developed in SE Asia. This cocoa production model tests cultural and other crop protection management practices to determine robust extension messages for farmers. The model allows for dynamic risks due to pests, climate and prices to be assessed. See **Exercise 3** to systematically collect field data and assess the situation.

Regular and complete harvest (Rampassen)

In the early days of the 20th century, regular and complete harvesting, or *rampassen*, was considered to be the only feasible control method. Research on the life cycle and oviposition habits of pod borer in the early 1980s confirmed that removing all pods longer than 6-7 cm from a field for 6 weeks would break the life cycle of the insect, as female moths will not usually lay eggs on younger pods. The main set-back for *rampassen* is the migration of female moths from uncontrolled cocoa farms, unless communal action is taken. Also, without appropriate pruning, complete elimination of a population of pod borer through *rampassen* is difficult. **Exercise 5** explains about cocoa pruning methods.

If pods are picked at the earliest stage of ripeness, then almost 90% of the larvae will still be inside the pods. If pods are broken quickly and the husks destroyed, buried or covered with transparent plastic, the larval death rate will be very high and a good degree of control can be achieved. Alternatively, unbroken pods can be kept in plastic bags for several days, either to contain emerging larvae or to kill them through over-heating inside the bag. The interval between harvesting should be 14 days or less. An alternative would be to abandon harvesting during the low crop, and at the first sign of the rising crop to begin very intensive complete harvesting for several months. The economic implications of both alternatives would need to be tested in farmer trials (see **Exercise 21** to do an economic analysis).

Mechanical Control

In pod borer infested areas in southern Philippines, some cocoa has been planted at very high densities as hedges with access for small tractors between pairs of rows. Trees are kept to a low height so that all harvesting can be done within easy reach. Mechanisation allows frequent, regular harvesting, and the hedge-like structure of the crop (1-m squares within the double rows, and 2-3 m between rows for mini-tractor access) allows thorough complete harvesting. Under this system, infestations of pod borer were at insignificant levels during the late 1980s, without any other form of control.

The idea of sleeving pods with bags of plastic or other materials to prevent egg laying originated in Indonesia. Thin plastic bags, with open bottoms for ventilation, are placed on very young pods (less than 7 cm long) and left throughout the pod maturation period result in virtually complete protection from pod borers. The main problems are that bags are sometimes placed too late, or that insufficient ventilation may result in rots. In addition, this method is labour intensive. The economics of this method will depend on cost of labour versus cocoa yields (see **Exercise 21** to do an economic analysis).

Biological Control

Dutch entomologists in the early part of the 20th century advocated that ants (the large black ant (*Dolichoderus* sp.) and the weaver ant (*Oecophylla smaragdina*) should be encouraged to prey on prepupal larvae of the pod borer on emergence from the pod and on pupae, and to disturb adults. Research during the 1980s suggested that most predation was actually due to the small 'sugar' ants (*Iridomyrmex* spp.) which are much more difficult to augment or manipulate. A long-term study during the early 1980s showed that ant predation was almost constantly 40% of pupae each month throughout a 4-year period.

Low levels of natural pupal parasitism were found in Sabah, Malaysia, but little progress was made in finding alternative hosts for the parasites. An intensive programme of rearing a parasitic wasp (*Trichogrammatoidea* sp.) from Sabah on an alternative host (*Corcyra cephalonica* – rice moths) in laboratories and commercial breeding rooms, and release into the field of about 12500 wasps/ha/day gave surprisingly good levels of control. The costs however were prohibitive. Two other wasp species (*Ceraphron* and *Ooencyrtus*) were introduced in the field in small numbers in Sabah. A third species (*Nesolynx*) failed to survive in field cages. However, none of these have established successfully.

Six genera of fungi have been found to infect larvae and pupae. The most effective was *Beauveria bassiana*, causing 100% death during pupation if larvae were exposed to the fungus on emerging from the pod. More than 40% of larvae that emerged from infected pods that had been dipped in a spore suspension of *B. bassiana*, died during pupation. Other fungus species, *Penicillium, Acrostalagmus, Verticillium, Fusarium* and *Spicaria* have been successful, but aren't used on a large scale.

Host Plant Resistance

Early Dutch interest in host-plant resistance focused on the surface of the pod. Eggs were generally found in the furrows on the pod surface, smoother pods being less attractive than deeply ridged cultivars. In the mid-1980s, considerable differences in larval mortality were found inside pods of different cultivars. Greater mortality occurred in pods with either thicker or harder stony endocarp layers in the pod wall. Larval survival was as much as 10 times greater in soft/thin-walled cultivars. A major constraint to the adoption of host-plant resistance in the mid-1980s was the time and cost involved in replanting existing stands with hard-podded cultivars. Recent innovations, particularly in Sabah (Malaysia), in clonal tissue culture and in grafting clonal tissue onto mature stems, may allow partial host-plant resistance to play a much greater part in cocoa pod borer control in the future.

In Indonesia during the first half of the 1990s, research was undertaken on strains of *Bacillus thuringiensis* that expressed the cry gene that is lethal to CPB. The potential would have been to develop transgenic cocoa clones or endophytic microorganisms containing the lethal gene to CPB, the line of research has not been progressed.

Pheromonal Control or Trapping

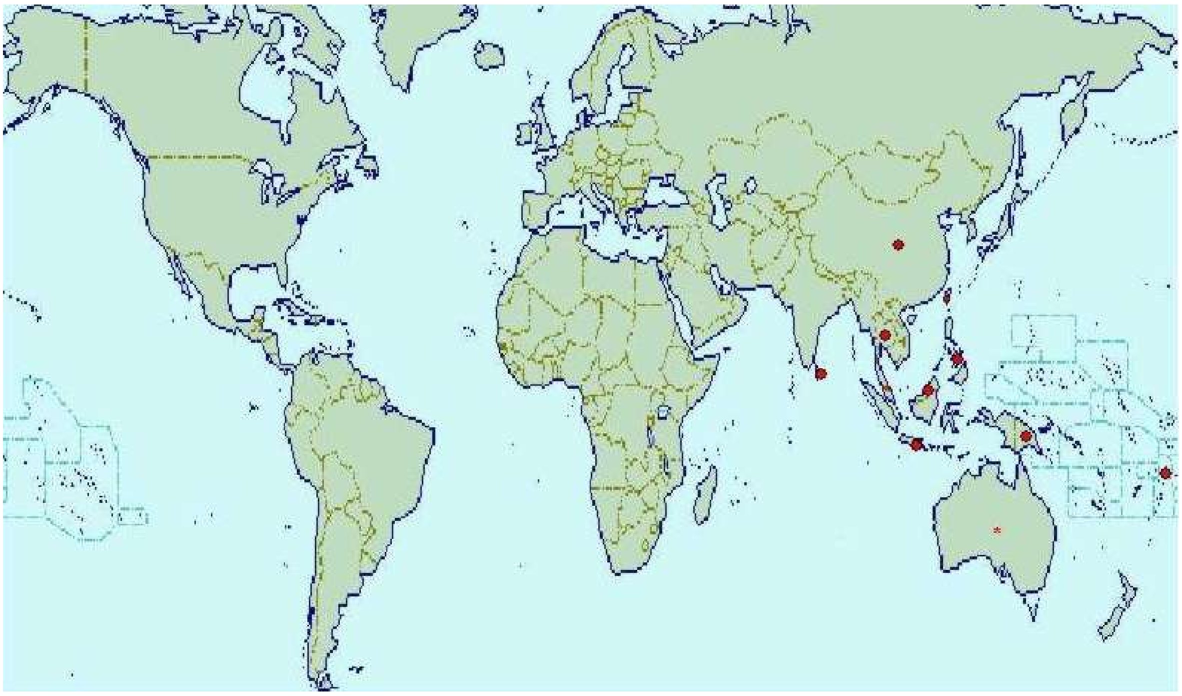
In the mid 1980s, synthetic pod borer pheromones were investigated: Many more male moths were trapped using synthetic pheromones than could be caught in traps baited with female pod borer moths and these traps could be used for both monitoring and control. However, control can only be achieved if a large proportion of male moths are trapped before they can mate. A 200-ha trial was conducted over 4 years at BAL Estates and elsewhere in Sabah (Malaysia) to test pheromonal control. Trap densities of four and eight per ha were used. Results of these trials indicated that losses were reduced by about one-third in trapped areas compared with untreated areas. The pheromones were shown to catch moths as far as 800 metres from infested cocoa. Unfortunately, in 1987 a new pod borer race was found in West Malaysia that did not respond to the pheromone used in Sabah. A new mixture was prepared that caught both races, but further races could develop and frequent changes of pheromone components would add to costs and limit efficacy. As a result, pheromones are not nowadays used for pod borer control. Pheromone traps may, however, still be useful for quarantine detection in uninfested areas.

Chemical Control

Observations in the mid 1900s showed that cocoa in South-East Asia could not survive continuous blanket sprays of broad-spectrum insecticides, because of outbreaks of secondary pests freed from their normal control by natural predators and parasites (see **Exercise 17** to understand the impact of pesticides on natural enemies). Several developments in the 1980s have improved chemical control, without resulting in serious secondary pest outbreaks. Relatively small amounts of contact insecticide, either pyrethroid or carbamate, applied to undersides of lower branches during the low-crop period, kept pod borer populations below economic damage levels during subsequent peak populations in several trials. **Exercise 16** can be done to appreciate the risks of spraying hazardous pesticides.

INTEGRATED PEST MANAGEMENT

The most immediate reductions in cocoa pod borer are likely to come about through integration of cultural control, viz. *rampassen*, and rational pesticide use. Both of these rely on well-pruned trees kept to a height low enough to collect and/or spray all pods. See **Exercise 5** for cocoa pruning methods. Longer-term control may be improved by grafting or replanting with hard-walled clones. See **Exercise 4** for grafting. Further releases of exotic natural enemies may provide additional partial control, if suitable parasites can be found.



In-country presence of Cocoa Pod Borer (source: Crop Protection Compendium 2002, CAB International)

Cocoa Swollen Shoot Virus – CSSV

Importance

Cocoa Swollen Shoot Virus is a serious constraint to cocoa production in West Africa, particularly in Ghana. Severe strains of this virus can kill susceptible cocoa trees within 2-3 years. CSSV affects Amelonado cocoa (widely considered to give the best quality cocoa beans) more seriously than Upper Amazon cocoa. See page 25 for distribution.

The disease was first recognized in 1936 but almost certainly already occurred in West Africa in 1920. It is an example of a new encounter disease, where the virus originated from a forest tree species and 'jumped host' to cocoa. Estimates of annual yield losses due to this virus vary from about 20,000 tonnes to approximately 120,000 tonnes of cocoa from the Eastern Region of Ghana alone. The average annual loss between 1946 and 1974 in Ghana was estimated to be worth over 3.5 million Pounds (£). Attempts at CSSV control in Ghana have required substantial inputs in terms of finance and manpower. In Ghana, 'cutting-out' policies have been in place since the early 1940s. This policy has resulted in over 190 million infected trees being removed up to 1988. The 'cutting-out' policy was effective if conducted quickly and efficiently.

The virus is also found in trees used for shade - in *Adansonia digitata* (baobab) symptoms are of a leaf chlorosis. Transient leaf chlorosis symptoms are found in *Ceiba pentandra* (silk cotton tree), *Cola chlamydantha*, *Cola gigantea* var. *glabrescens*, and *Sterculia tragacantha*, but generally, few symptoms are seen on these hosts which may indicate a long association with the virus.

Note: Despite the well know distribution of this virus and the disease in West Africa, virus particles similar to CSSV badnavirus (unenveloped bacilliform particles) have also been found in cocoa growing in Sumatra (Indonesia) and Sri Lanka. Their role as disease causing agents has not been confirmed.

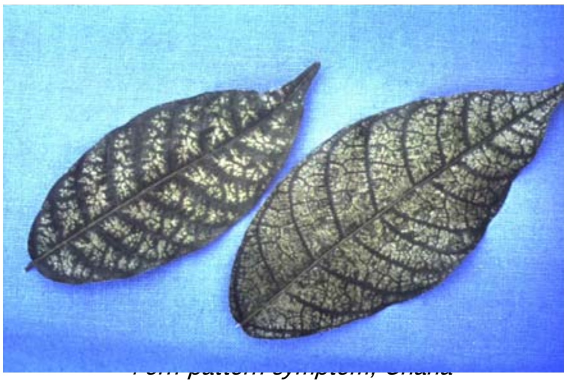
Phytosanitary Risk

CSSV is currently confined to West Africa (Côte d'Ivoire; Ghana; Nigeria; Sierra Leone; Togo), and this has serious implications on international germplasm movement. International attempts at crop improvement are restricted by the need to test (or index) cocoa germplasm for this virus, particularly if germplasm is to be moved to locations where highly susceptible varieties are grown. Thus, material from West Africa is sent to Intermediate Quarantine facilities and then tested for presence of the virus. One method currently used is to test a given clone for the presence of the virus by grafting onto Amelonado rootstocks using patch budding. Should the virus be present then this will manifest itself in the Amelonado material over time. The "test plants" are inspected every 2 weeks for signs of the virus. The quarantine period is now 2 years.

In addition to this grafting technique, which is time consuming and thus limits the speed that germplasm can be moved around in international breeding programmes, serological (ELISA and ISEM) methods and molecular methods including PCR methodologies are under development. These approaches can also detect a range of badnaviruses including those found in bananas, plantains, sugarcane and other species commonly found associated with cocoa. Specific primers and a database of sequences are under development in Ghana with the specific objective to provide a sensitive, specific system for detecting CSSV. A successful rapid detection method would greatly aid the movement of germplasm from West Africa.

Description

Symptoms of this disease are very difficult to see in the growing crop. Symptoms are mostly seen in leaves, but stem and root swellings as well as pod deformation also occur.



Fern pattern symptom, Ghana
Photo © T. Legg

In some varieties of cocoa, particularly Amelonado cocoa, initial reddening of primary veins and veinlets in flush leaves is characteristic. There can be various symptoms on mature leaves, depending on cocoa variety and virus strain, including: yellow clearing along main veins; tiny pin-point to larger spots; diffused blotching; blotches or streaks. Chlorotic vein streaking or banding is common and may extend along larger veins to give angular patterns. Common terms used include 'vein clearing', 'diffuse flecking', 'red-vein-banding' and 'fern-pattern'.

Blotching, Ghana.
Photo H. Evans © CABI Bioscience

Stem swellings result from abnormal proliferation of plant cells and may develop at the nodes, internodes or shoot tips. These may be on the chupons, fans or branches. Many strains of CSSV also induce root swellings. Infected trees may suffer from leaf-loss and dieback.

Stem swelling, Ghana. Photo H. Evans © CABI Bioscience

Initially, there can be partial leaf-loss. In highly susceptible varieties, complete leaf-loss occurs. Small, rounded pods may be found on trees infected with severe-strains. Sometimes green mottling of these pods is seen and their surface may be smoother than the surface of healthy pods.

Green mottling of pod surface, note the surface is smoother than healthy pods, Ghana.
Photo © T. Legg

Ecology

CSSV can infect cocoa at any stage of plant growth. The virus is believed to be only partially systemic in cocoa, as some branches on an infected tree may be symptomless. In susceptible cocoa varieties, yield losses of up to 25% are experienced within the first year after infection.
Natural transmission of this virus is by mealybug vectors in a semi-persistent manner. See **Exercise 15** to better understand spread of viruses by insects. As many as 16 mealybug species have been reported to transmit this virus, all from the Pseudococcidae family-group, including: *Planococcoides njalensis*, *Planococcus citri*, *Phenacoccus hargreavesi*, *Pseudococcus concavocerrari*, *Ferrisia virgata*, *Pseudococcus longispinus*, *Delococcus tafoensis* and *Paraputo anomalus*.

The virus is retained when the mealybug vector moults, but it does not multiply in the vector nor is the virus transmitted to the vector offspring. Nymphs of both sexes and adult females spread the disease radially between adjacent trees by crawling through the canopy from infected to healthy trees or by being carried by attendant ants (*Crematogaster* and *Camponotus* species).

Occasionally 'jump-spread' may occur when mealybugs are blown by the wind and then infect trees at some distance from the original site of infection. CSSV is not transmitted through seed in cocoa. CSSV has been transmitted experimentally to susceptible species by grafting and mechanical inoculation and by infection using biotechnology techniques.

PEST MANAGEMENT

Sanitation

The removal or 'cutting-out' of visibly infected trees together with contact trees has been the control method advocated in Ghana where the disease has been of economic importance since the 1940s. The cutting-out strategy depends on the size of the outbreak. For outbreaks of less than 10 trees, only the adjacent trees are removed (to a distance of 5m from the outbreak). However, when more than 100 trees are infected in any one outbreak, the adjacent trees and any other trees to a distance of 15m from the visibly-infected trees are removed. There is much debate about the effectiveness of this approach as many infected trees are not noticed or are in a latent stage. Eradication (zero tolerance) has been expensive both in financial terms and through impact on the environment and farming communities. Many farmers have moved into new forests and this has led to loss of forest cover and abandoned farms become degraded..

Host Plant Resistance

A lot of effort has gone into the breeding for resistance to this disease, notably in Ghana and Togo. It is unlikely that there is any specific resistance to the virus in wild germplasm, as the pathogen does not exist in the centre of origin of the host (South America). Thus, the breeding strategy aims at combining properties from different genotypes that may be useful against the disease. These properties may include sap palatability to the vector and production of antiviral compounds and other forms of induced resistance. In practice, breeders need better disease indexing methods to check for viruses in their new materials and better inoculation methods to ensure their initial screens for resistance are accurate

Cultural Control

Consideration must be given to isolating new cocoa plantings from infected cocoa by using barriers of CSSV-immune crops. This disease in cocoa is described as a 'new encounter disease' as it was present in those forest trees that are in the same plant family as cocoa (Sterculariaceae). When cocoa was planted on a large scale it presented an opportunity for the vector to move onto a new host and take the virus with it. Any crop used as a barrier to prevent the movement of the vectors into new cocoa should not be from the cocoa plant family. Examples of possible barrier crops include oil palm, coffee, and citrus.

Mild-Strain Cross-Protection

Mild-strains, which appear to give some protection against severe-strains, are available and being field-tested in Ghana. However, the degree of protection afforded so far, is not economic and further research is necessary.

Vector control

Pesticides could in principle control the mealybug vectors of CSSV, however in practice the effectiveness of this control method leaves much to be desired requiring wide scale pesticide use.

Ants guarding and caring for mealybugs. Photo © C. Prior

In-country presence of CSSV (source: Crop Protection Compendium 2002, CAB International).

Frosty Pod Rot - *Crinipellis roreri*

Note on Names

Frosty Pod Rot of cocoa is caused by *Crinipellis roreri*. The Latin name has recently been changed from *Moniliophthora roreri*. Common Spanish names are *helado, hielo, pasmo, aguado del cacao*. Technically incorrect or misleading common English and Spanish names, such as *La moniliasis* continue to persist. *Podredumbre acuosa* is particularly misleading as this name is also shared with Witches' Broom.

Importance

This fungal disease is currently found in the cocoa growing areas of Central and South America (Costa Rica, Guatemala, Honduras, Nicaragua, Panama, Colombia, Ecuador, Peru and Venezuela). Although considered a relatively minor disease globally, compared to Black Pod and Witches' Broom diseases (see respective Datasheets) it is potentially the greatest threat to cocoa production. Wherever *C. roreri* has invaded, crop production has been severely reduced. In 1978 the disease appeared in Costa Rica where pod loss of 60-90% occurred. Similarly, after its invasion into Peru in the 1990s, production fell to 40-50%, with total crop loss in some areas. In summary, if this disease were accidentally exported to other cocoa growing regions of the world, in particular West Africa, its effects on world production could be devastating. See page 29 for distribution.

Description

Frosty Pod spores germinate on cocoa pods in the presence of free water or high humidity, with low temperatures. Penetration occurs directly through the pod surface or stomata. Symptoms appear after 4-10 weeks, depending mostly on the age of the pod (conduct **Exercises 12 and 13** to better understand disease infection and symptom development). When young pods (less than 1 month old), are infected they develop chlorotic swellings and distortions in about a month, followed by general necrosis. The pod's seed mass can become soft and watery.

Soft and watery seed mass, Ecuador. Photo H. Evans © CABI Bioscience

All these symptoms are indistinguishable from Witches' Broom infection (see **Witches' Broom Datasheet**). Pods that are infected when over 3 months old may have no external symptoms or only limited necrosis. This limited necrosis is often slightly sunken and surrounded by areas of premature ripening. Inside, the pod may have more advanced (partial or total) reddish-brown necrosis.

Infected pod with internal reddish brown necrosis, Costa Rica. Photo H. Evans © CABI Bioscience

In contrast to infection in young pods, older pods exhibit overproduction of tissue inside the pod leading to dense, compacted, heavier pods. The first visual symptoms in older pods are large dark-brown spots with irregular edges that grow rapidly and cover all or part of the pod surface. Fungal growth appears a few days later turning quickly into a frost-like, dense, white, felt-like mat. The white mat first turns cream-coloured, tan and then light-brown from the centre of the infection outward, eventually becoming powdery. Within a few days, more than 6 billion spores can be formed per pod, which are subsequently released over a couple of months. Spore formation, release and dispersal do not require high humidity.

Powdery fungus growth containing billions of spores, Ecuador. Photo H. Evans © CABI Bioscience

The dry, powdery spores are readily released in very large numbers by air currents and tree vibrations, such as during harvesting or pruning. Wind or air currents can disperse these spores over tens or even hundreds of kilometres.

Biology & Ecology

The fungus is considered to have originated on *Theobroma gileri* in Colombia, a close relative of cocoa. It infects cocoa (cultivated and wild), other *Theobroma* and *Herrania* species.

Once established in a cocoa plantation, dispersal of the fungus is continuous throughout the year. The intensity of the infection rate is dependant on the prevailing environmental conditions and availability of pods/host material.

High incidence of new infections occurs when heavy pod-set, hot rainy weather and inoculum sources (sporulating, infected pods) are available. There is a positive relationship between the percentage of pods showing symptoms and the amount of rainfall that occurred 3-4 months before. Temperatures in the daily range of 22-32°C favour incidence of Frosty Pod; at cooler temperatures the disease is less severe, as incubation periods become longer. The process accelerates as increasing numbers of young pods are infected, as long as the flowering and pod-set cycle continues. In regions with a well-defined dry season, disease incidence tends to decrease as rains subside, particularly if flowering also ceases. Necrotic pods covered with old spore producing mats persist as potential sources of inoculum during these periods of low disease activity, but they tend to be less infective as they get old and mummify. Nevertheless, viable spores have been collected from mummified pods up to 9 months after infection.

Infected cocoa pods, Panama. Photo H. Evans © CABI Bioscience

If infected pods are cut off the tree and left on the ground, spores can be released for several hours, but in a few days turgor changes and invasion by other microorganisms generally immobilise the remaining spores.

Pest Management

Cultural Control and Sanitary Methods

Removal of diseased pods from the cocoa trees is the main cultural approach to Frosty Pod control. Diseased pods must be removed from the tree, weekly during peaks of pod-set and development, but less frequently when fruiting is sparse. Infected pod removal should happen at the first sight of symptoms, before spore production starts, else pod removal will help dislodge the spores and spore dissemination!

Once cut off, all diseased pods can be left undisturbed on the ground or covered with leaf litter. Better still is to bury them, as this will allow other microorganisms to colonise, inhibit and inactivate any remaining spores.

Diseased pods left on the ground, some partially covered with leaf litter, Peru. Photo H. Evans © CABI Bioscience

Spraying the discarded pods with urea (3%) accelerates decomposition. Urea burns flowers, so it can't be applied to the trees themselves.
The tree canopy should be kept low and thinned by frequent light pruning, to provide ventilation and to aid detection and removal of diseased pods. (See **Exercise 5** for pruning methods and **Exercise 6** for understanding the impact of shading on humidity in a cocoa farm.) Make sure that sanitary harvesting is done prior to pruning as pruning can dislodge Frosty Pod spores.

In regions with a well-defined harvest peak, with incidence of Frosty Pod increasing towards harvest, total removal of both healthy and diseased pods at the end of the peak may be necessary to break the disease cycle. In any case, all mummified pods should be removed from the trees before the next flowering peaks. Elimination of inoculum sources is most effective if practised on a large scale. Community action and/or the enforcement of local phytosanitary regulations would help to ensure success.

