Pacific Community
Communauté du Pacifique

Plant Health Clinics
A training manual for plant health doctors in Pacific island countries

ACIAR HORT/2016/185: Responding to emerging pest and disease threats to horticulture in the Pacific islands

Plant Health Clinics
A training manual for plant health doctors in Pacific island countries

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Dedication

We dedicate this second edition of the manual to Osanti Luda, from Takwa village, north Malaita, Solomon Islands. He was a remarkable man, growing watermelon, and a variety of root crops on soils depleted by overuse in an area of high population. As an organic farmer, his answer was to incorporate a legume fallow into the system. He was generous to show us his farm and explain how he grew taro with yam intercrops following *Pueraria* fallows. Figures 3.44-3.46 in the soil Chapter 3 illustrate his technique. We are thankful to have known him, and for being part of the team trialling PHCs.

Foreword

This Foreword to the Second Edition of the Plant Health Clinics (PHC) manual is an opportunity for heads of agriculture and national universities of countries involved in PHCs to take stock of the program. We are pleased to do this, to look back on the last three years since the First Edition, to assess progress, and to contemplate the future.

Looking back, we recall that the launch of the manual in January 2020 coincided with the arrival of the COVID-19 pandemic. However, national agricultural agencies, universities, regional organisations and implementing agencies kept the project on track, notwithstanding the major economic and social upheavals caused by the virus. The manual was put to use: national trainer teams were trained to train extension staff who, in turn, provided farmers with the information they needed to grow healthy crops. We can all be very proud of this outstanding achievement.

At the same time, the project welcomed new members. The University of Goroka, Papua New Guinea, and the Department of Agriculture and Rural Development, Vanuatu, joined to work alongside the agricultural agencies of the original countries (Fiji, Samoa, Solomon Islands and Tonga). This was significant progress, signalling to development assistance agencies that PHCs were gaining traction in the Pacific. We understand that this expansion is likely to continue, with indication that several other countries wish to take up PHCs in the near future.

Going forward, major challenges remain as national agricultural agencies scale up PHCs from their pilot phases, and universities embed PHCs in their curricula. More immediately there are requirements to: further train extension staff, improving diagnostic and managerial capabilities, especially in those newly recruited to the service; to build confidence in extension departments to lead PHC programs, drawing support from research and biosecurity, civil society and the private sector; and to monitor the impact of PHCs in the farming community.

As for universities, we have already seen their excellent response to their role in the development of PHCs. They have opened their courses to include PHCs, not only to take on the role of training recruits and carry out research into pests and diseases, but also by offering policy directions on plant protection. We expect consolidation of these aspects in the years to come. We also anticipate that a consortium of universities, led by those where PHCs have been established, will provide guidance and support to those wishing to offer PHC courses for the first time.

Finally, we note that this Second Edition has a chapter on soils and a rewritten introductory chapter telling the story of PHCs as they developed across the world, including in the Pacific region. For soils, and in keeping with the other chapters, there is an introduction to the subject with a wealth of technical information, as well as exercises and quizzes to reinforce theory. We are pleased to see both these additions.

We commend the commitment of all those involved in the production of this Second Edition and look forward to seeing our staff using it to benefit our farmers.

Professor Transform Aqorau
Vice Chancellor
Solomon Islands National University
PO Box R113
Kukum Campus
Honirara
Solomon Islands

Dr Seuseu Tauati
Chief Executive Officer
Ministry of Agriculture and Fisheries
SAMOA

The Common Seal of the Ministry of Agriculture and Fisheries

Dr Viliami T. Manu
Chief Executive Officer
Ministry of Agriculture, Food and Forests

Dr Andrew Tukana
Permanent Secretary of Agriculture & Waterways
Ministry of Agriculture & Waterways
Government of the Republic of Fiji

15/9/23
Prof. Unaisi Nabobo-Baba
Acting Vice Chancellor
Fiji National University

Dr Teng Waninga
The Vice Chancellor
University of Goroka, Papua New Guinea

Cynthia. W. Regenvanu
Executive Secretary
Ministry of Agriculture, Livestock,
Forestry, Fisheries (MALFFB), Vanuatu

Yours Sincerely,

Elda Leah Wate
Deputy Secretary Corporate (PS, Sup)
FOR: Permanent Secretary
Ministry of Agriculture and livestock
Solomon Islands

Authors

This manual has been developed, reviewed and tested by many people in Pacific island countries, including:

Fiji

Mereia Fong-Lomavatu (FNU), Taniela Navuku (MoAW,
Makereta Rasukamaimaleya (MoAW), Toloi Vasuidreketi (MoAW),
Sereana Takayawa (FNU)

Papua New Guinea

Lilly Sar (UoG); Robert Geno (NARI)

Samoa

Sailo Pao (MAF), Fa'alelei Tunupopo (MAF), Tommy Tuuamalii (MAF),
Aleni Uelese (SROS); Angelika Tugaga (SROS)

Solomon Islands

Rosemary Alabae (MAL), John Fasi (SINU),
John Bosco Sulifoa, (SINU); Pita Tikai (KGA), Marvin Baekisapa (SINU)

Tonga

Emeline Ahoafi (MAFF), Tevita Tukunga (MAFF), Sela Tupouniua (MAFF),
Siosiua Halavatau (Consultant), Sione Kelo Foliaki (MAFF)

Pacific Community (SPC)

Fereti Atumurirava, Unaisi Turaganivalu, Visoni Timote,
Nitesh Nand, Mani Mua

Original design and layout:	Cody Ellen Murray
Second edition layout:	Terracircle Inc.
Life cycle drawings:	Graham Smith
Clearance of copyright:	Fuatino Fatiaki
Editors:	Grahame Jackson
	Caroline Smith
	Michael Furlong

Abbreviations

ACIAR	Australian Centre for International Agricultural Research
AM	Arbuscular mycorrhizae
ATP	Adenosine triphosphate
Bt	*Bacillus thuringiensis*
CRP	Cardiopulmonary resuscitation
DBM	Diamondback moth
DNA	Deoxyribonucleic acid
FAW	Fall