Biological Control

Application of antagonistic fungi or bacteria has been shown to be effective in reducing the incidence of Frosty Pod in field experiments. Bacteria from the genera *Bacillus* and *Pseudomonas* have been successful under experimental conditions in Costa Rica. In Peru, the mycoparasitic fungi, *Clonostachys rosea* and *Trichoderma* spp., reduced the incidence of frosty pod. However, no agent is currently commercially available.

Regulatory Control

Regions or countries free from Frosty Pod must maintain strict quarantine regulations, aimed not only at pod transport from infested areas, but also related plant residues that may harbour spores. Quarantine examinations must be imposed on pod/seed transport for research or breeding purposes. A 'holding period' of a minimum of 2 weeks should be imposed on pods to allow latent infections to develop symptoms. Vegetatively propagated material should be dipped in fungicide suspension to prevent external transport of disease spores. Internal quarantine control should be applied through the enforcement of local/national phytosanitary regulations, to ensure the movement of disease-free material.

Host Plant Resistance

There is variability in susceptibility to Frosty Pod in most cocoa clonal collections tested. At CATIE (Costa Rica) after evaluating more than 500 cocoa clones with different geographical origin using artificial inoculations, it was observed that susceptibility to Frosty Pod was the most common reaction and resistance an infrequent character. Some clones holding resistant genes are ICS-43, ICS-95, PA-169, EET-75, UF-273, UF-712, CC-252. Additionally, EET-233 has shown a resistant reaction in Ecuador.

Chemical Control

Numerous fungicides are applied on young pods to reduce the incidence of frosty pod, but their cost-benefit balance is often questionable. Only in high-yielding plantations, with one or two well-defined production peaks, can fungicides be cost-effective. Spraying should be concentrated on the early stages of pod development, from the start of the main pod-set peaks until most pods are 3 months old, and complemented by frequent removal of diseased pods. Where hand pollination is economically feasible, it combines well with fungicidal protection. Copper fungicides and organic protectants (especially chlorothalonil, WHO[1] Class II) have generally proven effective and may be economical (**Exercise 21** pays

[1] World Health Organisation (WHO) classification of pesticides according to acute toxicity, ranging from I (highly to extremely hazardous) to III (slightly hazardous) in addition to U (unlikely to present acute hazard in normal use). IPM programmes should avoid use of WHO Class I and II pesticides. Note that formulation can move active ingredients to a lower hazard classification.

attention to the economics of pest management). With regard to copper fungicides, it should be noted that these are generally toxic to humans (WHO Class I and II) and highly persistent in soils, and are being phased out in organic production. (**Exercise 16** raises awareness of risks posed to farmers when applying hazardous pesticides.) Research is ongoing to investigate the effectiveness of oxathiin fungicides, which are cheap (off-patent) and much safer (generally WHO Class IV) and hence preferable in the absence of commercially available biological agents.

In-country presence of Frosty Pod (source: Crop Protection Compendium 2002, CAB International)

Mirids (Capsids) -
Sap sucking bugs

Note on names

The general names, Mirids and Capsids describe the same types of insects that feed on cocoa and belong to the family Miridae. The term Mirid is commonly used in the Americas and Asia whereas Capsid is the common term in Africa. In Malaysia, common names are Mosquito Bug and Bee Bug. In this manual we are using the term Mirid to cover both Mirids and Capsids.

Importance

These insects attack by piercing the surface of the cocoa stems, branches and pods and sucking the sap. Mirids are described as the most injurious and widespread of insect pests. On cocoa, there are forty or more species that can be described as 'Mirids'. The action of feeding by these insects, piercing the plant tissues with their needle-like stylet (mouth part) and injecting toxic saliva (spit) into the plant causes the internal tissues to die.

The most important in West Africa are *Sahlbergella singularis* and *Distantiella theobromae; Bryocoropsis* and *Odoniella* are also present in West Africa. A species similar to *Sahlbergella, Boxiopsis madagascariensis* has been reported as a cocoa pest on the East Coast of Madagascar. *Afropeltis* (formerly called *Helopeltis*) is present in West and East Africa.

Helopeltis species are the most important in Asia; *Pseudodoniella* in Papua New Guinea and *Platyngomiriodes* in Borneo. *Monalonion* species are present in South and Central America. See page 34 for distribution.

Adult Pseudodoniella, Papua New Guinea. Photo © C. Prior

Description

Mirids are good flyers and are active during the warm hours of the day. Feeding by sucking plant juices causes small water-soaked areas that quickly turn black.

Circular black lesions on pods caused by Mirid feeding, Cameroon. Photo © J. Vos

The lesions on pods are circular, while the lesions on stems are usually oval and of a larger size (conduct **Exercise 10** to study feeding patterns). Soft and hard stem tissues are attacked, with feeding on soft stems resulting in wilting and terminal death and allowing entry of wound fungi.

Soft shoot terminal death, Papua New Guinea. Photo © M. Holderness

Biology & Ecology

The life cycles of the various Mirid species are very similar. Single or small groups of eggs are buried in the skin layers of pods, pod stalks, chupons and fan branches. The eggs hatch, generally within a range from 6-20 days, but longer if climate conditions are not favourable.

Two breathing structures project from each egg above the plant surface and are just visible to the naked eye. Mirids do not have a pupal stage, but have five successive juvenile larva instars (nymph) stages, a process which takes on average 18-30 days. The nymphs increase in size with each moult and the last moult produces a winged adult. The adults are 7-12mm long and very slender. *Monalonion* and *Helopeltis* have long legs and antennae while in other genera the legs and antennae are more thickset.

Adult Afropeltis, Uganda. Photo © C. Prior

Incubation periods of most Asian *Helopeltis* species vary with locality and season, but are generally 6-11 days. The rate of larval development of the five instars is affected by climatic factors such as temperature and humidity, and by food quality. The average lifespans (first to fifth instar) are 9-19 days. Adult lifespan and fertility vary between approximately 6 and 30 days depending on local conditions and availability of pods and young shoots for feeding. There is a continuous cycle of generations through the year. In Malaysia, populations of *H. theivora* peak in October and are lowest in April/May. *Helopeltis* populations do not do well under conditions of heavy rain, high winds and low humidity.

In Africa, the development cycle of *Sahlbergella singularis* takes between 37 and 41 days. When they reach sexual maturity, adults feed actively on young shoots prior to mating. Females bury their eggs under the bark of lignified stems or in the pods and can lay between 30 and 40 eggs under natural conditions. Mirid invasion into cocoa from surrounding forest takes place in two stages: firstly emerging adults colonise semi-shaded trees. After sexual maturity, the adults move to brighter lighter zones, where females lay their eggs. When the eggs hatch, the larvae congregate leading to the formation of Mirid pockets where, under the combined effect of larva attacks and high evaporation due to exposure to sunlight, the cocoa trees first dry out and then die.

Installing forest shade in plantations forms part of

Shoot dieback as a result of Mirid attack, Ghana. Photo G. Oduor © CAB International

the integrated control of these pests (see **Exercise 6** to understand impact of shading on humidity in a cocoa farm). In addition to light, water and humidity play a decisive role in Mirid regulation within the ecosystem. In general, outbreak peaks occur either in the short rainy season (Côte d'Ivoire, Ghana, and Togo), or during the long rainy season (Cameroon). The sudden drop in relative humidity during the West African

Monalonion adult and nymphs on damaged pod, Ecuador. Photo H. Evans © CABI Bioscience

Harmattan (drying wind) speeds up cocoa tree water loss. The resulting water stress of the host-plant has a weakening effect on the insect's metabolism and causes a high larval death rate.

Development of *Distantiella theobromae* from egg to adult took 41.2 days in Nigeria and the average fertility was 73 eggs per female. The fertility of *D. theobromae* females is consistently higher than that of its rival species *Sahlbergella singularis* in Africa. However, the time taken for the development of these species is more variable and is dependent upon environmental conditions. Nevertheless, in zones where *D. theobromae* and *S. singularis* live side-by-side, their fluctuations over time are very similar, with population peaks usually occurring in October-November.

Pest Management

Integrated Pest Management

Cultural techniques (installing temporary shading in young plantings, upkeep and sucker removal in farms and the maintenance of a complete canopy) have been routinely applied, as a sole control practice or in addition to the rational use of pesticides, with the aim of minimizing pest damage to cocoa plantations. A number of trees are known to serve as alternate hosts of Mirids, including *Cola* sp., other *Theobroma* sp. and *Adansonia digitata*. These should not be used as shade trees in cocoa farms.

Many species have been used as shade for cocoa (see box in **Exercise 6**).

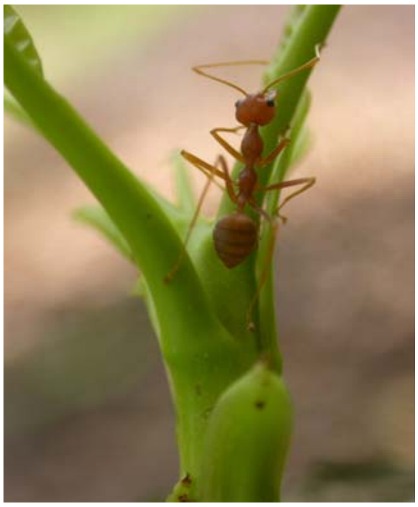
Integrated control programmes with reduced pesticide use and the monitoring of natural enemies have been suggested as an alternative to blanket spraying of chemicals. See **Exercise 3** on Agro-Ecosystem Analysis to learn about systematic monitoring. Reduced pesticide use would allow populations of natural enemies to increase and provide more suitable environments for improved biological control. **Exercise 17** raises awareness on the impact of different pesticides on both pests and natural enemies.

Biological control

Since 1900, cocoa planters in Indonesia have been aware that damage is less when cocoa trees are colonised by ants, notably *Dolichoderus thoracicus* which is not aggressive to plantation staff. This ant has been deliberately released into some cocoa farms as a control measure. The introduction of ants has been developed as a component of integrated pest management in Indonesia (against *H. antonii* and *H. theivora*) and in Malaysia (against *H. theobromae*). The area to be colonised is first treated with ground applications of insecticides to suppress antagonistic ants and then colonies of *D. thoracicus* are introduced.

Ants attacking a caterpillar.
Photo P. Van Mele © CABI Bioscience

Mealybug species, which do not cause damage to cocoa pods, are also introduced to provide honeydew and encourage the ants to remain in the farm. The proximal ends of the cocoa pods are left on the trees at harvest to conserve the mealybugs. However, in areas with Cocoa Swollen Shoot Virus (see CSSV datasheet), this practise should be avoided as mealybugs can transmit CSSV! The litter layer on the ground is also conserved to provide nesting sites for the ants. Another ant (*Oecophylla smaragdina*) is equally beneficial, but it is aggressive and therefore not liked by cocoa workers.



Ant guarding a young green shoot. Photo P. Van Mele © CABI Bioscience

The value of other predators, such as assassin bugs (Reduviidae) and spiders, in biological control programmes is questionable because these insects are not specific to Mirids.

High levels of parasitism have been demonstrated by some egg and nymph parasitoids. Egg parasitoids of the genus *Telenomus* and the mymarid *Erythmelus helopeltidis* are particularly promising, as are the nymphal parasitoids of the genus *Leiophron*.

Pathogens of cocoa mirids have been isolated in Ghana and oil formulations tested for efficacy. Further evaluations at farmer level will be needed before this biocontrol method could become available at a large scale. The same can be said about the use of pheromone traps to capture male mirids that are attracted to a sex bait in specially designed traps, which looks promising at the laboratory level but needs further field testing.

Host plant resistance

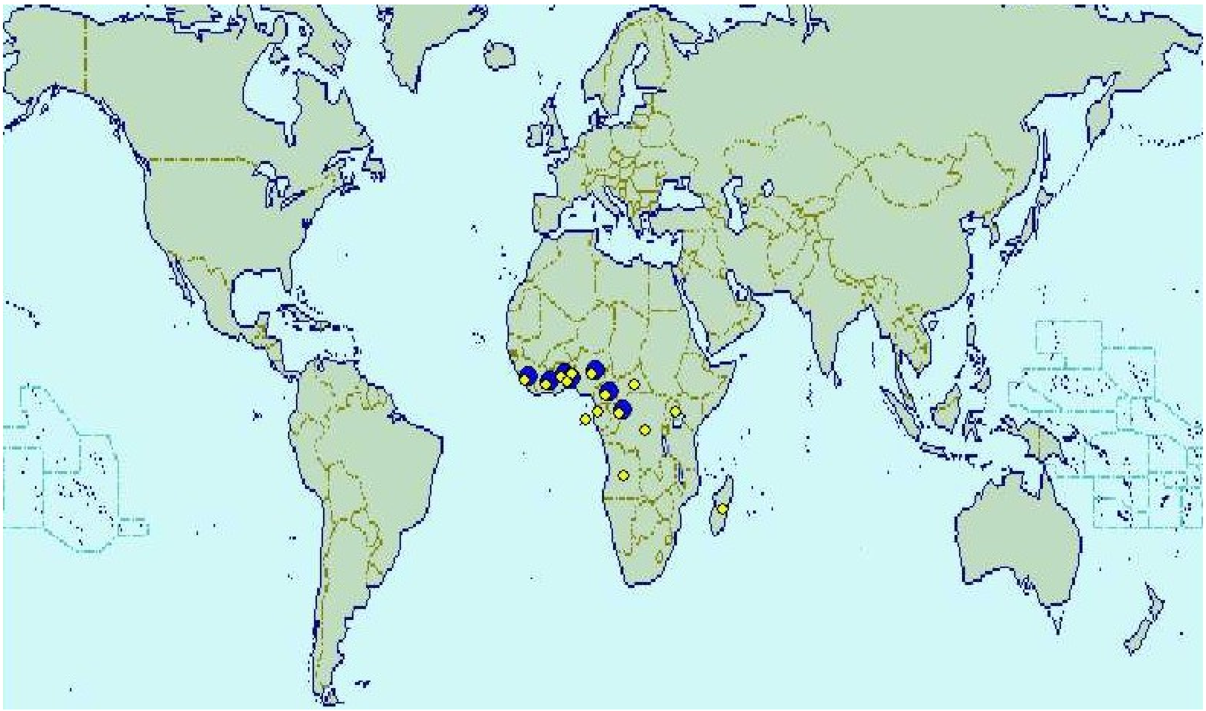
In terms of genetic control, hybrids have been obtained from clones with mirid tolerance. Cultivar SNK 413 is less vulnerable to attack than Catongo varieties. The low water content in the stems of some Upper Amazon cultivars is also a major factor in making these clones unattractive to mirids.

Chemical control

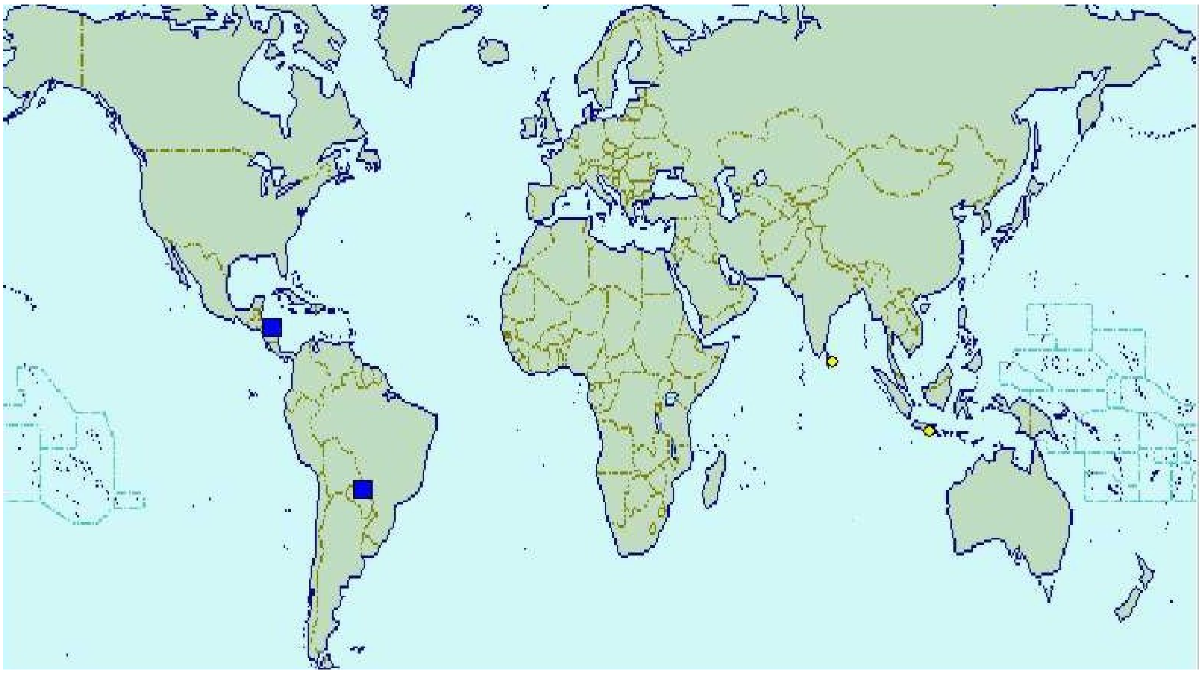
Chemical applications remain the primary method of controlling mirids. Cocoa-producing countries launched national mirid control campaigns as early as 1958-1960. Annual eradication of the pest by chemical control was ensured by State companies under the authority of the Ministries of Agriculture in Ghana, the Cote d'Ivoire, Cameroon and Togo. This is possible for state and private companies, but for small holders chemical application using appropriate equipment is too expensive (sees **Exercise 21** for an economic analysis of a cocoa enterprise). Insect eradication operations start at the beginning of rising mirid populations, coinciding with the peak cropping periods. Complete treatment consists of two rounds one month apart. The second round is intended to reach young instars, which were not affected by the first spraying. Research on reducing the flow rate (Low Volume Treatment) has been undertaken and the results have been extended. This rational chemical control programme against mirids has been a success in West Africa.

Lindane 20 (WHO[1] Class II), which is highly effective against mirids, was used in most African countries, either by spraying or by hot fogging (Cameroon, Togo). When cases of mirid resistance to lindane were reported in Ghana and in the Côte d'Ivoire, lindane was superseded by organophosphorus products with a lower vapour effect (diazinon – WHO Class II, fenthion – WHO Class II, fenitrothion – WHO Class II, etc.), then by carbamates (propoxur – WHO Class II, fenobucarb – WHO Class II, dioxacarb – WHO Class I-II and discontinued, etc.). **Exercise 19** explains about development and impact of pesticide resistance in insects. Lindane has now been banned from use on cocoa in West Africa for human toxicity reasons. Imidacloprid (WHO Class II) has now been registered in Ghana to replace lindane. In addition, pyrethroids, including bifenthrin (WHO Class II) and an organochlorine endosulfan (WHO Class II) are also highly active against mirids (over 90% kill rate). However, the hazard of using these available products warrants an urgent need for less toxic pesticides to become available (see **Exercise 16** to learn about risks of spraying hazardous pesticides). Research on the use of the safe botanical, neem (*Azadirachta indica*) has shown some promising results in Ghana where investigations on neem and other potential botanicals are in progress.

[1] World Health Organisation (WHO) classification of pesticides according to acute toxicity, ranging from I (highly to extremely hazardous) to III (slightly hazardous) in addition to U (unlikely to present acute hazard in normal use). IPM programmes should avoid use of WHO Class I and II pesticides. Note that formulation can move active ingredients to a lower hazard classification.



In-country presence of Sahlbergella (yellow dots) and Distantiella species (blue dots)
(source: Crop Protection Compendium 2002, CAB International)



In-country presence of Helopeltis (yellow dots) and Monalonion species (blue dots)
(source: Crop Protection Compendium 2002, CAB International)

Mistletoes - Plant parasites of cocoa

IMPORTANCE

Mistletoes are plant parasites that live on other plants to obtain food and water. Mistletoes belong to the family of plants known as the Loranthaceae. Mistletoes can infest many plants including cocoa, and if unchecked can cause serious problems in cocoa farms. Infestation by Mistletoe results in death of a branch from the point of attack, with heavy infestations leading to the death of many branches. This in turn leads to loss of vigour, reduced pod yield and eventually death of the tree.

Mistletoe infecting cocoa branches, Cameroon. Photo J. Vos © CABI Bioscience

Regular pruning to remove the Mistletoe plants is an essential part of good crop management. However, gaps in the canopy encourage regrowth of chupons and infestation by Mirids (see **Mirids datasheet**). The cocoa–Mistletoe union also provides a suitable habitat for *Crematogaster sp.* ants which tend and protect mealybugs which in turn serve as vectors of the Cocoa Swollen Shoot Virus (see **CSSV datasheet**).

DESCRIPTION

West Africa

At least 6 different species of Mistletoe have been found on cocoa. One species *Tapinanthus bangwensis* accounts for about 70% of infestations in Ghana. This species is recognised by its red flowers and berries, it flowers twice a year in Ghana and can live for up to 18 years. Another, *Phragmanthera incana* causes about 20% infestation and has yellow flowers and blue fruit. Four other species cause the remaining 10% of infestations.

South America

In Colombia, three Mistletoes (*Phoradendron, Pthirusa and Psittacanthus*) have started to cause serious problems not only in cocoa but also in coffee, avocado and citrus.

Central America

In Costa Rica, 2 Mistletoes are a major pest on the Atlantic coast (*Oryctanthus* sp. and *Phoradendron piperoides*). In Trinidad, yet another Mistletoe species (*Struthanthus dichlortrianthus*) causes significant damage on a number of crops including cocoa.

Asia

In Malaysia, two species of Mistletoe have infested a large portion of cocoa trees in a clearly defined but substantial area near Tawau in the state of Sabah. One species, *Loranthus ferrugineus* has small leaves and the other, *Dendrophthoe constricta* has larger leaves.

BIOLOGY AND ECOLOGY

Mistletoe infestations can occur in all cocoa farm types, although heavy infestations are more common in poorly maintained farms with no or inadequate shade. Infested trees tend to occur in clusters, these groups are called pockets.

Brightly coloured Mistletoe flowers are usually pollinated by birds or bees. The resulting seeds have a sticky coating. Many different bird species will eat the fruits and the seeds pass very quickly through the gut of the birds. The seeds emerge unharmed and, because they are still sticky, the bird has great difficulty in removing it from its rear end. The bird will wipe its rear end along a branch and the seed then sticks to the branch. Cocoa pruning and harvesting equipment, together with squirrels and porcupines are also thought to spread the seeds of this parasitic weed. In some Mistletoe species, the sticky coating hardens when it is exposed to the air; in other Mistletoe species the action of the bird wiping its rear end along the branch pushes the seed into the grooves of the bark. The bark of the branch must be thin enough for the germinating root of the seed to penetrate the bark, so young branches are normally those that become infected. The seed will not germinate in shade. Mistletoes are able to photosynthesise to some extent and can produce some of their own nutrients, but most of their nutrients are taken from the cocoa or other host plant. The seedling root penetrates deeply into the sap stream of the branch, the nutrient and water supply to the rest of the branch is cut off and eventually the branch dies back from the tip. Mistletoes also have indirect harmful effects on cocoa in Ghana as their presence favours infestation by Mirids (*Sahlbergella singularis* and *Distantiella theobromae).*

PEST MANAGEMENT

Cultural control is so far the only method that is effective; chemicals are not effective, as it is impossible to apply them safely and efficiently. Good maintenance of top shade to prevent germination of Mistletoe seeds is a useful long-term measure, but manual pruning is still the best method for immediate results. Cutting-out/removal of Mistletoes is recommended every other year, but care must be taken to ensure removal of each Mistletoe plant. The recommended time is when the Mistletoe is in flower as this makes it easier to spot them in the cocoa canopy. Young Mistletoes are easier to remove as older plants have tough stems. If infestation is heavy within a cocoa farm then cutting-out yearly is recommended until the situation is under control. Pruning should always be carried out as soon as a Mistletoe plant is spotted, this should help to keep down the number of ripe fruits available for birds to spread.

A cutlass can be used in small young cocoa trees to cut-out Mistletoe plants as these are fairly accessible using a ladder. A pod-harvesting hook (a small sickle) tied securely to a long pole can be used as an alternative to a cutlass and is useful for cutting out young Mistletoes. A long-handled pruner is needed in taller older trees. Problems arise in very tall trees as it can be impossible to reach Mistletoe plants even with long-handled pruners. Some farmers have resorted to climbing the trees to cut out the plants but care should be taken, as the chance of accidents is very common. **Exercise 5** explains about pruning methods and **Exercise 3** creates an understanding of the importance of regular monitoring.

Mistletoe in cocoa, Cameroon. Photo J. Vos © CABI Bioscience

Stem Borers

Importance

There are three main insect genera that bore into cocoa stems and branches and may be very damaging. In Africa, *Eulophonotus myrmeleon* (Lepidoptera) is widespread and also attacks pecan (*Carya illinoinensis*), coffee (*Coffea* sp.) and cola (*Cola nitida*). In recent years, serious outbreaks due to *E. myrmeleon* have occurred in almost all the cocoa producing countries in West Africa. *Zeuzera coffeae* (Lepidoptera) attacks many other hosts apart from cocoa and is found in South East Asia and Papua New Guinea. In parts of Indonesia, stem borers are increasingly becoming a pest. See page 41 for distribution.

Pantorhytes species (Coleoptera) are found usually in the islands of New Guinea and the Solomons, although one species is found in Cape York Peninsula of Australia. Six *Pantorhytes* species are primary pests and at least eight others have been associated with stem boring damage of cocoa.

Other stem boring insects occur but these are of local or minor importance.

Description

The larvae attack stems that are from 1.5-20.0cm in diameter causing damage to seedlings and mature trees. The tunnel bored by the larva has a single entrance hole at its base and it runs length-ways inside the stem and is not normally longer than 30cms. The entrance hole is the same width as the tunnel.

Stem borer larva in length-ways tunnel inside stem, Cameroon. Photo J. Flood © CABI Bioscience

When the larva is active inside, a sticky sap dribbles down the bark causing a distinctive dark water stain. In thin stems the tunnel is simple but in larger stems several tunnels may start from one entrance hole. Stems of medium thickness may have side tunnels in the form of a loop. Tunnel entrances in cocoa taproots have been found as deep as 20cms below the soil. Sometimes the bark of the trunk and larger branches splits lengthways at a point not more than 30cms above the entrance hole. Such cracks are superficial but considerable amounts of sticky sap can escape.

Sticky sap exuding from cracked stem, Ghana. Photo G. Odour © CAB International

Attack by stem borers allows many diseases to gain entrance into the cocoa tree, such as *Phytophthora* species, which will cause extensive stem and trunk cankers and often lead to sudden wilt and rapid death. This process is worsened by successive prolonged wet seasons.

Biology & Ecology

The larvae of *Eulophonotus myrmeleon* bore into woody stems and branches and occasionally the roots of cocoa. Enormous damage can occur during high populations and dry weather. Larvae desert dry tunnels and bore new tunnels in moist wood, this leads to drying out of the new tunnels and the larvae move again and more stems are destroyed. The larval stage lasts about three months.

Pupation takes place at or close to the top end of the gallery, which the larva closes off by spinning about six frail cross-walls (septa). The larva interweaves wood particles into the bottom cross-wall and the gap between the bottom and second cross-wall is filled with fine silk webbing. Pupation takes about three weeks and shortly before emergence the pupa moves towards the entrance of the gallery and its lower body sticks out of the gallery entrance. Adults do not live for more than four days as they do not have mouthparts and are unable to feed. The adults mate within 24 hours of emerging from the pupa. Egg-laying begins within one hour of mating; each female lays about 500 eggs. The eggs are frequently laid in dead tissue and cankered wounds especially above petioles and pod stalks and hatch within eleven days.

Zeuzera coffeae adults are called leopard moths because of the pattern of dark bluish spots on a translucent white background on the forewings.

Adult Zeuzera coffeae, Malaysia. Photo © C. Prior

Sticky strings or groups of pale yellow eggs are laid on small stems and branches. No attempt is made to hide them in bark cracks. After about 10-11 days the eggs turn dark yellow-red before hatching. The larvae stay together and spin a communal web. From this web each larva lowers itself on silk threads. The threads are caught by the breeze and act as 'parachutes' and the larvae can be carried considerable distances. The death-rate is very high at this stage, but a larva lucky enough to land on a suitable host bores into the bark. Early tunnels may be formed in thin stems (petioles), which are later deserted for thicker stems. In cocoa the larvae tunnel up to 30cms along the centre of a branch and finally makes a cross tunnel before pupation. The pupa sticks out of the entrance of the cross tunnel before emergence.

Pantorhytes weevils lay their eggs in crevices in the bark especially at the jorquette and branch unions and later on the trunks and branches. In all species the eggs take an average of about 2 weeks to hatch. The range is between 7-33 days depending on many environmental factors.

Adult Pantorhytes batesi, Papua New Guinea. Photo © C. Prior

Larvae burrow (depending on species) to depths of between 1.0-2.5cm and feed in tunnels more or less parallel to the surface. The larvae take between 5 to 9 months to develop. Fresh frass at the entrance of the tunnel indicates the presence of a larva inside. The effect of many larvae feeding around the jorquette causes cracking of the stem leading to death of the tree. Affected trees may split at the jorquette after high winds. Ring-barking can occur. Larvae can even occur in pods when populations are high.

The pupation takes about 2 weeks. The adult reaches sexual maturity in about 11 weeks, with a range between 38 and 139 days. Adults are 15mm long, flightless and very long lived, up to 15 months in the field and have been known to live for at least 25 months in the laboratory.

Adults feed on young leaves, the veins on older leaves and on the bark of shoots up to six months old. Oval scars (about 1 x 0.5 cm) can be seen on pod husks and adults will also feed on cocoa flowers. During bright sunny weather in the mornings, the adults are usually found on the underside of leaves and the main fan branches in the outer canopy. During the heat of the day the adults move to the lower fan branches and as temperatures fall towards evening, they return to the outer canopy. **Exercises 10 and 11** help you understand (part of) the life-cycle and recognise feeding patterns of stem borers.

Biological control

The fungus *Beauveria bassiana* infects larvae of *Zeuzera coffeae*, but so far there have not been any field trials to test it as a biocontrol agent. In Java, larvae of *Z. coffeae* are parasitised by *Bracon zeuzerae* (Hymenoptera). In Malaysia, *Eulophonotus myrmeleon* larvae are parasitised by a *Glyptomorpha* (Hymenoptera). However, none of the many parasites and predators of *Pantorhytes* has shown any promise of providing natural control. The possibility of using ants (*Oecophylla* and *Anoplolepis* species) to reduce *Pantorhytes* larvae in Papua New Guinea and the Solomon Islands is promising. Live larvae are less likely to be found in trees foraged by the ants, but introduction of the ants to plantations has proved difficult and more studies are needed to find the best method for introduction and successful colonisation.

Other Hymenoptera parasites have been observed but no field trials have been carried out. Woodpeckers will frequently peck out borers.

Cultural control

Pruning of infested branches does reduce stem borer populations but is labour intensive (see **Exercise 5** for pruning methods). Hand picking of adults and removal of larvae using pieces of wire can achieve good results but it must start as soon as infestation is spotted. Also unfortunately this method can cause serious damage to the trees and its use should be strictly limited.

Planting of barrier crops such as dense stands of *Leucaena glauca*, taro or sweet potato or *Pueraria* species has also been suggested. The stands should be at least 15 m wide and established early for new plantings, removing alternative host plants is also recommended.

Chemical control

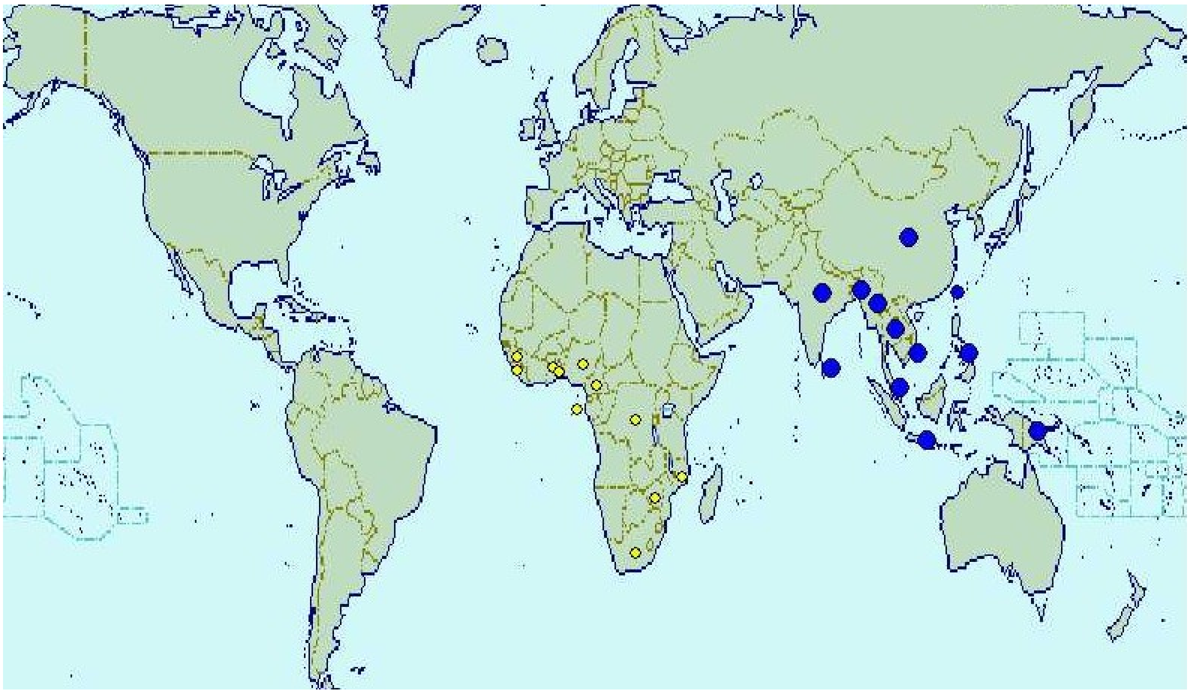
In Malaysia (Sabah), very high populations of *Zeuzera* were attributed to heavy spraying with pesticides currently banned in agriculture, such as DDT (WHO[1] Class II), destroying the parasites. Spraying stopped at the end of 1961 and towards the end of 1962 the populations of *Zeuzera* declined dramatically following the increase of parasitic Ichneumons (Hymenoptera). A similar situation occurred in Ghana with *Eulophonotus* and its parasites. Chemically laced bands, applied to trees when egg-laying is expected, have had some success but overall there are no effective chemical control methods. In Papua New Guinea, channel painting with dichlorvos (WHO Class Ib) was an effective but laborious practise. Nevertheless due to the selective application of this highly toxic pesticide, parasitoids were conserved. In Ghana, research is ongoing on applying a paste in borer holes containing aluminium phosphide, which is a precursor to the gas phosphine. Phosphine is highly toxic to humans (WHO Class I [2]), all insects, mites and rodents even though the method of recommended application reduces risk. Nevertheless, in IPM programmes, WHO Class I pesticides should be avoided at all costs, so unless there are lower toxicity formulations available, such practises cannot be recommended (see **Exercises 16 and 17** to appreciate the impact of pesticides on the sprayer as well as natural enemies).

Host plant resistance

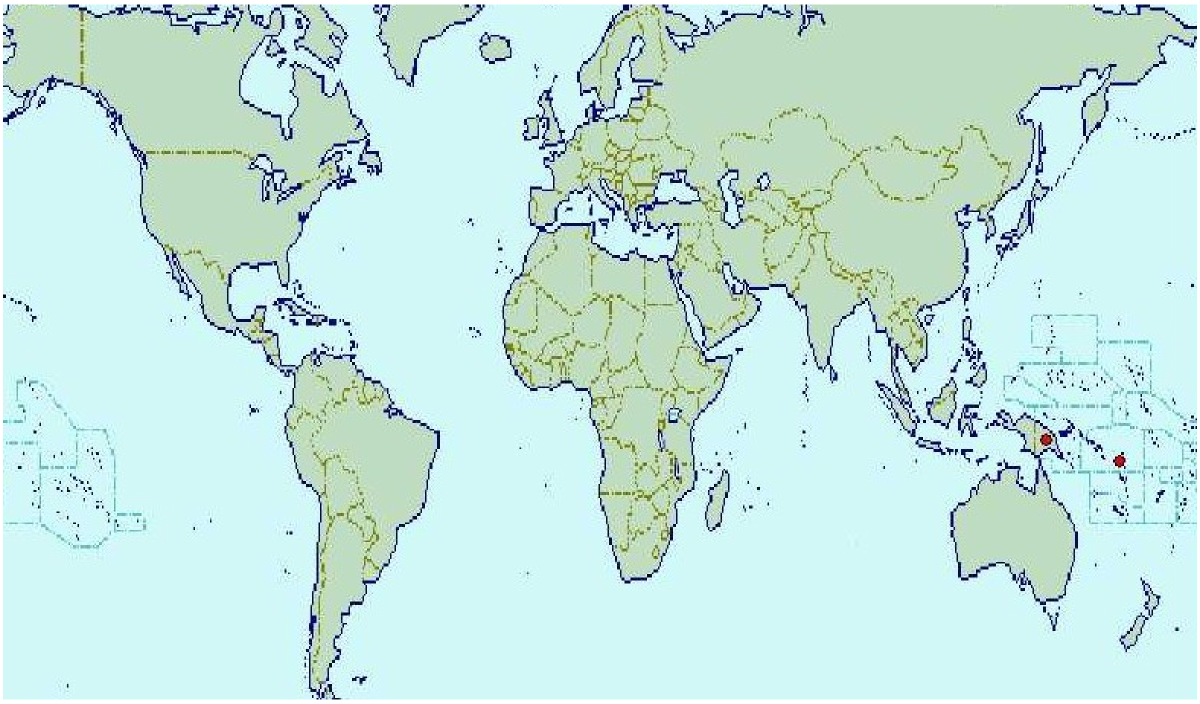
In the Solomon Islands, Amelonado and progeny of Na32 types appear to be less susceptible to damage by *Pantorhytes* larvae than Trinitario types. In Papua New Guinea, significant differences between Trinitario clones were shown in trials to assess the degree of damage caused by longicorn (*Glenea aluensis*) beetles. It is not yet known what factors influence these differences. Some physical characters may make the bark or trunk more or less attractive to female longicorns choosing a place to lay their eggs. The biochemical make-up of the different clones could make them more or less attractive.

[1] World Health Organisation (WHO) classification of pesticides according to acute toxicity, ranging from I (highly to extremely hazardous) to III (slightly hazardous) in addition to U (unlikely to present acute hazard in normal use). IPM programmes should avoid use of WHO Class I and II pesticides. Note that formulation can move active ingredients to a lower hazard classification.

[2] Full respirator protection should be used by all those handling this compound



In-country presence of Eulophonotus myrmeleon (yellow dots) and Zeuzera coffeae (blue dots) (source: Crop Protection Compendium 2002, CAB International)



In-country presence of Pantorhytes species (source: Crop Protection Compendium 2002, CAB International)

Termites or White Ants

Importance

Termite attack on living cocoa wood usually goes unnoticed until much damage has been done and the trees have wilted. Termites that make runs over the surface of the bark will also carry spores, especially those of one of the fungi that cause Black Pod (*Phytophthora palmivora* – see **Black Pod datasheet**). This fungus also causes cankers on the bark and stems. The chewing damage caused by termites also allows other wood-rotting fungi to enter. In addition, Termites will attack the shade trees causing the same type of damage as on cocoa. On the other hand, some termites play an important role in breaking down plant material (stems, leaves, etc.) and thereby facilitate nutrient recycling. They can also improve soil aeration and drainage through their tunnelling activities.

Termites on cocoa, Papua New Guinea.
Photo © C. Prior

Distribution & Description

Seventeen species of termite are of major importance in cocoa farms and are noted below, other species occur but are of limited local importance usually during dry periods or drought.
There are three families of termites that cause problems in cocoa around the world. The family Kalotermitidae [K] includes dry and damp-wood termites that are able to maintain themselves in cavities in wood and make nests that have no connection with the soil. Nests are small, there is a soldier caste and the nymphs carry out the work, as there are no workers.

Rhinotermitidae [R] are an underground species that mainly attack dead and decaying wood and only occasionally invade living tissue.

The Termitidae [T] are wood-eaters and mostly live underground or in mounds and four-fifths of all termites belong to this family.

A lack of taxonomic understanding has been a major constraint in the study and management of tropical termites. There is a high number of species and many of these are poorly or undescribed. There are very few specialists able to identify tropical termite species that may be of economic importance and this has resulted in a large number of incorrect, doubtful or incomplete identifications. Accurate information for farmers and extension personnel is very limited.

AFRICA		
Congo	*Cryptotermes havilandi [K]*	Will invade through dead wood and wounds in common with several other species.
Equatorial Guinea (Fernando Po now Bioko)	*Neotermes gestri [K]*	Common in older plantations, invades trunks and branches through untreated wounds and then spread down the branches and trunk. Attacked branches break off during storms and whole trees may become weakened and fall over.
Ghana	*Glyptotermes parvulus [K]* *Microcerotermes solidus [T]*	Found in dry and rotting branches, in wounds, in living stems and in very moist live branch wood. A soil-nesting species that builds shelter tubes and attacks branches through wounds.
Cote d'Ivoire	*Cryptotermes havilandi [K]* *Nasutitermes species [T]*	Attacks healthy wood and is not found in old stumps. A species is common in the south; it feeds on bark and old pods. It is soil nesting and builds tunnels up the tree from one pod to another.

Madagascar	*Bifiditermes madagascariensis [K]*	Attacks wood already damaged by xylophagous insects or fungi. The termites may burrow into the main stems of those cocoa trees that are growing poorly.
Nigeria	*Neotermes aburiensis [K]*	Often found in the dried parts of living trees and old wounds especially in old plantations. Termite colonies established in stem tissue that has been infected by a fungus-dieback caused by *Calonectria* can spread into healthy tissue but do not appear to spread the fungus infection.
	Macrotermes bellicosus [T]	This termite is a mound builder. Seedlings and basal chupons of mature trees are ring-barked. This starts at soil level and damage can spread upwards for 60cms. Damage has been seen as high as 5m. Most common where leaf litter or mulches have built up close to trunks or after earthling-up following coppicing. Usually first seen at the beginning of the rains.
	Pseudacanthotermes militaris [T]	This termite causes the same type of damage as *Macrotermes bellicosus*.
Sao Tome and Principe	*Neotermes gestri [K]*	As above.
	Microcerotermes theobromae [T]	A soil-nesting termite that builds shelter tubes up the trunk and attacks the branches through wounds. Damage can be severe especially in older and weaker trees.
West Africa	*Coptotermes sjostedti [R]*	This termite is widespread throughout West Africa in dead wood. Attacks in the trunks of old trees can spread to living tissues.
	Schedorhinotermes putorius [R]	This termite builds large and rough-textured runways of chewed wood. These connect the underground nests with dead wood on the tree. Sub-nests can be established in the dead wood.
	Macrotermes bellicosus [T]	Widespread.
SOUTH AMERICA		
Surinam	*Nasutitermes ephratae [T]*	The large brown carton nests of this termite have been found on the stems of young diseased cocoa trees. Healthy plants are not attacked. They are also found on coconut stems.
PACIFIC		
New Britain and Papua New Guinea	*Neotermes papua and other species [K]*	Several species attack cocoa through dead solid wood on the branches or through roots. The termites then attack the healthy wood and are usually well established before discovery. Weakened branches or trees can fall in wind or heavy rain. *Leucaena glauca* shade trees are also attacked by *N. papua*.
	Nasutitermes princeps [T]	Nests are found in healthy trees and cause primary attack.
Samoa	*Neotermes samoanus* *N. sarasini [K]*	These termites attack below the collar and burrow up through the trunk and heartwood to the branches.

Ecology

Termites attack cocoa trees in two different ways. Young plants in nurseries or the fields are attacked mostly in the collar area; the tap and other roots and the stem base. This usually happens in the dry season and, if the attacks are not noticed, the tree can be the victim of a severe and sudden wilt. The same type of damage occurs on chupons that are produced from the base of mature trees.

In mature trees the dry-wood termites attack injured and dying wood. Damp-wood termites damage living wood and these invade from wood in parts of the tree that have been damaged by other insects or disease.

Microtermes and *Ancistrotermes* species have underground nests and will attack plants by chewing into the roots and tunnelling up into the stem. They can continue through the collar area and spread upward inside the stem and branches. More commonly, the termites enter a wound higher up in the tree and spread downwards.

The underground tunnels leading out from nests can be as long as 50m. The area of land that one termite colony can exploit is extensive.

PEST MANAGEMENT

Management of termite infestation varies according to the type of termite and there are three general approaches (cultural, biological and chemical control), described below:

Termite damage of cocoa tree bark, Papua New Guinea. Photo © C. Prior

Cultural control

Deep ploughing or hand tilling breaks open underground nests and exposes termites to drying-out and predators. A traditional method for mound-building termites has been to break open the nest and remove the queen. Flooding nests washes away or drowns the termites. Burning straw suffocates and kills the colony.

Keeping plants healthy makes them less susceptible to attack (see **Growing a healthy crop** in Part I), clearing weeds removes competition for soil nutrients.

Removing plant debris from farms can reduce the potential termite food supply and lead to starvation of the colony. Please note that this could also lead to the termites attacking the crop as their alternative food supply has been removed!

Mulching either increases or decreases termite numbers depending on whether the mulch has termite-repelling properties. Different compositions of any mulch must be tested, as effectiveness will depend on the species of termite present locally. Various parts of plants that termites find poisonous or unpleasant have been mixed with mulches and scattered around plants. These have been successful on a small-scale but have not been tried on a large scale.

Wood ash heaped around trees is said to prevent termite infestation of coffee and date palm and to protect seedlings. It is mixed into nursery beds or applied as a top layer on the soil. The benefits of using ash to repel termites has been collected from farmers and could be a good subject for local validation using farmer participatory research methods.

Biological control

Ants are the greatest enemies of termites and under natural conditions limit their numbers. In Uganda a traditional practice of using dead animals, meat bones and sugarcane husks to poison *Macrotermes* mounds was used to develop baits for predatory ants and was tested for termite control in maize. The protein-based baits attracted significant numbers of ants and more nests established near maize plants, which reduced the termite damage and increased yield.

Various micro-organisms have been laboratory-tested as biological termite control agents. A fungus (*Metarhizium anisopliae*) has proved the best candidate. In the USA, a fungus has been developed into a commercial product for controlling termites in buildings in the USA, Brazil and Australia (Bio-Blast®).

A similar approach was tried successfully in Kenya against *Macrotermes* and *Ondotermes*. Control of *Cornitermes* has been achieved in South America pastures. In Kenya and Uganda, the fungus controlled termites in maize cropping systems.

The success of the fungus has had limitations because of application difficulties, mixing the formulated product with low doses of the insecticide imidacloprid (WHO[1] Class II) has had better results than using each agent alone. **Exercises 16 and 17** raise awareness of risks of spraying hazardous pesticides and impact on natural enemies.

Chemical control

Some controlled-release formulations of non-persistent insecticides (e.g. permethrin – WHO Class II, and deltamethrin – WHO Class II) can be used as barriers in the soil around roots. These are effective and long-lasting but are not cost-effective for the majority of small-holders. Home made botanicals from neem, wild tobacco and dried chilli have been used to control termites in the field and in storage warehouses. Such local practices are good subjects for validation through farmer participatory research.

[1] World Health Organisation (WHO) classification of pesticides according to acute toxicity, ranging from I (highly to extremely hazardous) to III (slightly hazardous) in addition to U (unlikely to present acute hazard in normal use). IPM programmes should avoid use of WHO Class I and II pesticides. Note that formulation can move active ingredients to a lower hazard classification.

Vascular Streak Dieback (VSD) – *Oncobasidium theobromae*

Importance

Vascular Streak Dieback (VSD) was described in the 1960s in Papua New Guinea and distinguished from the various dieback syndromes of cocoa induced by environmental factors and insects. It caused heavy losses in mature plantations and among seedlings planted in the vicinity of older cocoa.

The disease has since been found in most cocoa growing areas in South East Asia. There is strong evidence that the fungus evolved on an indigenous host, as yet unidentified, in South East Asia/Melanesia and transferred to cocoa introduced to the region. Thus, VSD is another example of a new encounter disease in cocoa.

Cocoa leaf yellowing, Papua New Guinea. Photo © J. Flood

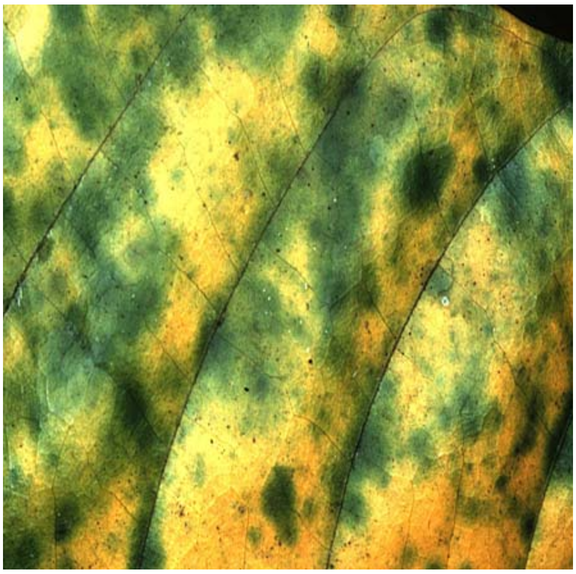
In Papua New Guinea, VSD is seen as being most damaging during the establishment phase of cocoa, when infection is likely to penetrate the main stem and kill the plants, whereas in Malaysia and Indonesia, the disease is also regarded as dangerous to mature trees. Seedlings that become infected before jorquetting (less than 10 months old) are the most susceptible to the disease. The younger the seedling is at the time of infection, the greater its chance of being killed.

In older trees, only the most susceptible clones are killed by infections beginning in outer branches. One Trinitario clone K1-102, selected for breeding for promising agronomic traits, before the VSD epidemic developed in Papua New Guinea, proved exceptionally susceptible and was completely destroyed by the disease. In mature trees in Malaysia, 4 to 29 infected branches per tree were seen per month, depending on the rainfall, whereas under nursery conditions disease incidence rose to 59% of the seedlings in the first 10 months after planting.

The fungus causes a very similar disease in avocado seedlings that were growing under heavily infected cocoa in Papua New Guinea in the late 1980s, however the disease has not been found in avocado outside Papua New Guinea. See page 49 for distribution.

Description

Infection always occurs through young flush leaves at a growing point with the fungus growing down the stem. Seedlings have only one growing point and are killed by the infection. After the jorquette is formed, the infection may progress into the main stem and kill the plant. Once trees are mature they have thousands of growing points, all of which can potentially be infected. The disease does not progress into the larger branches of mature trees except perhaps in the most susceptible material, within which it can spread to the trunk causing the tree to die. There are no visible symptoms during initial fungal growth within the plant.



Yellowing of cocoa leaves, Papua New Guinea. Photo © M. Holderness

However, the most characteristic initial symptom, which can easily be seen, is the yellowing (chlorosis) of one leaf, usually on the second or third flush behind the tip, with scattered green patches about 2 – 5 mm in diameter. This appears after a few weeks in young seedlings compared to 2-3 months in branches on mature trees.

Within a few days, this leaf is shed and adjacent

VSD brown streaking in split cocoa stem, Papua New Guinea. Photo © M. Holderness

leaves turn yellowish in the same way, are subsequently shed and this leaves a characteristic gap in the leaf architecture on infected branches. Very characteristic symptoms are the blackening of the vascular bundles of the remaining leaf scar, giving three black spots. Die-back of the growing tips is also characteristic of the disease (hence name). Brown streaking is visible when stems are split.

Blackened vascular bundles on a leaf scar showing typical three black spots, Papua New Guinea. Photo © J. Flood

Eventually, leaf fall occurs up until the growing tip of the flush subsequently dies, followed by the rest of the seedling or branch. The fungus may spread internally to other branches or the trunk. If the trunk is infected, the tree usually dies. The disease development from the initial infection to death of a growing tip takes usually 5 months on a mature tree, but only a few weeks in a young seedling. The disease often peaks 3 to 5 months after high seasonal rainfall.

When an infected leaf falls during wet weather, fungal strands may emerge from the leaf scar and develop into a spore forming body, which is evident as a white, velvety coating over the leaf scar and adjacent bark. In dry weather, leaf scars quickly become hardened and this prevents the emergence of the fungus.

BIOLOGY & ECOLOGY

Formation of spores and sporulation occurs mainly at night, after the spore producing bodies have been wet by afternoon rain. Onset of darkness is also a stimulus for sporulation. Sporulation occurs for an average of 10 days on attached branches, on detached branches only for 2 days. Extended periods of leaf wetness are required for infection and even longer periods of bark wetness are required for spore body formation and sporulation.

Spore producing body of VSD fungus covering a cocoa leaf scar, Papua New Guinea. Photo © M. Holderness

Spores are dispersed by wind and rapidly destroyed by sunlight. Therefore, effective spore dispersal is probably limited to the few hours of darkness and high humidity following their discharge. Spore dispersal is probably further limited by the dense canopy of cocoa and shade trees in plantations. As a result, disease spread from older, infected cocoa into adjacent younger, healthy populations, occurs along a steep gradient, with very few primary infections occurring beyond 80 m from diseased cocoa. The

VSD fungus can colonise the vascular system of pods: this has some potential importance for quarantine, with the possibility of transmitting the disease via infected pods distributed for seed. However no infection was ever detected in seed and the possibility for seed transmission has been discounted. Similarly, infected budwood does not graft and it is highly unlikely that infection will occur.

The fungal spores have no dormancy and free water is required for germination and infection. Spores germinate within 30 min if leaves remain wet, but do not grow further once the water evaporates. It appears that, as with sporulation, infection requires very particular conditions that are difficult to simulate in the laboratory. In tests, 3-week-old seedlings were inoculated which caused symptoms after 6-9 weeks. Inoculation of 6-month-old seedlings caused symptoms after 10-12 weeks. Peaks in disease occurrence in the field are often observed to occur 3-5 months after seasonal rainfall peaks. The fungus penetrates young (up to 10 cm long), unhardened leaves. After penetration, the branch or seedling grows for another 3-5 months (two or three growth flushes) before the fungus has ramified sufficiently to induce disease symptoms in the penetrated leaves. This incubation period explains the occurrence of the first symptoms on the second or third flush behind the growing tip.

Infection rate is closely related to rainfall incidence and hence the disease is most common in wetter regions. Experience in Papua New Guinea indicates that 2500 mm rainfall per annum is required for VSD to be destructive.

PEST MANAGEMENT

Host plant resistance

In Papua New Guinea, during the VSD epidemic in the 1960s, a natural selection took place, only trees with some resistance to the disease survived. Growers tended to replant with seedlings derived from survivors of the epidemic, which were likely to be more resistant. Excellent resistance now occurs in most cocoa types, except for Amelonado, which appears rather susceptible. Resistance has remained stable for 30 years in Papua New Guinea.

Much fully resistant material is now available in many of the affected countries in the region and its widespread planting has reduced the disease to minor importance under most planting conditions. The resistance is likely to be partial, as resistant varieties still become infected, but there are fewer infections per tree, the pathogen grows more slowly and sporulates rarely. Also, infections do not spread from lateral into main branches.

Cultural control

Healthy seedling raising

Seedlings should be raised well away from infected areas to ensure that stock transplanted into the field is initially disease-free. Nurseries should be protected by growing seedlings in a shade house or under a plastic shelter, which keeps the leaves dry for all but a few hours after watering. Covering nurseries with roofs also stop spores falling on the young cocoa seedlings.

Sanitation

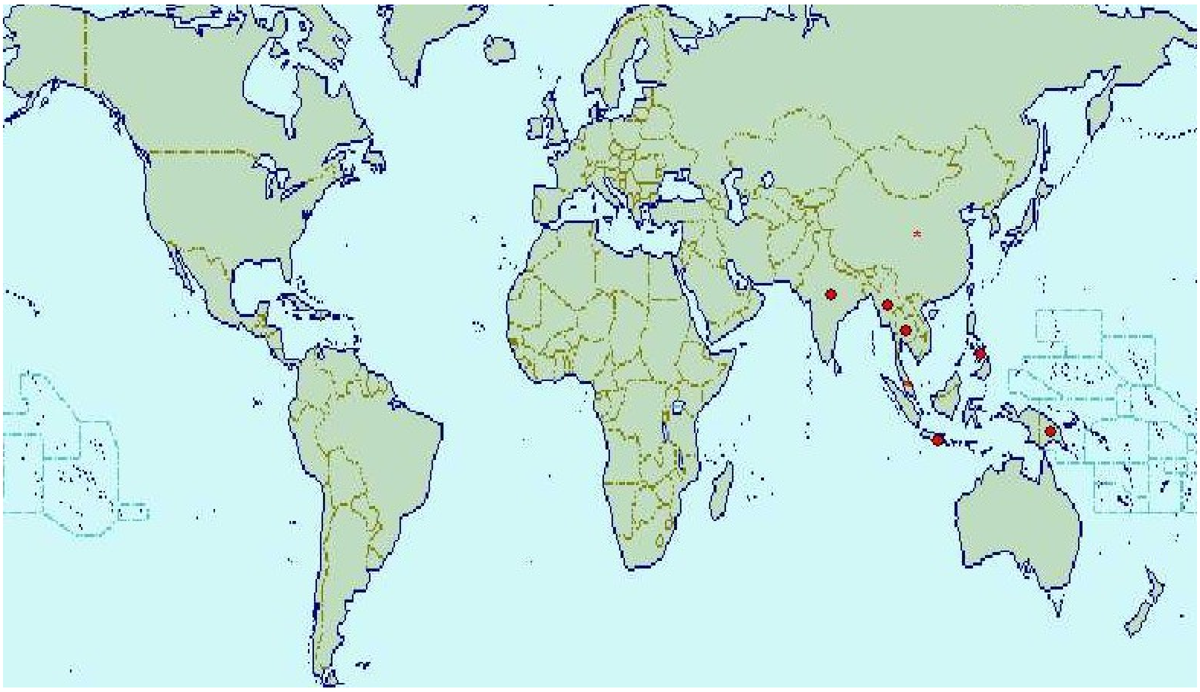
Monthly inspection and pruning of infected stems with the first sign of yellowing has been practised in Papua New Guinea and Malaysia. (See **Exercise 3** to learn about systematic monitoring in cocoa and **Exercise 5** for pruning methods.) Pruning prevents the disease from spreading within individual plants and also lowers the inoculum level. Pruning can be effective when combined with moderate levels of resistance, but it is often ineffective when inoculum levels are high and planting materials susceptible. Pruning should be conducted to 30cm below discoloured veins (the area with brown streaks when the stem is split) although in practice this may not always be possible in young seedlings. In older trees, pruning can result in complete recovery, but may also lead to an uneven stand. In Java, incidence of tree infection was kept below 1 % in mature stands when every two weeks over a period of 2 years, trained teams detected and pruned out infected branches.

Structural pruning

Opening up the canopy by pruning to increase air circulation and hence reduce the humidity is also crucial as that can help avoid spore formation, sporulation and infection.

Phytosanitary measures

Whole plants or cuttings from areas infested with VSD should not be used. When clonal material is required, it should be supplied as budwood from disease-free areas where possible. Budwood from plants grown in infested areas should be sent to an Intermediate Quarantine Station in a disease-free area and budded onto rootstocks raised from seed collected from a disease-free area. An extremely strict quarantine procedure instituted in Papua New Guinea in the 1970s enabled successful in-country transfer of superior clones from the infected cocoa area in New Britain to the



In-country presence of Vascular Streak Dieback (source: Crop Protection Compendium 2002, CAB International)

disease-free islands of the North Solomons and New Ireland.

Chemical control

Protective fungicides are unlikely to be effective against this disease as infection occurs during wet weather when protective chemicals will tend to be washed from the trees. Also, infection occurs into rapidly expanding leaves. Chemical control has therefore been investigated primarily to protect young seedlings in the first year of field planting when disease pressure is high.

Some triazole fungicides have shown promise, for example as soil drenches with the systemic fungicides triadimefon (WHO[1] class III) or triadimenol (WHO class III) in Malaysia. Seeds are not known to transmit the disease, but a precautionary dip in a triazole fungicide could be used. Tebuconazole (WHO Class III) was the most effective systemic triazole fungicide tested as monthly foliar sprays in Papua New Guinea, but proved to have a growth hormonal effect in seedlings.

Fungicides used for systemic protection are likely to be too expensive for smallholder growers and curative sprays are not effective. (Also see **Exercise 16** to understand risks of spraying hazardous pesticides.)

[1]World Health Organisation (WHO) classification of pesticides according to acute toxicity, ranging from I (highly to extremely hazardous) to III (slightly hazardous) in addition to U (unlikely to present acute hazard in normal use). IPM programmes should avoid use of WHO Class I and II pesticides. Note that formulation can move active ingredients to a lower hazard classification.

Witches' Broom – *Crinipellis perniciosa*

Importance

Crinipellis perniciosa evolved with cocoa in the forests of the Upper Amazon, from where it has invaded the cocoa growing regions of Latin America. It is now to be found in Ecuador, Brazil, Peru, Bolivia, Colombia, Venezuela, Guyana, Surinam, Trinidad, Tobago, Grenada and Panama. See page 53 for distribution.

Its introduction into a cocoa growing area can be devastating. Its arrival in 1989 in Bahia, Brazil, led to a reduction in production from 400,000 tons to 150,000 tons within 10 years. Witches' Broom disease in cocoa can cause average losses of between 30 and 100 %, depending on the (non-) application of cultural control measures. Globally, losses to Witches' Broom account for 21 % of the cocoa crop loss to disease.

Fruiting body of the Witches' Broom fungus, Bolivia. Photo H. Evans © CABI Bioscience

Ecology

Witches' Broom is indigenous to the Upper Amazon, where as well as infecting wild cocoa it is also known to infect other *Theobroma* and *Herrania* species, such as *Theobroma grandiflorum* (cupu acu). There are two distinct phases in the disease cycle of the fungus *Crinipellis perniciosa*. First the pathogen invades young growing tissue, as a parasite growing between the plant cells. Then the surrounding plant cells become enlarged and increase in number. During the second, saprophytic, stage, the affected cocoa tissue dies and the fungus invades the dead cells. In due course, when conditions are favourable, spore-producing fruitbodies are formed.

The time taken for symptoms to appear can vary considerably (3-14 weeks), but is usually about 5-6 weeks after infection. The fungus appears to cause a hormonal imbalance, so that host cells become larger than usual, and the tissues become swollen. On vegetative shoots, apical dominance is lost, many side buds develop into shoots, and a broom is formed.

Witches' Broom on green cocoa shoots, Ecuador. Photo H. Evans © CABI Bioscience

In green brooms, the first phase of the fungus colonises the various tissues of the broom to different extents. Brooms usually remain green for a relatively short period. They begin to dry out from the shoot tips, turn brown in about 5-6 weeks and then become progressively dry.

The broom becomes extensively colonized by the saprophytic phase, which usually has a dormant (induction) period of 2 - 16 months before forming fruit bodies (even if the brooms are transferred to favourable regimes of wetting and drying).

Brown brooms, Ecuador. Photo H. Evans
© CABI Bioscience

Production of Inoculum

Crinipellis perniciosa evolved with cocoa and as such, its life cycle is synchronised with that of its host. The environmental and host factors that influence disease development are complex. The primary driving factor in Witches' Broom disease is water, with the production of fruiting bodies on brooms dependant on periods of wet and dry. Most brooms form fruiting bodies with moderate periods of wetness (8-16 hours), less than four and more than 20 hours inhibits fruiting body formation. Favourable mean daily temperatures are 20-30ºC. Brooms in the canopy can maintain production of spores for over 2 years. The environmental conditions that promote spore production and release are the same that promote cocoa growth, thus synchronising spore release with the presence of new flushes that represent new infection sites.

Spores are released at night, provided that the humidity is high enough (80% RH or above) and that temperatures range between 10-30ºC. Each fruiting body can produce millions of spores. The spores are spread locally by movement of water and air and over larger distances by winds. In Ecuador, it was estimated that under favourable conditions spores could be dispersed over a range of up to 150 km.

Infection

C. perniciosa only infects actively growing tissues, including shoots, flowers and pods. Hardened host tissue cannot be penetrated. Young cocoa flushes, particularly the developing buds, are most susceptible.

The susceptibility of pods changes with time. The period of susceptibility is about 12-15 weeks from pod set. Infection is also influenced by environmental factors of which the most important appears to be water films on susceptible tissues. The spores require free water for germination and infection of the host. The relationship between infection and shade is, as yet not clear.

Young cocoa flush with brooms, Bolivia.
Photo H. Evans © CABI Bioscience

PEST MANAGEMENT

Cultural Control

Phytosanitation is based on the concept that by removing infected plant parts, the production of inoculum will be reduced to low levels. This approach has remained the basis of Witches' Broom control since the beginning of the twentieth century. In practice, phytosanitation entails the pruning of brooms. Diseased pods generally contribute little inoculum and can be removed during harvesting. Essentially the frequency of pruning depends on the long (induction) period for fungal fruiting bodies to develop on brooms. There is generally only one disease cycle per rainy season, and pruning could be done during the dry season when brooms are more visible and before fungal fruiting bodies start producing spores. The exception to this being Bahia, in Brazil, which has no defined dry season. Phytosanitation should involve cutting off vegetative brooms at least 15-20 cm below the point of infection. Diseased material on cushions should be carefully removed by cutting it off as close as possible to the bark. Diseased pods together with their peduncles should be removed whenever healthy pods are harvested. The removal must be as thorough as possible to have any chance of success.

Elimination of the diseased tissues from the plantation after pruning is necessary in some circumstances. The practice is recommended if annual phytosanitation has lapsed for more than one year, because older brooms on the ground could produce fungal fruiting bodies within a few days of rain. Where phytosanitation is regular, pruned tissues can be left scattered on the ground in the plantation as long as leaf-litter is placed over the diseased material. If structural pruning is done (see **Exercise 5** for pruning methods), any infected branches should be cut into small pieces and spread on the ground so that it is all in contact with cocoa leaf litter, which will speed up decomposition. Phytosanitation should not be attempted where it is not possible to complete the primary removal at the recommended time. Phytosanitation is most effective where it is routinely practised every year, so that numbers of second-year brooms are kept to a minimum.

Research has shown that careful broom removal reduces disease incidence dramatically in some, but not all, situations. Successful phytosanitation is in vain when inoculum from adjacent or nearby farms reaches the sanitized area in sufficient quantity. In discontinuous plantings (farms separated by at least several hundred metres) where phytosanitation is not practised in the neighbouring cocoa, the chances of achieving a successful reduction in pod loss are moderate.

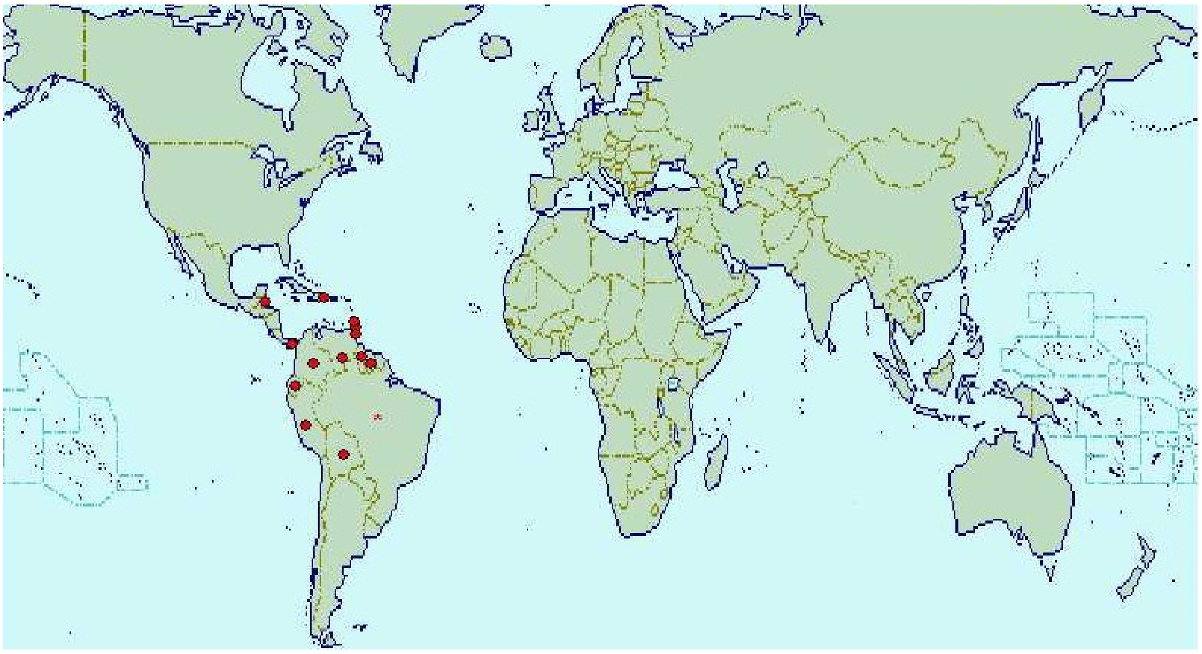
Rehabilitation of Witches' Broom-infected plantations needs to be associated with a commitment to regular maintenance and phytosanitation pruning to maintain any improvement in yield. Cocoa should receive a structural pruning to reduce height and improve access to the canopy, followed by a phytosanitation pruning (see **Exercise 5**). Cocoa that lacks any side branches below 3-4 m, needs to be cut-off at between 0.5 and 1.5 m from the ground to stimulate chupons for the regeneration of the tree or to be bud-grafted with basal chupons. Grafting is being adopted in Brazil to rejuvenate Witches' Broom infected farms. Young cocoa trees that are exceptionally heavily attacked by Witches' Broom should be removed, destroyed and replaced by better material. In cases where the potential production of the existing cocoa is generally low, interplanting with improved seedlings followed by gradual removal of the old trees ('Turrialba' Method – see **Cocoa raising and rehabilitation** in Part I) might be preferable to instant rehabilitation.

These treatments are intended to increase pod production in the medium term, but will immediately reduce pod production as they involve the removal of either part or most of the fruit-bearing wood and/or the leaf area of the canopy. Preliminary investigations indicate that about 1-3 years are required for the two recommended rehabilitation pruning methods. If carefully managed, the 'Turrialba' method involves no appreciable yield loss.

Host plant resistance

It is widely recognized that improvements in long-term control of Witches' Broom can best be achieved by the use of resistant cocoa planting material. The development of such material is urgently required. The possibility of selecting for resistance was considered in the earliest reports of Witches' Broom and this approach was also used in Trinidad after extensive screening within the Trinitario population failed to detect any highly resistant material. Some clones, such as ICS 95, showed considerable resistance.

In the 1930s, a search for immune or resistant trees was made in South America in several expeditions. Three clones, Scavina 6, Scavina 12 and IMC 67, contributed a high degree of Witches' Broom resistance to progeny bred from them to improve bean size. These Trinidad Selected Hybrids have been widely planted in Trinidad since the late 1950s and appear to have been a major factor in reducing Witches' Broom there to its present relatively low levels. However, when apparently resistant selections of Scavina 6 were sent to Ecuador they became severely infected, probably because they encountered a more aggressive strain of the fungus. Breeding for Witches' Broom resistance was subsequently started in other countries, often following further searches for germplasm. While there are selections with some resistance to isolates of the Witches' Broom fungus in Brazil, Trinidad and Venezuela, the level of resistance in commercial cocoa is still less than satisfactory. In other countries such as Bolivia, Colombia and Ecuador, which have more virulent isolates, the situation is even worse. Witches' Broom is currently confined to Latin America, however it needs to be noted that all material in West Africa is susceptible to this disease and hence strict quarantine is essential to mitigate against the threat of introduction.



In-country presence of Witches' Broom (source: Crop Protection Compendium 2002, CAB International)

Biological Control

Within cocoa plantations there is a natural biological control of the Witches' Broom fungus in fallen brooms by other micro-organisms, some of which might be exploited either by manipulating the environment of the brooms or by using the antibiotic effect of substances they produce. In Peru, field studies have been carried out with *Clonostachys rosea* and *Trichoderma* spp. to control Witches' Broom. The only commercially available biocontrol agent for Witches' Broom is *Trichoderma stromaticum*. It is marketed as Tricovab by the Brazilian Ministry of Agriculture, and currently in use in Bahia state (Brazil) for combating Witches' Broom. This functions through mycoparasitism to reduce inoculum pressure in the field.

Chemical Control

Commercial application of fungicides for the control of Witches' Broom has not been adopted in any cocoa-producing country, because increases in production have not given sufficient economic return to motivate farmers into applying the treatments. In Brazil, copper compounds are recommended, however it is not always cost-effective (see **Exercise 21** for an economic analysis). The systemic fungicide tebuconazole (WHO[1] Class III) is considered to be effective as well, but again the cost-benefit ratio will depend on factors such as cocoa price, cost of labour, etc.

[1] World Health Organisation (WHO) classification of pesticides according to acute toxicity, ranging from I (highly to extremely hazardous) to III (slightly hazardous) in addition to U (unlikely to present acute hazard in normal use). IPM programmes should avoid use of WHO Class I and II pesticides. Note that formulation can move active ingredients to a lower hazard classification.

PART III

DISCOVERY BASED EXERCISES

Farmers observing their graft, Cameroon. Photo J. Vos © CABI Bioscience

EXERCISE 1: Appraisal of cocoa production

OBJECTIVES

- To obtain information on farmers' cocoa management practises and identify the major problems encountered by farmers
- To prepare a seasonal calendar as a guideline for farmer field school study plots

MATERIALS

- Cocoa farms
- Flip charts
- Colour markers
- Notebooks
- Pens

PROCEDURE

In the meeting place

Facilitate a general interactive discussion session to discuss the kind of information that needs to be gathered from cocoa farmers. Work through the entire cocoa production cycle, including land preparation, seedling management, planting, flowering stage, pod forming stage, harvesting, fermenting, etc. At each step, decide what kind of information needs to be gathered from cocoa farmers, in terms of production constraints and the management practices associated with each stage of the crop, including pest and disease management (e.g. spraying, cultural controls), pruning practices, fertilisation practices, post harvest practices, etc.

Visiting cocoa farm, Peru. Photo source unknown.

In the farm

In small groups of 4-6 participants, visit different cocoa farms. Discuss farmers' practices and problems with each farmer according to the agreed information needs. Visit the fields to observe and verify/understand some of the problems and local names that are mentioned by farmers.

Back in the meeting place

Each small group prepares posters to present their findings to the rest of the group. After the discussions, develop a seasonal calendar, which is a record of crop growth and development stages plus, per stage, what is done, by when, by whom and for what reason. This becomes a guideline for the farmers' practice treatment in comparative experiments to test alternative, IPM management options in a field school set-up.

Cocoa cropping calendar, Nigeria. Photo J. Gockowski © IITA

GUIDE QUESTIONS FOR ANALYSIS

1. What do farmers see as the main constraints to cocoa production?
2. At what stage(s) of the cropping season is each constraint important?
3. What options do farmers perceive they currently have to overcome these constraints? Are there other IPM options available?
4. Which of the constraints could be addressed in a farmer field school programme? How?

EXERCISE 2: Monitoring cocoa fields

OBJECTIVES

To understand the importance of field monitoring

MATERIALS

- Polythene sheets
- Vials
- Polythene bags
- Hand lens
- Cocoa fields (preferably unsprayed)
- Flip charts
- Colour pens
- Mosquito spray can

PROCEDURE

In small groups, visit different cocoa fields (preferably those that haven't been sprayed recently) and make observations on insects, diseased leaves, branches, pods etc that are known or can be recognised by the participants.

In each field, each group selects and tags one or more cocoa trees. Each tagged tree is observed systematically through detailed observations of main and side branches (up until as high one can reach).

Spread a polythene sheet on the ground below the tree. Beat or shake tree stems so that the insects, diseased pods, and leaves fall on the sheet. Spray with the mosquito spray into the canopy to knock-down insects that can't be shaken off the tree. Gather the polythene sheet carefully and observe its content: how many different types of insects are found, which of these are known as pests, how many pods and leaves are found and why did they drop off the tree?

To record the results, draw a large picture of the cocoa tree in the correct colours and draw the major pests and other constraints that were observed. Present the results per group.

During the discussions, establish the local names of insects and diseases observed and any differences between the different fields. Differentiate as much as possible the various insect pests from the natural enemies (farmers' friends). Arrive at a consensus on why cocoa fields should be observed.

GUIDE QUESTIONS FOR ANALYSIS

1. Which insects were found and what are the local names for these?
2. Can you differentiate those insects that are pest insects and those that are natural enemies ('friends of the farmers')? If not, please introduce the concept of Insect Zoo (Exercises 9, 10, 11).
3. Was there a difference in results between the various fields? Why (/why not) and what can we learn from this observation?
4. Is there a need to observe cocoa fields regularly? Why (/why not)?

Farmer Field School, Cameroon. Photo J. Vos © CABI Bioscience

EXERCISE 3: Agro-Ecosystem Analysis (AESA) in cocoa

OBJECTIVES

- Analyse the field situation by making observations, drawing findings and discussing potential management actions needed
- Study the cocoa agro-ecosystem for informed decision making
- Understand the various interactions that occur amongst the components in the cocoa ecosystem and demonstrate their balance

MATERIALS

- Cocoa field
- Vials
- Polythene bags
- Alcohol
- Cotton wool
- Sweep nets
- Hand lenses
- Notebooks, pencils, sharpeners and erasers, colour markers and crayons
- Poster paper (flip charts/newsprint) and markers
- Wooden backing board and masking tape
- Ruler and tape measure
- Cutlass

PROCEDURE

Agro-ecosystem observation

The FFS learning field typically has 2 plots. One treatment is the common farmers' practice in the area, following a locally made cocoa cropping calendar (see Exercise 1: Appraisal of cocoa production) and the other one is the IPM practice, where decisions are made about crop management based on the Agro-Ecosystem Analysis (AESA). AESA data are also collected from the various treatments (e.g. IPM versus Farmers' Practice) to learn about the impacts of those treatments.

Early in the morning (about 7 a.m.), the participants enter the FFS learning fields[1] in groups of 4 to 6. Each group selects one person to record all data (recording can be rotated amongst group members). Each group should move diagonally across the field and select and tag at least 5 - 10 cocoa trees for agronomic observations (these trees will be observed for agronomic characteristics throughout the field school). Each group also chooses 5 - 10 trees randomly for pest observations.

For each randomly selected cocoa tree:

- Carefully observe and count all insects you can find, and whether they are a pest or a beneficial. Collect any insects that you do not recognise in the vials or in plastic bags. Take them back to the meeting place to see if any of the other groups can help you.

- Carefully observe 5 leaves and pods (if available) on each of these branches and the branches themselves, recording disease or other symptoms. Observe and record how many of the leaves and pods are diseased. If you recognise the diseases, record them. If you don't recognise them, collect

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[1]It is best when each working group makes observations in both IPM and non-IPM (farmers' practices) plots. Alternatively, few groups can make observations in IPM plots and few groups in non-IPM plots.

them in vials and take them back to the meeting place. If ladders are available, climb into the tree to observe insects and diseases in the canopy. Look for signs of mirid damage on side branches.

- Count the number of trees where major pests and diseases are found.

- Record the number and species of any weeds on or around the tree. If you are not sure whether a plant is a weed, collect it in a polythene bag, and take it back to the meeting place. The other groups may be able to help you decide.

On each of the tagged cocoa trees:

- Record the number of flower clusters on the tree trunk. Also count the number of buds without flowers. Count the number of cherelles and pods (unripe and mature).

- Record estimated shade coverage (heavy, medium, light or unshaded) and average spacing of cocoa tree to other cocoa trees

- Record the average % of flowering, average number of flower clusters, average number of cherelles, average number of unripe pods, average number of mature pods, average number of chupons on the main branch, estimated canopy diameter, tree trunk circumference, average number of main branches, average height of branching, ground cover (leave litter, bare and other).

- Record the general condition of the plant (Healthy, Moderately Healthy, Weak).

- Record the soil moisture levels (High, Medium, Low). Check whether there are signs of soil erosion. What is the health of the soil (structure, organic matter)?

- Record the weather conditions at the time you make your observations.

It is advisable to also do a rapid field walk per plot to check for any unnoticed problems.

Drawing the Agro-Ecosystem, Cameroon. Photo J. Gockowski © IITA

Agro-ecosystem drawing

In a shaded area close to the field, all the observations on the field were drawn on flip chart paper. The plant is drawn at its present state of growth, with the sun or clouds symbolising weather conditions.

Design of agro-ecosystem analysis presentation

Group name: (you can draw) **Type of plot**: IPM or FP

Date: **AESA No:**

General information	***Agronomic data***
• Tree varieties: • Estimated age of trees: • Estimated shade coverage (heavy, medium, light or unshaded): • Average spacing of cocoa tree to other cocoa trees:	• Average % of flowering: • Average number of flower clusters: • Average number of cherelles: • Average number of unripe pods: • Average number of mature pods: • Average number of chupons on the main branch: • Estimated canopy diameter: • Tree circumference: • Average number of main branches: • Average height of branching: • Ground cover (leave litter, bare and other): • Soil moisture :

Weather (Draw the weather at the time when you made your observation)

Left of the tree	***Draw one large picture of cocoa tree***	***Right of the tree***
Draw the insects pests and the diseases symptoms found and indicate the number or abundance	At the base of the plant draw the weeds found and indicate the number and the species.	Draw the natural enemies found and indicate the number or abundance

Analysis

Observations	***Possible Causes***	***Group recommendations***

Agro-ecosystem analysis

Comparisons are made between numbers and types of pests, natural enemies and growing stage of the plant. Conclusions are drawn about the overall situation at present compared to the previous AESA. Observations of specific problem areas are listed in the AESA drawing with the possible causes.

Agro-ecosystem decision making

GUIDE QUESTIONS FOR DECISION-MAKING

The final stage of the AESA is the decision-making. Discuss in the group what management decisions to take. For example, given the relative pest and natural enemy populations, diseases levels, do we need to spray or are there other management options?

If you do need to do something, how and when and what will be the impact on the agro-ecosystem. E.g. if you opt to spray a pesticide, what chemical should you use? Is it necessary to spray the whole field? Is it necessary to spray the whole plant? What will happen to the natural enemies if you spray? And what knock-on effect would you expect if natural enemies would be killed by spraying?

AESA drawing with Observations, Causes and Recommendations, Cameroon. Photo J. Gockowski © IITA

What is the condition of the soil? What is the structure of the soil? If it is poor, can we improve it? Do we need to take measures against soil erosion? If so, what? Etc.

The action decisions of the small group can include:

- There is a balance in the relationship of natural enemies to pests so there is no need to spray
- We need to make "insect zoo"[2] to understand how these natural enemies control these pests.
- The field is clean so no need to weed it.
- The soil humidity is enough for normal growing of plants.
- We will continue to observe our field

Such group recommendations are filled into the decision-making portion under group recommendations in the AESA drawing.

A representative of each small group presents its findings and conclusions to the whole group for further discussion, questioning and refinement. Sometimes, the decision made by a group is modified or rejected by the plenary. A consensus needs to be reached as to what will be done and when, if any pest control measures or other crop management operations (weeding, fertilising, etc.) are necessary.

HOW CAN AESA BE USED?

One can't answer all questions that arise straight away. In a way, one can use the AESA to identify topics the field school needs to study or to give ideas on which IPM/ICM methods you would like to try out.

[2]The objective of this experiment is to help farmers to observe and understand the insects-crop relationships, the insect pest status and gauge the relative strength of natural controls.

EXERCISE 4: Top-grafting on chupons of mature trees

Top grafting of improved cocoa tree stock can be done using existing super trees in farmers' fields or from budwood gardens of improved materials developed by research institutions. The technique provides a means of improving tree stocks by farmers themselves.

OBJECTIVE

To practise top-grafting of cocoa for rehabilitation and introduction of resistant material in existing cocoa farms

MATERIALS

- Sharp knife (special grafting knives are used professionally, but a well sharpened kitchen knife can be used too) and pruning shears
- Sharpening stone
- Cotton thread or other organic twine (raffia palm)
- 75 g fungicide (benomyl[3])
- 50 cl alcohol
- Chupons of non-productive trees as recipients of improved material
- Grafting material of same diameter as chupon
- Clear plastic bags
- 2 plastic pails (5 litre)
- Clean water
- Cotton balls

PROCEDURE

In one pail, dilute alcohol with water 50:50 and dip all cutting tools in this diluted alcohol before and regularly during the grafting process. Also disinfect hands using the diluted alcohol. Identify the improved tree (super tree) that is to deliver scions. Collect scions for grafting from the new growth flushes in the top of the tree (fan branches). Using a pair of pruning shears, cut scions with a minimum of 2, but preferably 3 or 4 "eyes" (i.e. leaf axils). Eliminate all leaves from the cutting.

Identify the chupon of healthy but non-productive cocoa trees for replacement with super scions. Such chupons should be 3 to 4 months old with bark of a generally light brown colour. Cut the chupon horizontally in the area of light brown-greenish bark. Apply diluted alcohol to the cut area of the rootstock to eliminate possible pathogens on the rootstock.

In the second pail, prepare a solution of 2 teaspoons of fungicide and 50 ml of clean water. Dip the scions in this solution and let them dry. Once the scions are dry, match them to a rootstock that has the same diameter. Use the sharp knife to make a well tapered V-cut on the scion.

Slit the rootstock the same length as the V-cut on the scion. Remove all leaves from the rootstock. Insert the scion into the rootstock ensuring that all the bud eyes are exposed and that the cambium of both rootstock and scion are in firm contact. With organic thread, secure union making sure that there are no gaps between the scion and the rootstock. It is best to wrap from the base upwards and then to cover the scion completely with a plastic bag.

Monitor the grafts for 3 weeks. Regularly check the rootstock for budding and remove them. Once the scion has started to sprout, remove the plastic to avoid disease infection. Also remove the organic wrapping. Once the graft is well established, after about 6 months, cut the parent tree down for the graft to take over. The graft can be expected to start producing cocoa pods as early as 18 months after grafting.

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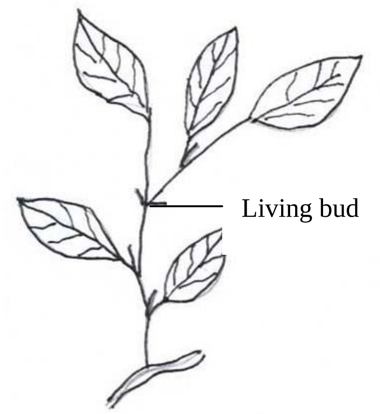
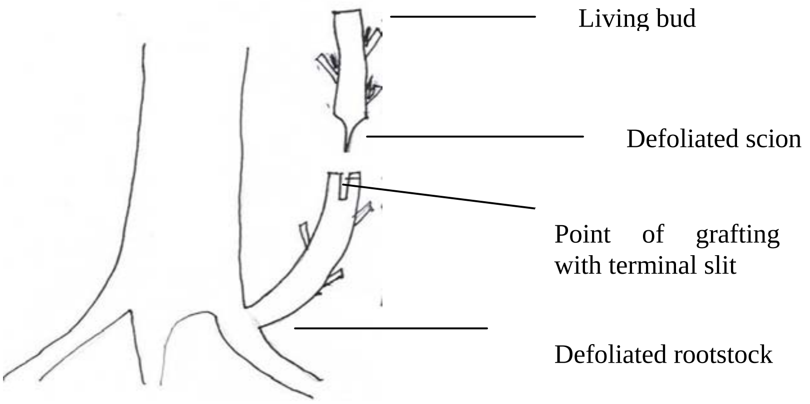
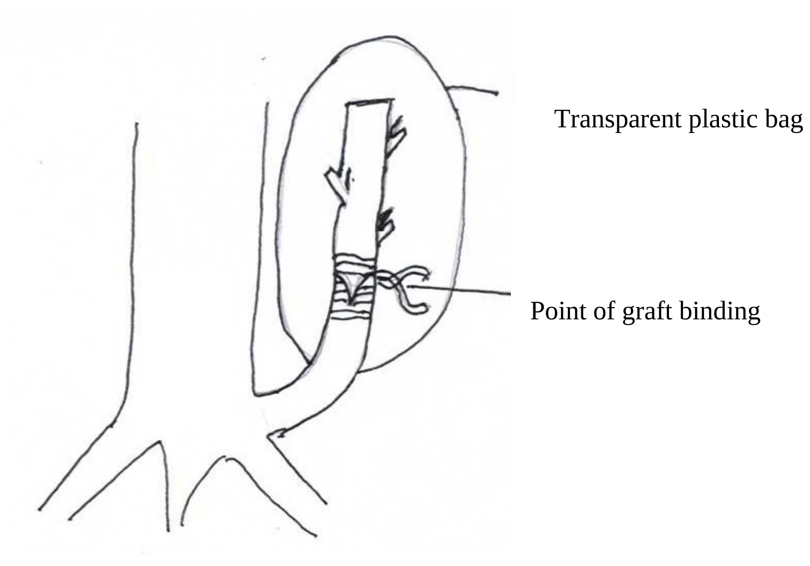
[3]Benomyl was originally recommended for use in this exercise, however this fungicide has been withdrawn from use throughout the European Union, as have its precursors carbendazim and thiophanate-methyl. Benomyl is a systemic broad spectrum fungicide. If this fungicide is unavailable locally you may wish to experiment with suitably safer substitutes such as triazoles or strobilurins.

Figure: Top-grafting of chupons (source S. Bassanaga, IRAD/IITA, Cameroon)



Scion taken





GUIDE QUESTIONS FOR ANALYSIS

1. What is the difference between a graft and a seedling of a super tree (graft gives identical twin, seedling gives offspring that is different. Discuss how fathers and sons are never the same)?
2. What are the costs and what are the benefits of grafting compared to growing and planting seedlings to rehabilitate established cocoa farms?

EXERCISE 5: Cocoa pruning methods (for seedling trees over 5 years old)

This exercise applies to cocoa farms that have been established for many years.

OBJECTIVE

To help farmers understand and implement appropriate cocoa pruning.

MATERIALS

- Un-pruned cocoa trees
- Machete/cutlass, small saws (use pruning saws if available) or other local pruning tools, such as pruning shears and extended pruning shears on a stick with pull rope for reaching higher branches
- Ladder
- Flip chart paper and markers, notebooks and pens
- Paint to label trees

PROCEDURE

Interactive classroom session

In an interactive session, the facilitator needs to assess local practices, knowledge, and beliefs of the farmers regarding pruning. Questions include: What is pruning? Why would you want to prune your trees (or why not)? What benefits does pruning offer? What are the hazards or problems you have experienced? How do you prune your trees? What tools have you used? How did you learn to prune your trees?

Write the responses on a flip-chart. This recognises the farmers' existing beliefs, knowledge, and experience regarding pruning. It also gives the facilitator a baseline idea of the pruning capabilities among the participants.


Pruning of cocoa, Cameroon. Photo J. Vos © CABI Bioscience

Information sharing:

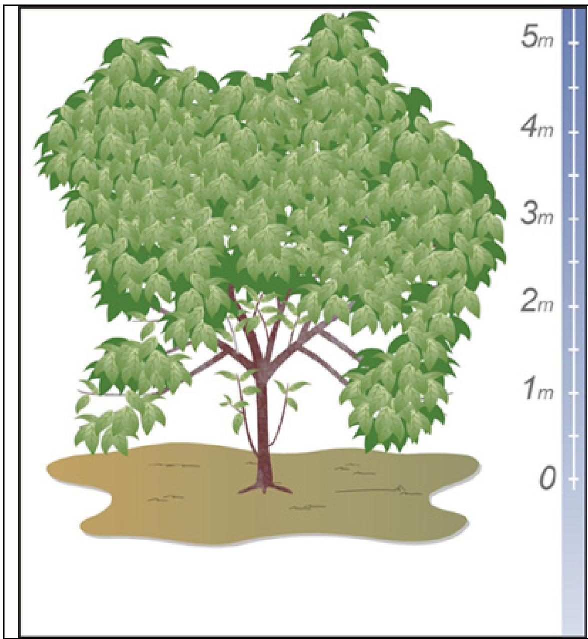
There are two levels of pruning: heavy pruning and maintenance pruning. For heavy pruning, it should be done during specific times of the year, preferably after the main harvest and just before the onset of the rains. This will need to be verified in the cropping calendar. Maintenance pruning should be carried out throughout the year, whenever the farmer is in the field.

Pruning can help achieve three objectives, namely:

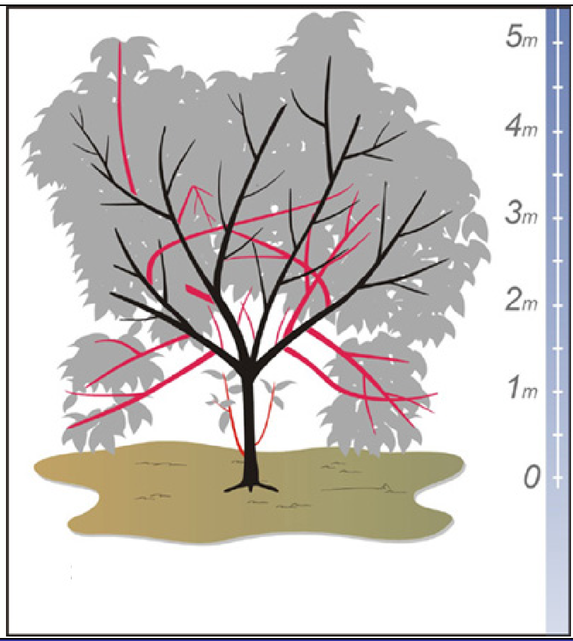
a) **Increasing the number of cocoa pods produced** through the reduction of non-producing branches, excessive leaves, and other biomass so that the trees' energy goes into production of more pods;
b) **Reduce the incidence of crop health problems**, such as black pod disease, mistletoes, witches broom, etc., through sanitation as well as reduction of the micro-humidity within the tree, which in general reduces diseases;
c) **Facilitate better maintenance and ease of harvesting,** as trees will be more manageable.

For trees that have not been pruned before, the farmer needs to determine which branches should be cut off. Below series of eight pictures will show how to determine which branches to prune.

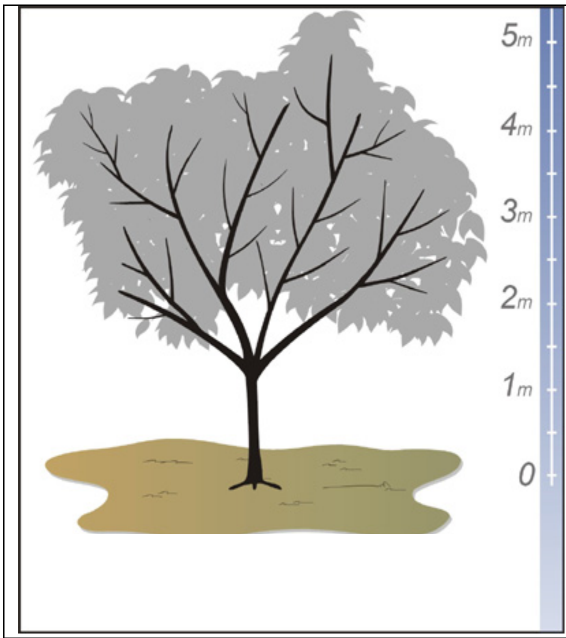
Figure: Selection of branches to prune in cocoa trees (Source: ACDI/VOCA SUCCESS project, Indonesia)



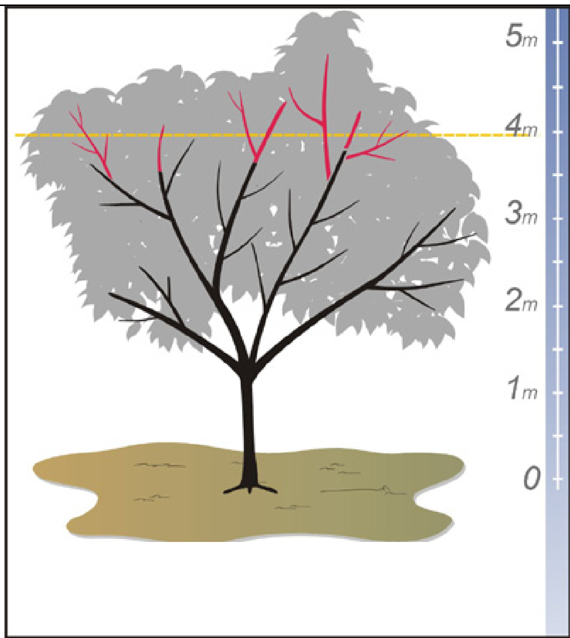
1. A tree before pruning that does not offer good ventilation or exposure to the sun.



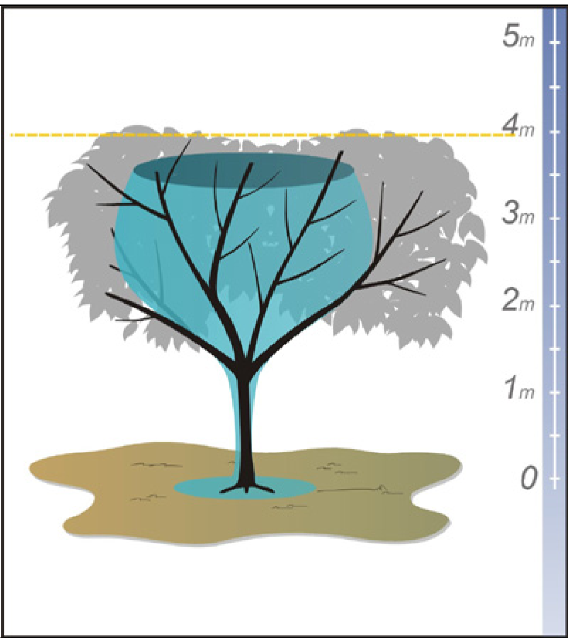
2. Cut low hanging branches first, then chupons and branches within 60 cm from the jorquette. Cut diseased or dead branches, and branches that grow back into the centre of the canopy.



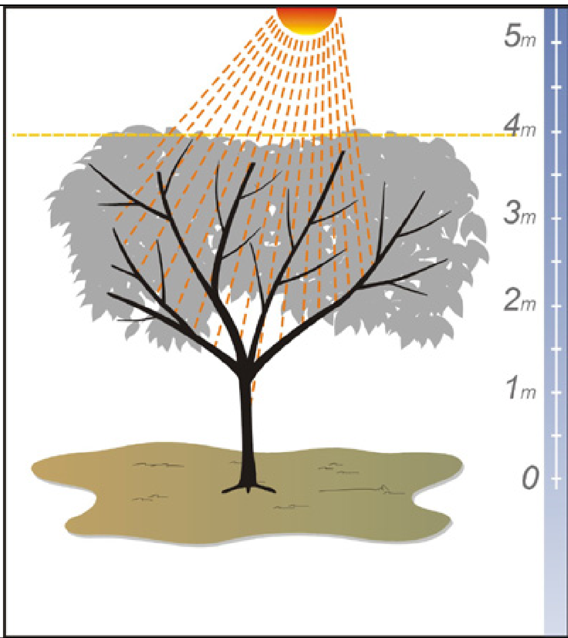
3. The results of initial pruning.



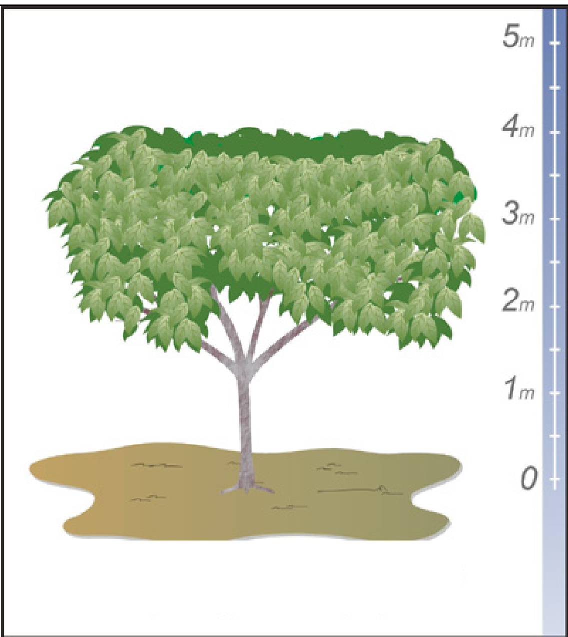
4. Top pruning to a height of 4m is recommended to facilitate harvesting and removal of mummified pods.



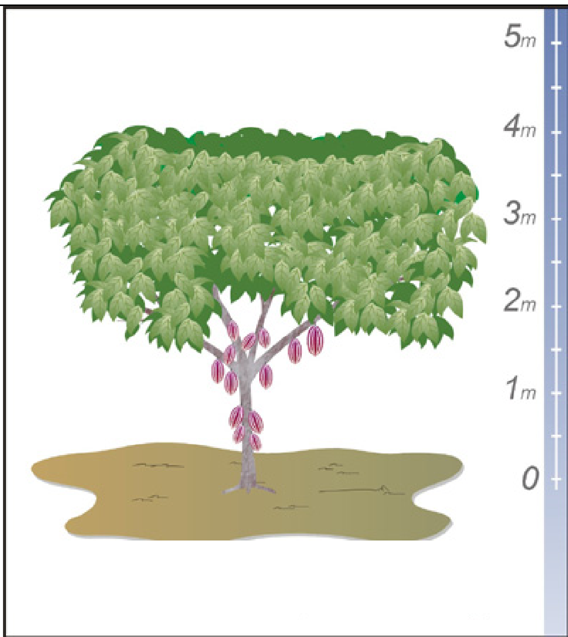
5. The architecture of a well pruned tree should be something like a funnel inside, with new branches growing out and up.



6. The result of the pruning will be a tree that allows sunlight to filter through to the main branches, jorquette and trunk, where it will stimulate flowering on these key areas.



7. After the initial pruning, the farmer will do maintenance pruning to maintain this structure.

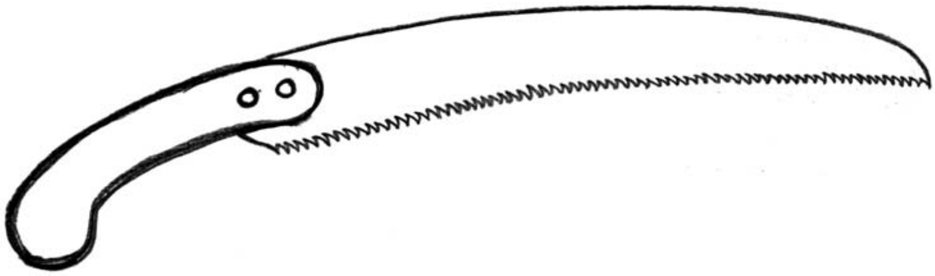


8. Part of the field school is to monitor the pruned trees and compare their productivity and health to trees that are not pruned. The difference should be noticeable.

After pruning, the sunlight should penetrate the tree to the extent that it is seen on the ground like spots on a leopard skin.

The farmer also needs to assess the appropriate method for pruning. The objective is to limit the possibility that a pruning wound becomes an entry point for diseases and pests into the tree. For large branches, use e.g. a pruning or ordinary saw rather than perhaps a machete, sawing close to the stem, making the cut perpendicular to the direction of the stem.

Figure: a pruning saw (Source: ACDI/VOCA SUCCESS project, Indonesia)



Activities in the cocoa farm:

Identify a cluster of 10 neighbouring cocoa trees to be pruned and label them ‘pruned’. At some distance, identify another cluster of 10 neighbouring trees that will serve as the unpruned control and label them ‘unpruned’.

Establish, in the ‘pruned’ plot, which twigs or branches need to be cut off to allow the sunshine penetrate the canopy. Refer to the figure with the 8 tree diagrams. Assess also how much land space is needed per tree to not compete with other trees for light, water and nutrients.

Perform the pruning in the ‘pruned’ plot using the correct method. The pruning wound to the tree should be smooth and at the base of the limb to be pruned. This can be easily shown using a pruning saw and compare that wound to a typical machete pruning wound.

Caution: Smooth cuts heal, ragged cuts can become the doors through which diseases or insects attack the plant!

Observations

Observe the two plots as in AgroEcosystem Analysis (Exercise 3), but specifically for:

- Flower and cocoa pod production
- Tree health
- Humidity within the plot (how quickly does dew dry in the pruned versus the unpruned plot?)

Guide questions for discussion

1. Considering the labour involved in pruning, do you think this is a worthwhile exercise? Why /why not?
2. What will be the consequences if the farmer does not prune his/her trees?
3. Can the farmer expect a high yield if he/she is not able to perform pruning?
4. What diseases or insects are able to enter the rotting wounds created by the decaying pruning stumps?
5. If a farmer thinks that he/she will not need to invest any energy or capital in his/her plantation, do you think this idea is sensible or not? Why (not)?

EXERCISE 6: Impact of shading on humidity in a cocoa farm

Cocoa in many locations is grown in a mixed crop system with shade trees. Many of these shade trees include economically valuable species such as the African plum (Dacryodes edulis), kola nut trees (Cola nitida), and guava (Psidium guajava) as well as several timber species (e.g. iroko-Chlorophora excelsa). Others are left for their compatibility as a shade species. However there is a trade-off between shade and pest management. Shade can suppress the level of attack by cocoa mirids while on the other hand it can increase the incidence of cocoa black pod, because of the effect on humidity in the plantation.

OBJECTIVE

Understand the relation between shading and humidity in a cocoa farm and its relation to specific cocoa pests.

MATERIALS

- Cocoa farm with variable shading levels
- Hand sprayer
- Water
- 3 Stopwatches
- Poster paper and markers

PROCEDURE

In the cocoa farm, select three niches with different shading levels

- Excessive shading
- Moderate shading
- Little or no shading

Divide the participants into 3 groups and assign them to one of the shade niches. Hand a stopwatch to them.

Spray cocoa pods with water using a hand sprayer until the water forms a droplet on the tip of the pod. Ask each group to time from the moment of spraying until the cocoa pod dries up.

Whilst waiting for the cocoa pod to dry, ask each group to describe the neighbour tree species present in each niche:

- Neighbour tree density (spacing)
- Neighbour tree height
- Neighbour tree crown shape
- Neighbour tree leaf area/Neighbour tree species
- Determine the cocoa density/spacing
- Describe the cocoa crown shape and canopy cover
- Estimate the weed pressure

Killing unwanted shade trees, Cameroon. Photo J. Vos © CABI Bioscience

At the same time, ask each group to estimate the intensity of important pests in each niche.

At the end of the exercise, return to a central location in the cocoa farm and note the collected data on a poster paper.

Guide questions for analysis

1. Which cocoa pods were the first to dry? Why?
2. To what do you attribute these differences?
    - Neighbour tree density?
    - Neighbour tree height?
    - Neighbour tree crown shape?
    - Neighbour tree leaf area
    - Neighbour tree species?
    - Other factors?
3. Did you observe any differences in pest infestation levels within the three niches?
4. Is it possible to manipulate the shading situation on this farm so that pest infestation levels are reduced? If yes, how?

Facilitator explaining about pruning and sanitation, Cameroon. Photo J. Vos © CABI Bioscience

TREE CHOICE FOR SHADE

Trees that are suitable in one country can be a complete failure in another. They can suffer some of the same diseases and harbour many of the same major insect pests as cocoa. The final choice will be influenced by local factors, such as growth habit, how easy it establishes, controlling growth once established and will it compete with cocoa. Other considerations include susceptibility to cocoa pests and diseases.

Some species used for permanent shade:

Species	Advantages	Disadvantages
Leucaena leucocephala	• Grows quickly and provides light feathery shade. • In Indonesia, *L. leucocephala* x *L. glabrata* produce vigorous sterile clones; these can be budded onto *L. leucocephala* seedlings.	• In Papua New Guinea, now known to harbour many major cocoa insect pests. • Low growing and canopies are almost continuous. • Reduces air movement above, within and below cocoa canopy and this encourages disease spread. • Hawaii variety seeds freely and seedlings develop rapidly in light shade becoming a severe weed problem in young cocoa.
Gliricidia sepium	• Easy to establish in most soils. • Can be used for first few years in new cocoa or in conjunction with other shade species on a permanent basis. • Grows quickly to 9m. • Fairly light foliage. • Already widely distributed in most cocoa growing countries	• Difficult to establish in heavy clay soils. • If slow to root or stakes rot then need to grow in a nursery before planting out at 3 months old. • During dry season leaves are shed, avoid by lopping just before dry season starts and new growth retains leaves. • Can be very vigorous and require heavy pruning.
***Erythrina* species**	• In Trinidad and parts of the Caribbean, *E. poeppigiana* used on hills and known as 'Anauca' and *E. glauca*, known as 'Bocaré' and used in lower wetter places. • Planted as stakes that quickly takes root and rapidly provide shade that is easy to control.	• In Trinidad, 'Bocaré' and 'Anauca' are attacked by disease; 'Anauca' is badly affected by a witches broom (cause not known). • Tend to lose leaves before the dry season, avoid by lopping just before dry season starts and new growth retains leaves. • Foliage liable to insect attack, where there is a danger of this plant in conjunction with another shade tree.

***Albizia* species**	• A spreading habit and light feathery foliage provides suitable shade. • *A. falcata* grows rapidly to a great height and is easy to establish. • *A. chinensis* is less brittle and has been successfully used in Malaysia. • Can be grown from seed on clean land otherwise grow in a nursery and plant out at 3-4 months.	• Not widely used. • *A. falcata* has brittle branches and is liable to wind damage. • *A. chinensis* grows more slowly, not so easy to establish.
Parkia javanica	• A tall tree that is easy to establish. • Light canopy.	• Provides little shade during early years. • Takes several years to reach maturity.
Some species used for temporary shade:		
Species	**Advantages**	**Disadvantages**
Bananas and plantains	• Easily grown and provide shade for young cocoa. • Normal practice in countries with higher rainfall and good soil moisture. • Provide food or cash.	• Competes with young cocoa for nutrients and water. • Not advisable in countries with a dry season. • Growers unwilling to cut them out as cocoa grows, this slows down development of the cocoa tree.
Manihot glazovii (tree cassava or Ceara rubber)	• Easily grown from stem cuttings. • Grows to 4-6m in height. • Forms fairly thick canopy. • In West Africa, is considered a useful plant for filling in gaps in forest shade.	• Must be deeply planted to ensure good anchorage. • Can become top-heavy and blow over easily in high winds. • In South-East Asia, pigs find the tubers attractive and dig them up. • Can be difficult to eradicate.

EXERCISE 7: Compost preparation

OBJECTIVE

To learn how to prepare compost for application on cocoa fields

MATERIALS

- Plenty of plant material both dry and green
- Ordinary top soil
- Animal manure or old compost
- Wood ashes and charcoal dust
- Several jars of water

PROCEDURE

- Select a location close to the place where the compost will be used. Make sure it is sheltered from the wind, rain and sun. The compost pile must not get too hot or dry.
- Measure an area one-and-a half meters to two meters wide and any convenient length depending on the available composting materials. It must be possible to work on the compost pit without actually stepping on it.
- Loosen the ground where the compost pile will be. The materials need close contact with the loose soil at the bottom. It is best to make a shallow trench about 30cm deep. In dry areas the trench or pit can be as much as one metre deep. The topsoil obtained will be used in the compost. Therefore, put it on one side beside the trench.
- The bottom layer should be of rough vegetation such as maize stalks or hedge cuttings. This layer should be about 30cm thick. Chop maize stalks etc into shorter lengths.
- The second layer should be manure or old compost or slurry. It should be about 10cm thick.
- Sprinkle some of the topsoil on top of this layer so that it just covers the material. Do not put on too much soil, and only use topsoil.
- The next layer should be made up of green vegetation about 15-20cm thick. Use green weeds, grass, hedge cuttings or kitchen waste.
- If you have wood ashes, sprinkle some on top of the green vegetation. If wood ash is not available, use topsoil.
- Add water to the pit. Use a watering can or any other convenient container, but make sure the pile is well watered.
- Repeat the whole process again, starting with rough vegetation then manure or old compost, top soil, green vegetation, ash or soil and finally water again. Repeat this process until the pile is 1-1.5m. A well-made pile has almost vertical sides and a flat top. If you have a lot of material to compost, build several smaller piles (about 2 m in length).
- To complete the pile, cover it with a 10cm layer of topsoil. This layer prevents fermentation gases escaping from the pile. *But make sure that the cover doesn't shut off any air circulation as that would promote rotting rather than composting of the organic material inside the pile.* Finally, cover the whole pile with dry vegetation to prevent loss of moisture through evaporation. Take a long, sharp stick ('thermometer') and drive it into the pile at an angle.

- Water the compost occasionally, about every 3 days depending on weather conditions. (If it is raining there is no need to water). The compost should be kept moist, but not too wet, angle, and use the stick to monitor the moisture levels in the pile. To monitor the moisture content, drive a stick long, pointed stick into the pile. The stick, when removed, will be warm. The stick also helps to check the condition of the pile from time to time. It will show whether the pile is dry or wet.

- After two to three days, decomposition will have started in the pile, and this decomposition will start to generate a lot of heat. Use the stick (‘thermometer’) to ensure that the compost is hot, i.e. that decomposition is in progress by pulling out the stick and checking the lower part for its humidity and warmth (feel with your bare hands – wash hands afterwards). Check the stick regularly, not only for temperature, but also for the presence of a fungus called “fire fang”. Fire fang destroys the compost once the compost pile becomes dry. Fire fang turns the stick white, and if you detect it you should add water immediately. Once there is no more heat generation, the decomposition process is slowing down and it’s time to turn the pile.

- If all goes well, the pile should be turned after three weeks. Do not add any fresh material during turning, except water if "fire fang” has developed. Make sure that while turning the bottom part of the pile ends up on the top. This is necessary because decomposition at the bottom goes slower than at the top.

- After three more weeks the pile should be turned a second time. The pile should stay moist, not wet. When the pile has been taken care of well, there is no need for further turning. By now the compost should have a fresh earth smell and no grass, leaves or animal droppings should be visible. Some woody branches or stalks may still be present as they take a long time to decompose.

- Three weeks after the second turning, the compost should be ready for use. If the planting season is still some time away, leave the pile where it is. Keep it well covered and moist, but not wet (*compost is wet when water drips-out of a handful which is squeezed tightly*).

GUIDE QUESTIONS FOR ANALYSIS

1. What happens with weed seeds, pupa of pest insects and disease spores inside the compost heap?
2. When is it better to compost crop residues rather than digging in crop residues (as e.g. in a smallholder cocoa farm where there is mixed cropping with vegetables)?
3. Do farmers in your area make compost? If not, why not? If yes, do they have alternative methods for doing so (e.g. discuss: ‘*above procedure looks complicated, do the odd alternating of layers of vegetation, soil and manure work as well?’)*?
4. What are the costs/benefits of making and utilising compost?

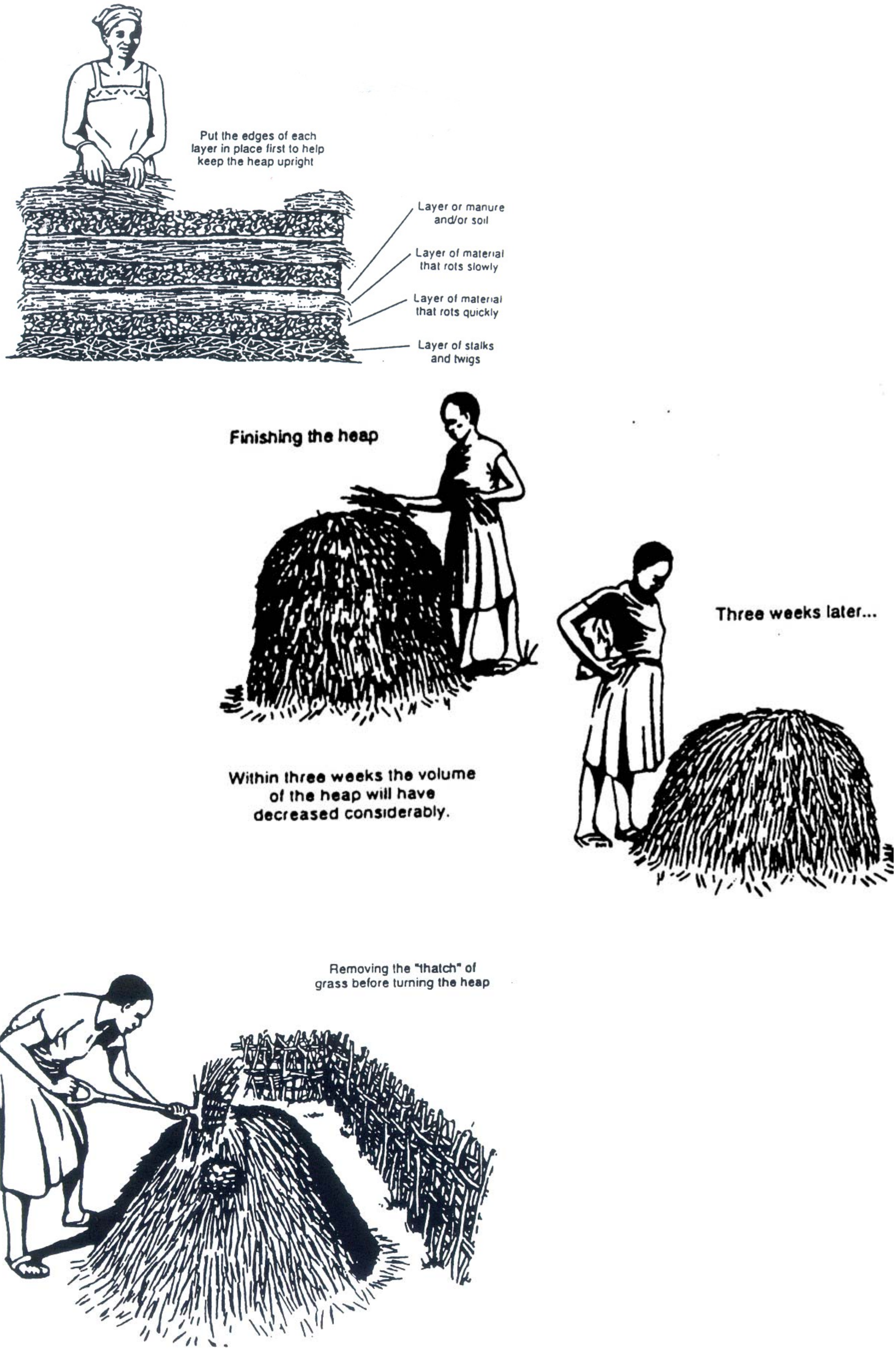


Figure: composting process (Source: Henry Double Day Research Association)

EXERCISE 8: Fertilising experiments

The impact of fertiliser use can be shown within a few months on short-duration crops, such as vegetables, which generally respond well to both inorganic and organic fertilisers. This exercise could be done on a homestead with vegetables, to demonstrate quick impact, and at the same time with cocoa that will give results in the longer run.

OBJECTIVE

To understand impact of use of fertilisers on plant health and production

MATERIALS

- Cocoa farm and homestead with vegetables
- Organic and inorganic fertilisers
- If available: pH meter or soil test kit

PROCEDURE

In a classroom session, discuss what nutrient requirements crops, in particular cocoa/vegetables, have. Draw a table on poster paper with three columns. List the nutrients in a first column 'nutritional needs' on poster paper (compare to what a healthy human body needs, such as protein, carbohydrates, minerals and vitamins). List in the second column, farmers' practices, how these needs are addressed through the current farmers' fertilising practise. In the third column, balanced fertilisation, list which available sources of nutrients could be used to fulfil the crops' needs.

Following the discussion, discuss dosages and add the dosages that farmers are applying currently to the second column under 'farmers practices' and the dosages that would result in balanced fertilisation in the third column. Compare the second with the third column and discuss any differences.

Visit the cocoa/vegetable field and take soil samples. Mix the samples well and use a pH meter or soil test kit to learn more about the soil content. Based on the soil test outcome and the column 'balanced fertilisation' in the table, design a field study comparing the farmers' fertilising practice with balanced fertilisation, or alternatively make up another field study design, e.g.:

- No fertilisation
- Balanced fertilisation
- Using organic fertilisers only
- Using chemical fertilisers only

Apply crop management and make observations following the Agro-Ecosystem format (see Exercise 3).

OBSERVATIONS

Monitor the different field plots and assess crop growth and health. Assess final yield at harvest and market price.

GUIDE QUESTIONS FOR ANALYSIS

1. Which treatment gave the best crop performance and yield? Why?
2. Were there any differences in pod size/quality of vegetable product? Why?
3. Which treatment gave the best return on investment?

Observing cocoa treated with a biocontrol agent against black pod, Cameroon.
Photo J. Vos © CABI Bioscience

EXERCISE 9: Cocoa insect zoo – observing biological control

Some insects or mites are pests, feeding on plant parts, others feed on insect prey, others live inside other insects and again others come from weeds or neighbouring crops, and are simply resting in the vegetable crop. Farmers do not always recognise the role of predatory insects in managing pests. To learn about insect biology, the 'insect zoo' (Exercise 9) and variations on the 'insect zoo' (Exercises 10 and 11) can be conducted.

OBJECTIVE

To understand biological control of insects and become aware of the role and importance of beneficial insects in pest management

MATERIALS

- Small plastic vials/empty water bottle containers and bags
- Plastic buckets (if possible transparent), large enough to hold cocoa pods of various sizes
- Tissue paper
- Camel or fine hair brush
- Labels
- Muslin cloth or fine mesh screen
- Rubber bands/pieces of string
- Hand lens
- Optional: Insect collection box and pins

PROCEDURE

Carefully collect unknown and known insects in a cocoa farm using a sweepnet or by capturing them in plastic vials/bottles and close these with cloth or screen. Be careful when handling the insects that you want to study as they won't be feeding when they've been handled too roughly. Study the insects and find out whether they have local names. Discuss what the insects might be feeding on, do you think they feed on cocoa or on other insects or mites?

To set-up zoos, line the plastic buckets with tissue paper to avoid condensation. Put one clean cocoa pod and/or some leaves in each bucket and label each bucket with the (local) name of the insect that you want to study.

An expected predatory insect (a 'natural enemy' or 'farmer's friend') can be put together with expected prey insects in a zoo, such as ladybeetles with aphids or preying mantis with a leaf feeding caterpillar. Make sure that you don't put different species of predators together as they might attack each other (e.g. spiders can become cannibalistic when hungry!)

Another way to build 'insect zoos' is to sleeve clean cocoa branches or pods on the tree in the field with plastic bags that have screen windows (make sure that there are no holes in the plastic or in the screen windows). Insert the insects that you want to study. Observe the zoos daily.

It is a good idea to build up a reference collection of pests and natural enemies during a field school season. To make a reference collection, pierce studied, dead insects on insect pins or fine tailor pins (pierce the pin through the thorax -the middle part of the body), add a small paper label to the pin with details of the collection date, place and crop.

OBSERVATIONS

Record the local names of the insects that were collected and the location where it was collected. Describe your observations with drawings on poster paper. Explain in presentation sessions which insects you collected, where you collected them, what they were feeding on.

GUIDE QUESTIONS FOR ANALYSIS

1. Were the studied insects 'friends of the farmer' or 'enemies of the farmer'?
2. If you found a farmer's friend, how many other insects could it eat over a period of 1 day? How can we use this information in the management of farmer's enemies?
3. What would happen to the farmer's friends when pesticides are sprayed in the cocoa farm?
4. What would happen to the farmer's enemies when no pesticides are sprayed in the cocoa farm?

Insect zoo on cocoa seedling, Cameroon.
Photo J. Vos © CABI Bioscience

EXERCISE 10: Cocoa insect zoo – symptom development

OBJECTIVE

To study insect feeding patterns and understand which insect causes which feeding pattern

MATERIALS

- Small plastic vials/empty water bottle containers and bags
- Plastic buckets (if possible transparent), large enough to hold cocoa pods of various sizes
- Tissue paper
- Camel or fine hair brush
- Labels
- Muslin cloth or fine mesh screen
- Rubber bands/pieces of string
- Hand lens
- Optional: Insect collection box and pins

PROCEDURE

Carefully collect unknown and known insects in a cocoa farm using a sweepnet or by capturing them in plastic vials/bottles and close these with cloth or screen. Be careful when handling the insects that you want to study as they won't be feeding when they've been handled too roughly. Study the insects and find out whether they have local names. Discuss what the insects might be feeding on, do you think they feed on cocoa or on other insects or mites?

To set-up zoos, line the plastic buckets with tissue paper to avoid condensation. Put one clean cocoa pod and/or some leaves in each bucket and label each bucket with the (local) name of the insect that you want to study.

To find out whether an arthropod is a pest that feeds on pods, put it on a cocoa pod in one bucket and cover the bucket with muslin cloth/screen, secured with a rubber band/piece of string. Put different insect species in different 'zoos'. Keep the buckets out of direct sunlight. Observe whether the insect feeds; observe the feeding symptoms. Check again after some time; how long does the insect survive?

Another way to build 'insect zoos' is to sleeve cocoa pods or branches on the tree in the field with plastic bags that have screen windows (make sure that there are no holes in the plastic or in the screen windows). Insert the insects that you want to study and daily observe the zoo.

It is a good idea to build up a reference collection of pests and natural enemies during a field school season. To make a reference collection, pierce studied, dead insects on insect pins or fine tailor pins (pierce the pin through the thorax -the middle part of the body), add a small paper label to the pin with details of the collection date, place and crop.

OBSERVATIONS

Record the local names of the insects that were collected and the location where it was collected and describe your observations on poster paper. Explain in presentation sessions which insect(s) you collected, where you collected them, what they were feeding on, whether they changed development stages and how long they remained in certain development stages. Illustrate the observations with drawings.

GUIDE QUESTIONS FOR ANALYSIS

1. Did the insect feed in your zoo? If no, why not (was the insect damaged, not hungry, or is the insect not a cocoa pest)
2. How long did the insect survive in the zoo?
3. Was the studied insect a 'friend of the farmer', a ‘visitor’ or an ‘enemy’ of the farmer'?
4. How could the information about the feeding pattern help you in pest management?

Insect zoo using cocoa pod, Cameroon.
Photo J. Vos © CABI Bioscience

EXERCISE 11: Cocoa insect zoo – observing life cycles

OBJECTIVE

To study insect life cycles, recognise and learn about their development stages

MATERIALS

- Small plastic vials/empty water bottle containers and bags
- Plastic buckets (if possible transparent), large enough to hold cocoa pods of various sizes
- Tissue paper
- Camel or fine hair brush
- Labels
- Muslin cloth or fine mesh screen
- Rubber bands/pieces of string
- Hand lens
- Optional: Insect collection box and pins

PROCEDURE

Carefully collect eggs or larvae of mirids, stem borers, pod borers and other cocoa pests by capturing them in plastic vials/bottles. Be careful when handling the insects that you want to study as they won't be feeding when they've been handled too roughly.

To set-up zoos to study life cycles, line the plastic buckets with tissue paper to avoid condensation. Put one clean cocoa pod and/or some leaves in each bucket and label each bucket with the (local) name of the insect that you want to study. When dealing with moths, add some soil to the buckets as a medium for pupation.

Rear the collected insects in the zoos with cocoa through the next stages until the adult stage. Feed the larval stage on appropriate food (leaves, pods, stems) every day, and observe them during development. Monitor the duration of each developmental stage. It is important to always keep checking the tissue paper lining in the bucket: when it gets wet it needs replacing with dry tissue paper.

Another way to build 'insect zoos' is to sleeve cocoa pods or a branch on the tree in the field with plastic bags that have screen windows (make sure that there are no holes in the plastic or in the screen windows). Insert the insect that you want to study and daily observe the zoo.

Insect collection, South-East Sulawesi, Indonesia. Photo © J. Mangan.

It is a good idea to build up a reference collection of pests and natural enemies during a field school season. To make a reference collection, pierce studied, dead insects on insect pins or fine tailor pins (pierce the pin through the thorax -the middle part of the body), add a small paper label to the pin with details of the collection date, place and crop.

OBSERVATIONS

Record the local names of the insects that were collected and the location where they were collected and describe your observations on poster paper. Explain in presentation sessions which insect(s) you collected, where you collected them, what they were feeding on, whether they changed development stages and how long they remained in certain development stages. Illustrate the observations with drawings of each developmental stage of the studied arthropod and record how long each stage lasts in number of days – try and come up with a complete cycle!

GUIDE QUESTIONS FOR ANALYSIS

1. What did you learn about the insect you studied in the insect zoo?
2. How could the information about duration of development stages help you in pest management?

EXERCISE 12: Disease zoo – infection study

This exercise protocol has been validated for Black Pod, but could be applicable to other cocoa pod diseases.

OBJECTIVE

To demonstrate that spores (disease seeds) cause infection in a humid environment

MATERIALS

- 2 Large plastic bowls/containers with lids
- Tissue paper
- 2 Healthy green cocoa pods
- 1 Actively sporulating cocoa pod (infected pods with disease seeds = spores) – if you can't find sporulating cocoa pods, take an infected cocoa pod and put it in a plastic bag with wet tissue paper in a shaded place for a day or two until white powdery spore masses are formed
- 2 Clean soft paint brushes
- Dry, clean stick
- Water
- 2 Cups
- Labels and marker
- Notebook and pen

PROCEDURE

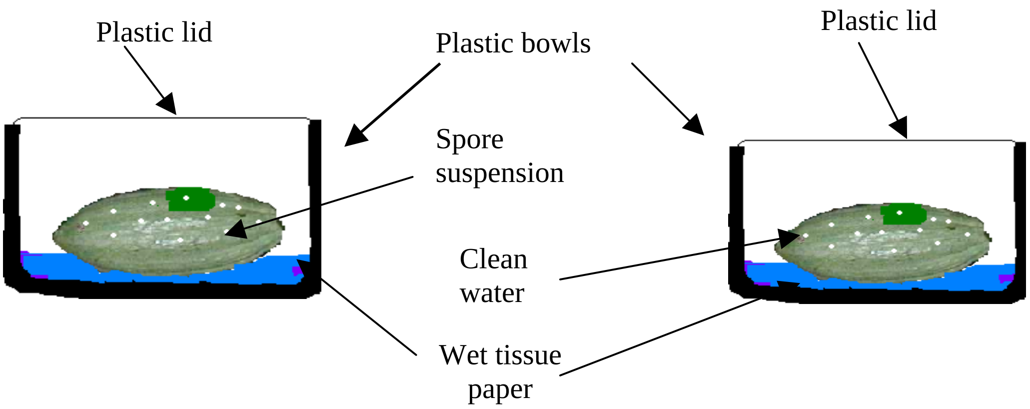
Please see figure in this exercise protocol. Line the bottom of two plastic bowls with tissue paper. Wet the tissue paper in both of the bowls with a similar amount of clean water to maintain a humid atmosphere. Wash and dry the healthy green cocoa pods. Put a healthy green pod in each of the two bowls. Label one bowl 'infected' and the other 'control'.

Take the sporulating cocoa pod and wash the white powder of the sporulating area into one cup with the aid of the soft paint brush. Label the cup 'infected water'. Stir the suspension in the 'infected water' cup with the dry stick for 5-10 minutes and leave for 30 minutes.

Fill another cup with clean water and label the cup 'clean water'.

Using the soft paint brush, put drops of the 'infected water' on the healthy pod in the 'infected disease zoo'. Using the other clean paint brush, put drops of the 'clean water' on the healthy pod in the 'control disease zoo'. Cover both bowls with the lids to maintain the humid environment.

Figure: Disease zoo (Source: P. Tondje, IRAD Cameroon)



Observations

Observe the set up daily for 5 days.

- Check for growth of emerging necrotic lesions on both green pods – note how many days after set-up you can see these emerging.
- Check for development of white powdery spore masses – note how many days after set-up you can see these emerging.

Guide question for analysis

1. Why did we include an uninfected ‘control’ disease zoo?
2. How long did it take for the symptoms to develop in the infected disease zoo?
3. How long did it take for the spore masses to develop?
4. Can we now figure out how long the disease cycle takes (from spore to spore) under class room conditions? Will this be the same in the field? Why (not)?
5. What does the result mean for disease development in a cocoa farm?
6. What lessons have farmers learnt from the exercise?

EXERCISE 13: Disease zoo – symptom development

This exercise protocol has been validated for Black Pod, but could be applicable to other cocoa pod diseases.

OBJECTIVE

To demonstrate the impact of humidity on disease development

MATERIALS

- 2 Large plastic bowls/containers with lids
- Knife
- Tissue paper
- 2 Healthy green cocoa pods (protocol I) or 2 cocoa pods with early infection (protocol II)
- 1 Actively sporulating cocoa pod (infected pods with disease seeds = spores) – if you can't find sporulating cocoa pods, take an infected cocoa pod and put it in a plastic bag with wet tissue paper in a shaded place for a day or two until white powdery spore masses are formed
- Water
- Labels and marker
- Ruler, notebook and pen

PROCEDURE

Please see figure in this exercise protocol. Line the bottom of two plastic bowls with tissue paper. Wet the tissue paper in one of the two bowls with a thin layer of clean water to maintain a humid atmosphere. Label that bowl 'humid disease zoo' and the other 'dry disease zoo'.

Protocol I.

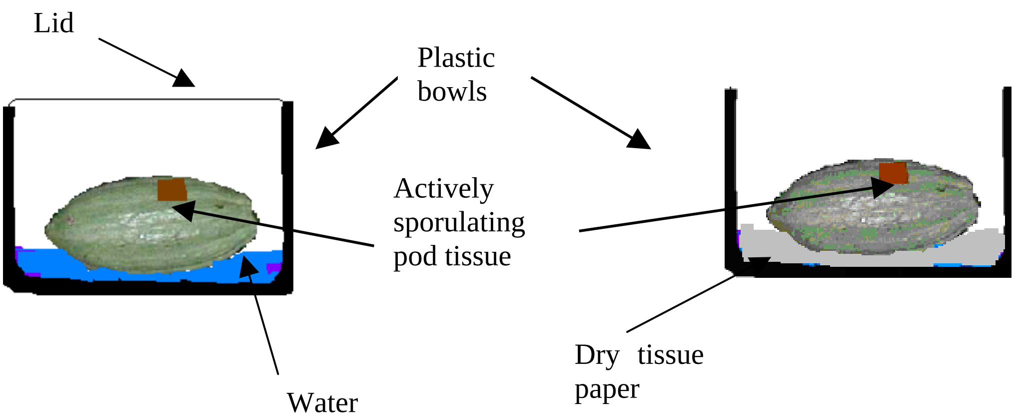
Wash and dry the healthy green cocoa pods. Put a healthy green pod in each of the two bowls.

With a clean knife, cut two small portions of the actively sporulating infected pod (portion of infected pod with white powder = seeds of the disease).

Place one each of the cut diseased portion on each of the green healthy pods in the two disease zoos such that the diseased surface is in direct and close contact with each other.

Cover the 'humid disease zoo' with a lid to maintain the humid environment, whilst the other 'dry disease zoo' remains uncovered.

Figure Disease zoo (Source P. Tondje, IRAD Cameroon)



Protocol II.

Wash and dry the 2 cocoa pods with early infections caused by a cocoa pod disease. Using a marker, trace the edge of the necrotic lesion that you want to study on both pods. Try and choose lesions of similar sizes.

Place one pod in each disease zoo.

Cover the 'humid disease zoo' with a lid to maintain the humid environment, whilst the other 'dry disease zoo' remains uncovered.

Observations

Observe the set up daily for 5 days.

- Check for growth of an emerging necrotic lesion on both green pods, once a lesion emerges in protocol I, measure the diameter of the emerging necrotic lesion daily using a ruler. Once the lesions start growing in protocol II, use a ruler to measure and note how many cm the lesion grows each day.
- Check for development of white powdery spore masses.

Guide questions for analysis

1. Is there a difference between growth of emerging symptoms in both bowls? If yes, why? What does the result mean for cocoa pod disease development in a cocoa farm?
2. Is there a difference between the starting time of sporulation between the two bowls? If yes, what does this mean for dissemination of cocoa pod diseases in a cocoa grove?
3. Are there any methods to reduce the humidity in a cocoa grove? If yes, what kind of impact would you expect of reduced humidity on the development and spread of cocoa pod diseases in a cocoa grove?

EXERCISE 14: Role of soil in disease spread

OBJECTIVE

To demonstrate the potential role of soil in disease spread

MATERIALS

- 1 Kg flour
- Water
- Poster papers
- Watering can
- Marker
- 1 Plastic bucket with lid
- 2 Healthy green cocoa pods
- Cocoa farm with a history of cocoa pod disease, which has a relation to soil, such as black pod

PROCEDURE

1. Walking the disease

Choose a location with bare soil. Make sure that the soil is dry. Sprinkle 1 kg of flour on the soil and explain that this represents spores of a fungal disease or nematode cysts. Ask the participants to wet the soles of their shoes/boots/feet with water and walk through the flour on their way to inspect nearby trees or crops. Observe spread of flour and also look at the soles of the shoes after the exercise. In case the field is wet, replace flour with fine seeds (such as watercress) and observe after germination of the seeds.

Discuss the distance of spread with the participants and what this means for diseases that survive in soil.

2. Soil and disease splash

Choose a location in the cocoa grove where there is a thick layer of leaf litter. Make sure that the soil is dry.

Remove the leaf litter from a portion of the location (about 1 x 2 m^2).

Fill the watering can with water. Ask one participant to hold a sheet of poster paper vertical from the bare soil with the bottom resting on the soil. Ask another participant to water the soil using the watering can to simulate rain. Observe soil splash onto the poster paper – use the marker to indicate the highest spot of soil on the poster paper.

Do the same, using a clean sheet of poster paper and a plot with leaf litter. Again observe the soil splash onto the poster paper – use the marker to indicate the highest spot of soil on the poster paper.

Compare and discuss both results.

Walking the disease, Trinidad.
Photos V. Lopez © CABI Bioscience

3. Disease infection from soil

Wash and dry the two healthy green cocoa pods. Take a few handfuls of soil from under a cocoa tree (select one which has infected pods on the tree trunk). Transfer the soil into the bucket and make it moist using clean water. Place the healthy cocoa pods on the soil and cover the bucket with the lid. Observe for about 5 days for symptoms of cocoa pod disease.

Observe the set up daily for 5 days.

- Check for growth of emerging necrotic lesions on both green pods – note how many days after set-up you can see these emerging.
- Check for development of white powdery spore masses – note how many days after set-up you can see these emerging.

Guide questions for analysis

1. How important is soil in disease development of the various cocoa diseases we know?
2. How might these methods of spreading of pathogen affect crops in the field?
3. How could spread of pathogens be prevented?
4. What lessons have farmers learnt from these exercises?

EXERCISE 15: Spread of virus by insects

OBJECTIVE

Demonstrate (symbolically) the spread of pathogens by insects, e.g. CSSV by mealybugs

MATERIALS

- A syringe or a drinking straw
- 5 transparent drinking glasses
- Instant coffee
- Clean water

Optional:
- Samples of healthy and diseased plants.
- Samples or photos of sucking insects.

PROCEDURE

Fill a glass with coffee and the others with clean water. The syringe or straw represents a sucking insect. The glass with coffee represents a diseased cocoa tree with a virus. The glasses of water represent healthy cocoa trees. Suck a bit of coffee into the syringe and go to the first healthy tree (glass of water). Dip the syringe into it, squirting ("spitting") a bit of coffee before sucking from the tree (the glass of water). Observe the colour of the water.

The healthy tree (the glass of water) gets a dose of virus (coffee). Go from glass to glass, squirting a bit of coffee into each one, "infecting" them. "Suck" a little water from each glass ("feeding"). Observe the colour of the water in the glasses, and that there is less inoculum in the syringe, because it has been diluted by the "healthy trees".

Spread of insect-vectored disease, Bolivia. Note the added samples to illustrate the symptoms of infected versus healthy plants. Photo © J. Bentley

GUIDE QUESTIONS FOR ANALYSIS

1. Which diseases are transmitted by sucking insects?
2. Which sucking insects do you know?
3. How can we avoid spreading diseases from one tree to another? (Emphasize deterring vectors through cultural practices. If infection is low, rogueing of diseased plants may be considered only when there is no further infection expected from outside the field.
4. Why can't insecticides prevent spread of insect vectored viruses effectively? (To caution farmers against making unnecessary applications of insecticides: generally speaking insects transmit the virus to sprayed trees before dying of the pesticide).

EXERCISE 16: Spray dye exercise

OBJECTIVE

- To create awareness of the direct exposure of farmers to pesticides when spraying
- To demonstrate drift to non-target organisms
- To initiate discussion on wastage during spraying

MATERIALS

- Various knapsack sprayers, including a farmer's sprayer
- Buckets, measuring can and water
- Non-toxic dye, e.g. food colorant (preferably red)
- White flip charts, paper kitchen towel, toilet paper
- Masking tape
- Cocoa plantation
- A few volunteers!

PROCEDURE

- Prepare 5 litres of dye solution for each sprayer.
- Wrap up the volunteers completely (apart from the eyes!) in white flip chart paper and/or paper kitchen towels or toilet paper, secured with masking tape.
- Ask the volunteer to fill his sprayer with the dye solution and subsequently spray for 10 minutes as though using a pesticide for an agreed pest problem.
- Ask the other participants to watch and make notes.
- After spraying, remove the sprayer and observe how much dye is on each part of the body (none, a little, a lot).

Different knapsack sprayers of variable ages, Indonesia. Photo J. Vos © CABI Bioscience

Spraying red dye, Cameroon. Photo J. Vos © CABI Bioscience

Observing results of spray dye exercise, Cameroon.
Photos by J. Vos © CABI Bioscience

- Examine the sprayed cocoa trees, and observe how far the spray has drifted and whether or not there is run-off from cocoa pods.
- Measure back the remaining amount of dye solution in each of the sprayers and check which sprayer has been most economical in its output.

GUIDE QUESTIONS FOR ANALYSIS

1. How much of the spray solution ended up on the operator?
2. What are the hazards that pesticide contamination might pose to the health of the people spraying?
3. What kind of protective clothing could sprayers use? (Discuss use of hats, shoes, boots, long-sleeved shirts, etc.)
4. How far did the spray drift? Under what conditions would the drift be greater? Under what conditions would it be less?
5. Was there any run-off? What does this mean with regard to cost of application and spray efficiency?
6. Which of the sprayers was most efficient and why? What does this mean for the cost of spraying? How could one improve the efficiency of sprayers?

EXERCISE 17: Pesticide specificity

When pesticides are applied in the field, they also spread into the environment. Generally, pesticides reach the soil either through application on the soil or through run-off. Gaseous chemicals may escape into the air. In the soil, pesticides can bind to soil particles and/or move into groundwater. When a pesticide is highly persistent in the environment, undesirable biological effects may be caused, such as negative effects on soil-flora and -fauna, on aquatic life, on ecological diversity and air quality (pollution). From the crop management viewpoint, there are some additional, serious disadvantages of the use of chemical pesticides. In addition to the target pest, pesticides kill beneficials such as natural enemies and antagonistic fungi.

OBJECTIVE

To evaluate the effect of sprayed leaves on the survival of natural enemies

MATERIALS

- A cocoa farm, preferably unsprayed
- Sweep net
- Plastic bags and small containers to collect various insects
- Small soft brush
- Tissue paper
- 4 Transparent buckets
- 4 Pieces of Muslin or mosquito screen cloth with rubber bands, to cover the buckets
- Labels and marker, note book, pen
- 4 Small hand-sprayers ((0.5 l), shared between groups)
- Water
- Small amounts of different insecticides [incl. broad spectrum and selective, if possible a bio-pesticide (e.g. B.t.) and botanical (e.g. neem)]
- Gloves and masks

PROCEDURE

1. Prepare 4 hand sprayers before the practical. If a sprayer has been used before, wash it thoroughly with detergent. Fill 1 hand sprayer with pure water (control). Prepare and fill 3 hand sprayers with commonly used insecticides, at field rate concentrations, for example: monocrotophos (organophosphate), cypermethrin (pyrethroid), *Bacillus thuringiensis* (biological insecticide) (**use gloves**). Label the hand sprayers to avoid confusion!

2. Collect cocoa leaves: three per spray treatment. Spray each set of leaves with a selected spray solution and let the leaves dry (**use gloves and masks**).

3. Transfer the dried leaves per treatment to the transparent buckets (one leaf per bucket) (**use gloves**). Label the jars. Each group should have one jar of each spray treatment (4 jars in total). Try to get the leaf to lie flat on the inside surface of the bucket.

4. Collect pests (e.g. mirids or leaf eating caterpillars), predators (e.g. spiders or syrphid larvae) and unknowns or neutrals, from the cocoa farm, using sweep net and picking insects from leaves. Try not to touch the insects but use a brush to collect them in jars. Carefully transfer them to the treatments (one of each species per bucket). If possible, use the same insect species in all treatments and make sure they are of similar size. Close the jar with the cloth and rubber band.

OBSERVATIONS

Check and record the condition of the insects hourly for 4 hours, after 8 hours and after 24 hours. Count the number of dead insects. It may be necessary to touch the insect with a pen or pencil to determine if it is dead. If it does not walk off in a normal manner, then record it as dead.

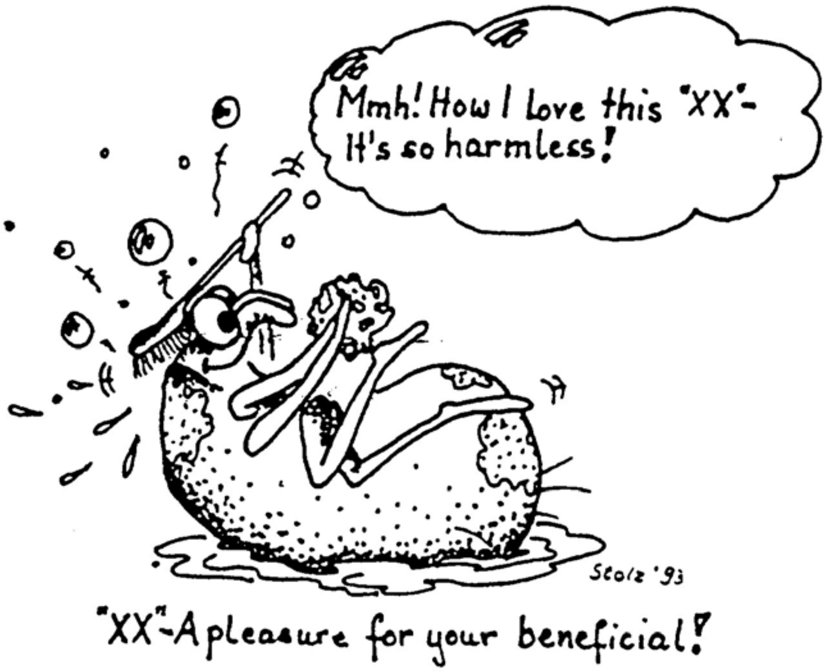


Figure: Biological pesticides conserve natural enemies (Source: G Stolz)

GUIDE QUESTIONS FOR ANALYSIS

1. What happened to the insects in the different jars? Why?
2. Did you observe any differences in the behaviour of the insects?
3. Which of the insects would you prefer on your farm? Why?
4. What happens in the field when a farmer sprays against a certain pest?
5. What will happen in a field 1, 2, 3 weeks after spraying?
6. What other options do you have, besides the spray solutions tested, to manage cocoa pests and diseases, whilst conserving natural enemies?

EXERCISE 18: Disease resistance deployment game[4]

The exercise is a kind of game which simulates the spread of wind-, rain- or soil-borne diseases, such as rice blast, cabbage leaf spot, tomato nematodes. It explains why one can find so-called 'foci' in fields with very clear symptoms of a disease while other plants still look healthy. Those foci are the sources of infection from where the disease is spreading. The exercise is adapted for cocoa to create an understanding of the impact of introducing disease resistant varieties in rehabilitation of existing cocoa farms.

Objective

To understand how deployment of disease resistant varieties can reduce disease spread

Materials

- Poster paper
- Cocoa beans or other large seeds or small stones
- Cups or matrix on paper sheet
- Markers (red and green)

Procedure

Prepare a matrix of 8 by 8 squares (1 square = 1 tree) which represents a field with 64 trees, or alternatively, place 64 cups in a way representing a cocoa farm.

Place one bean in the middle to represent the initial source of infection, representing one plant infected with the pathogen. Using the red marker, mark the square or cup to simulate that the infected plant starts showing symptoms and becomes a source of infection for other plants (i.e. a leaf spot starts sporulating or nematodes start multiplying). That was the first cycle of infection.

Then, place a bean in each of the surrounding 8 squares or cups representing infection of the neighbouring trees of the source of infection. Also mark those 8 trees with the red marker to simulate the development of symptoms in those plants. That was the second cycle of infection.

Go through the next cycles in the same way (see the illustration in this protocol).

After the simulation, discuss and analyse what happened.

Now simulate a farm with susceptible and resistant trees (as is the case in a farm where rehabilitation is done using disease resistant varieties). Prepare a new matrix (or another set of cups) marking e.g. 10% of the squares or cups with green, indicating that those trees are resistant to the disease.

Go through the cycles as before, but when beans are put in green squares/cups, those aren't marked with red as they don't become infected and hence don't become sources of infection for other trees. So, in between cycles, it is best to remove those beans from the green squares/cups to avoid confusion during the game.

Again, go through the same number of cycles as before. Observe what happens and compare the outcomes of the two games.

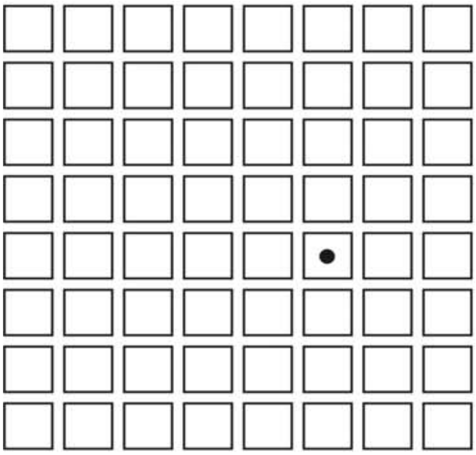
Guide questions for analysis

1. What is the difference in outcome of the two games and how does this relate to cocoa?
2. Does the pattern of spread of pathogens simulate the process of disease development in a cocoa farm?
3. Have you observed similar 'foci' of disease in cocoa farms before?
4. Which diseases spread in this way?
5. Besides using resistant varieties, how could the spread of such diseases be hampered, slowed down?

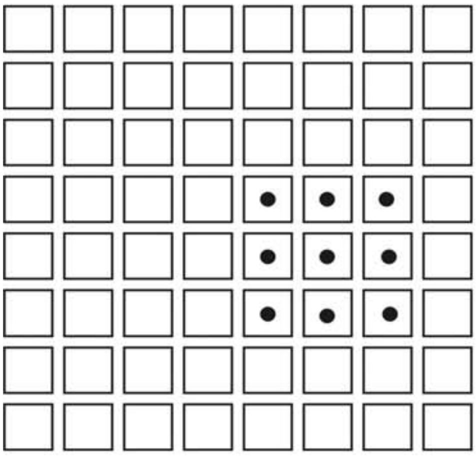
[4]After Vietnam Field Guide on Disease Management and Varietal Evaluation for Rice (1996)

__Figure: Disease Spread (Source: Vietnam rice field guide, 1996)__

Mark this first bean, as the source of inoculum for the second cycle of infection.

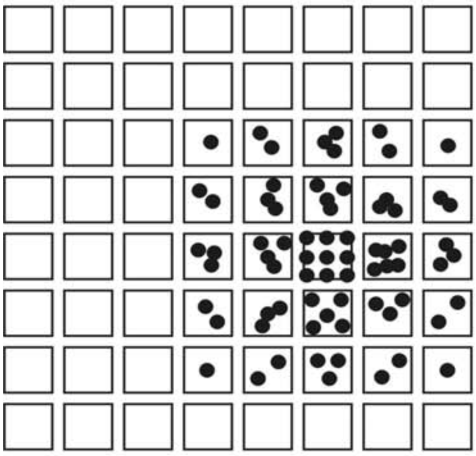


Place a bean in each of the eight "plants" (cups, circles, or squares) surrounding the infected plant.



Go through the next cycle of infection by marking the infected plants and placing a bean in all eight surrounding plants for every infected plant.

Continue this for a total of 5 cycles.



EXERCISE 19: Pesticide resistance role play[5]

When pesticides are used on a frequent basis, there is a risk of build-up of pest resistance against pesticides. Serious outbreaks of pests, e.g. diamond back moth on cabbage and brown plant hopper on rice, have been documented in several SE Asian countries after intensive use of chemicals resulted in the reduction of natural enemies, and meanwhile building up of pest resistance to pesticides. Last but not least, farmers tend to increase the frequency and dosage of pesticide applications when crop health problems persist. As farmers get caught in the 'pesticide treadmill', costs of production escalate. In this role play, experiences are shared about the reduction of effectiveness of insecticides due to build-up of pest resistance.

Objective

To understand how insect populations become resistant to insecticides

Materials

- Tissues to cover noses of 'Super Insects'
- 1 'Poison-sprayer' (hand sprayer filled with water)
- 6 Chairs as cocoa trees (you can decorate them with leaves and pods!)

Procedure

Organise the group for the mime role play. You will need the following volunteers:

- 1 Participant acting as the Story Teller
- 1 Participant acting as the Farmer (he will keep the 'Poison-sprayer' with him)
- 7 Participants, to be 'Ordinary insects'
- 14 Participants, to be 'Super insects', who cover their noses with tissues
- A group of 'observers' (all remaining participants), who will take notes of what happens

Ask the 'Ordinary insects' to stay at one side of the room and the 'Super insects' on the opposite side. The middle of the room is the cocoa farm (you could draw a boundary on the floor, using chalk, being the edge of the field, and put 6 chairs or stools as trees in the field).

The Story Teller starts reading the script whilst the acting participants mime the role play (instructions in italic):

> "In the first week of the cocoa season, a Farmer went to his farm and he found 5 insects. He complained bitterly about the presence of these insects because he regularly sprayed the farm in the lean season. He did not know it, but 1 of these, a Super insect, was resistant to the pesticide that he usually used. All the others were Ordinary insects."

(1 Super insect and 4 Ordinary insects go into the farm and settle feeding on the cocoa trees. After that, the Farmer comes in and acts as if he is observing his crop and complaining about the insect population)

> "The Farmer became very worried that his cocoa pods would be eaten by the insects, and he decided to spray poison immediately. He went home and brought his Poison-sprayer and sprayed the farm. One lucky 'Ordinary insect' managed to escape the poison by hiding behind a cocoa pod."

(The Farmer brings the Poison-sprayer into the farm and sprays all except one Ordinary insect)

> "All but one of the Ordinary worms' died of poisoning and the 'super worm' happily survived because of the resistance he/she has against the poison."

[5]Adapted from Philippine farmers' folk play developed in farmer field schools during the mid 1990's

(All Ordinary insects, except one, die, while the Super insect shows his nose cover to the public as his protection and smiles)

"Now the Farmer was happy, so he went away for a week. In that week, the surviving insects gave birth to babies. Each adult insect could make 3 babies, so in the next generation, there were 3 Ordinary insects and 3 Super insects. After the mating and making babies, the adult insects died."

(Surviving insects get babies by inviting 3 more Ordinary insects and 3 more Super insects into the field, then fly away and die)

"The next week the Farmer came to the field and found 6 insects. Of course he did not know that among the 6, there were 3 Super insects that were resistant against poison. Again he was worried and he decided to spray. This time he mixed the poison a bit stronger and took care to cover all areas of plants where the insects could be hiding."

(Farmer looks around carefully and sprays all the insects, not excluding anyone)

"All Ordinary insects died of the poison spray, but the Super insects survived."

(Ordinary insects die, while the Super insects again show their nose covers to the public and smile)

"Again the remaining insects (3 Super insects) made babies. As before, each adult made 3 babies, flew away and died. Because all the parents were Super insects, the 9 new babies were all Super insects."

(Surviving Super insects get babies by inviting 9 more Super insects into the field, then fly away and die)

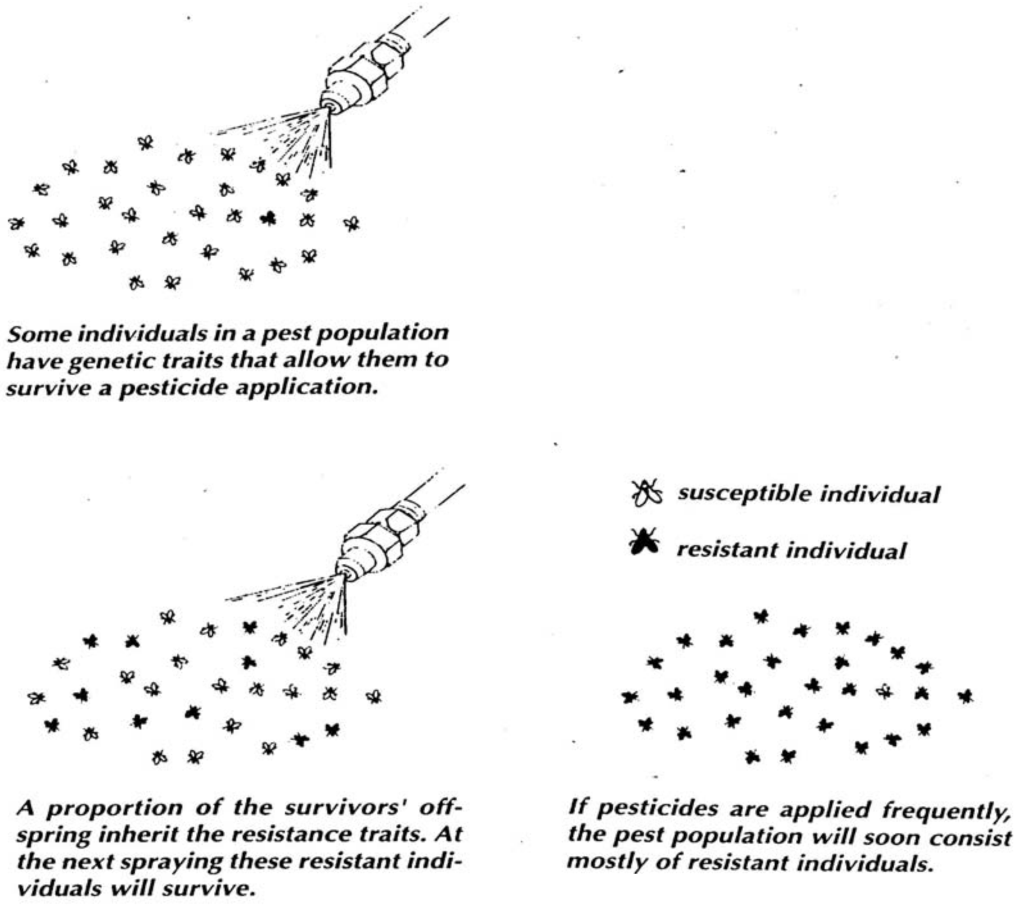
"The next week, the farmer visited the field again. Now he found 9 insects. He sprayed again with an even stronger poison, but now, none of the worms died!"

(Farmer takes his poison sprayer, looks around carefully and sprays all the insects, not excluding anyone. The 'super worms' again show their caps to the public and smile. Farmer looks puzzled)

"What should the farmer do now?"

(End of the role play: all players stand up and all observers applaud)

Figure: Insecticide resistance (Source: University of California, 1990)



Observations

Get the observers to report their observations. Use the following guide questions for the following discussion.

Guide questions for analysis

1. What did you observe in the role play?
2. How many insects died out of how many in each generation?
3. How and why did this change between the generations?
4. What would happen if the farmer would continue spraying pesticides?
5. What else could the farmer try to do?

Farmer protecting himself whilst spraying, Cameroon. Photo J. Vos © CABI Bioscience

EXERCISE 20: Field area measurement[6]

Many farmers often use local units for area, volume and weight that may not have a fixed conversion to standard units. Internationally accepted standard units for area are square meter (m^2) and hectare (10000 m^2), for weight grams (g), kilograms (kg = 1000 g) and ton (t = 1000 kg), for volume millilitres (ml) and litres (l = 1000 ml). In Cameroon, some local units (e.g. an empty tomato paste can) are relatively standard in volume and often used as measuring devices for determining application quantities of pesticides. Local measures of area include field measurements in terms of the number of power line pole units or others. Local measures of weight include e.g. specific sized baskets that would contain 10 kg dry beans. Many of these local measures vary from one person to the other.

OBJECTIVE

To understand why we need to use standard units

MATERIALS

- Poster paper and markers
- Field measure tape (50 m)
- Local small volume measuring units (e.g. tomato paste cans)

PROCEDURE

Explain the objective and background of the activity as stated above and ask participants to mention the local measuring units for lengths, areas, weight and volume. List them on poster paper. Ask participants to assist in attempting to convert these into standard units (m^2, kg, ml, etc).

E.g. (activity implemented with cocoa farmers in Cameroon):

Measure:	***Local units:***	***Converted into:***
Volume	Tomato can Spoon Bottle cover	? ? ?
Length	Distance between cocoa trees Bamboo length Palm leaf	About 3 m About 1 m About 1 m
Area	*Gabarit* (local name for 2.5 m sticks)	About 6.25 m^2
Weight	25 Cocoa pods Heaped basket	Yielding 1 kg of dry beans 10 kg dry beans

For certain local units, such as a tomato can or spoon, one can validate the volume using volumetric measure cans.

Next, 4 participants are asked to come forward. One participant is asked to draw an estimated plot of 1 m^2 on the soil. Another participant is asked to use a palm leaf to draw a plot of 1 m^2 on the soil. The third participant is asked to try and draw a plot of 1 m^2 on the soil using the measurement of a step (often used to measure a metre). The last participant is asked to draw a plot of 1 m^2 on the soil using a tape measure.

Ask all participants to compare the 4 plots drawn in the soil and see whether they are of the same size. If they aren't the same, ask why not?

Facilitate a discussion what this means if e.g. farmers report to each other on treatments and yields or profits.

[6]Adapted from *Farmer Field School for Integrated Crop Management of Sweet Potato* by E. van der Fliert and A. R. Braun, CIP, Bogor, Indonesia

GUIDE QUESTIONS FOR ANALYSIS:

1. What shapes do cocoa farms have? How would you measure those shapes?
2. Why do we need to know field areas in hectares or pesticide quantities in ml?
3. When conducting comparative field studies, why should we use standard measures for e.g. plot sizes, amount of inputs and outputs?

Harvested cocoa, Cameroon. Photo J. Vos © CABI Bioscience

EXERCISE 21: Economic analysis of the cocoa enterprise[7]

OBJECTIVE

To enhance the participants' skills in making an economic analysis of the cocoa growing enterprise, as a tool for crop management decision making.

MATERIALS

- Cocoa cultivation record cards (see attachment for one example) one for each cocoa farm of each participant plus one extra for recording the management data of the FFS field
- Poster paper and markers

PROCEDURE

The pluses and minuses of the cocoa enterprise

- The facilitator explains the purpose of this activity that is to understand the factors determining the profit of the cocoa enterprise and to present a method for economic record keeping and analysis.

- A participatory wealth ranking exercise is conducted with participants. This is followed by a list of factors (e.g. large cocoa farms, better management, more labour etc.) that contribute to the wealth differences among participants.

- A hypothetical cocoa farm of 1 ha is analysed. The participants are asked to mention all activities throughout a growing season, including post harvest practices and marketing, which are listed by facilitator on a piece of newsprint. For each activity a cost is determined by the group including both purchased inputs and labour. Household labour should be converted to its opportunity cost in agricultural wages (that is what farmers could earn working in a similar job for others). E.g. in Cameroon in areas where horticulture is important labour is hired for 5 hours per day at 1000 FCFA so cocoa farmers in these areas should evaluate the cost of their own labour at that level.

- Gross and net incomes are calculated. The net income is the gross income (quantity produced multiplied by expected price) minus the total expenditures (cost of purchased inputs, labour costs and opportunity cost of household labour).

Cocoa cultivation record keeping:

- The facilitator distributes the Cocoa Cultivation Record (attached) cards to the participants. One participant is asked to keep a seasonal record of the farmer field school field plots (conventional practice versus IPM).

- The facilitator explains what the columns and rows on the card mean and how the record should be kept.

- It is recommended that during each farmer field school session, several minutes are spent on jointly determining what has to be filled in on the record for the field school field plots and to check whether participants have any problems in keeping their own records.

- During the evaluation of the field school at the end of the season, the economic analysis of the field school plots is made by the group.

[7]Adapted from *Farmer Field School for Integrated Crop Management of Sweet Potato* by E. van der Fliert and A. R. Braun, CIP, Bogor, Indonesia

GUIDE QUESTIONS FOR ANALYSIS

1. What is the most important factor that determines the net income from cocoa farming?
2. Which expenditures can be reduced and how?
3. In order to obtain a reasonable income, what should the cocoa price be?
4. What is the farmers' daily wage? How much should it be for cocoa cultivation to become an attractive enterprise?
5. What are the differences in the costs and returns between the IPM and conventional practice plot in the field school?
6. Determine which were the most profitable IPM interventions and discuss why.

Dried cocoa beans, Cameroon. Photo J. Vos © CABI Bioscience

COCOA CULTIVATION RECORD

Name:	
Season:	Age of farm
Field area:	Cocoa variety:

		Labour quantity used (6 hour days)								
		Nonpaid		Paid			Inputs			
Week/ date	Activity	Adult	Child	Adult	Child	Expense	Type	Qty	Cost	Remarks
1-2										
3-4										
5-6										
7-8										
9-10										
11-12										
13-14										
15-16										
17-18										
19-20										
21-22										
23-24										
25-26										
25-26										
27-28										
29-30										
31-32										

		Nonpaid		Paid			Inputs			
Week/ Date	Activity	Adult	Child	Adult	Child	Expense	Type	Qty	Cost	Remarks
33-34										
35-36										
37-38										
39-40										
41-42										
43-44										
45-46										
48-50										
51-52										
Total Paid Labour and Input Expense										
Total amount of unpaid labour used										
Marketed cocoa : sale 1:________ kg sale 2:________ kg sale 3:________kg sale 4:________kg sale 5:________kg sale 6:________kg										
Gross income from harvest(s): value sale 1:_______ + value sale 2_______ + value sale 3_______ + value sale 4_______ + value sale 5_______ = ________________ total gross income										
Net income for unpaid labour, management and land: (total gross income -total paid labour and input expense)										
Net income for management and land: (total gross income -total paid labour and input expense – opportunity cost of unpaid labour)										

EXERCISE 22: Water brigade

OBJECTIVE

To demonstrate in a group dynamic the importance of co-operation

MATERIALS

- 2 Pails
- 2 Large buckets
- Water

PROCEDURE

Divide the participants into two groups of equal sizes. Line up the members of each group away from one pail, located in between the two groups.

Game I

Fill the pail located in the centre of the two groups with 6 litres of water. Announce the following instruction to the two groups:

> *"You have to use your hands to pass the water from one person to the other. The last person pours it into the bucket of your team. Everybody has to remain where he/she stands, and has to hand over the water only to the person standing exactly beside him/her. The team with the highest amount of water in the bucket at the end of this activity will be the winner".*

Start the game, and watch to make sure that nobody cheats. There is no time limit, so let the teams pass water on through the brigades until the central pail is empty. Measure the water in the three buckets to determine which team is the winner. The team having the highest amount of water in its bucket is the winner.

Note: Usually, teams spill a lot of water while competing for the common resource (water in the central pail). Show this to all of the participants.

Now team up the same teams in the same way as before.

Game II

This time, give each team its own pail containing 3 litres of water. Once again, announce the following instruction:

> *"You have to use your hands to pass the water from one person to the other. The last person pours it into the bucket of your team. Everybody has to remain where he/she stands, and has to hand over the water only to the person standing exactly beside him/her. The team with the highest amount of water in the bucket at the end of this activity will be the winner".*

Once again, start the game and check that nobody cheats. After both teams have finished taking all the water from the pails placed in the centre and passed it from one person to the next etc. into their bucket, measure the water in the receiving bucket of each of the teams and announce the winner.

Show the difference of the amount of waters in the buckets from this game compared that to the result in the first game. Ask them what was the difference between the first competition and the last one.

Water brigade group dynamic in Pakistan. Photo S. Williamson © CABI Bioscience

GUIDE QUESTIONS FOR ANALYSIS

1. Why is the amount of water in the buckets from the second game more than that from the first game?
2. What was the time difference between the first game and the second game?
3. Were there any time limitations in the first and second games?
4. Why did everybody rush during the first game but perhaps not so during the second game?
5. Why did the winning team win? Did they organise themselves prior to the second game or did they have a better team spirit and co-operated better? Was there a gender balance, if not, what gender were the members of the winning team? Why?
6. Does the game teach us something about how natural resources, such as rainforest close to cocoa growing areas, could be preserved?
7. Does this game teach us something about co-operation and how cocoa farmers can help one another?

DISCOVERY LEARNING ABOUT COCOA

Pests, including diseases, continue to place important constraints on production of cocoa worldwide, and are likely to grow more severe through further spread of aggressive pathogens. Integrated Pest Management strategies are now widely recognised as key corner stones of sustainable and environmentally sound approaches to crop production. Farmer participatory approaches are fast gaining acceptance to build farmers' capacities to make informed crop management decisions, based on a better understanding of the agro-ecology in their own fields. With farmer participatory approaches, the role of extension becomes one of a facilitator of a learning process by the farmer community. This manual is a resource for such facilitators of farmer participatory cocoa IPM programmes. It contains illustrated pest datasheets extracted from scientific databases, and field exercises that contribute to discovery based learning. The manual is expected to function as a source of inspiration for further cocoa IPM training curriculum development.

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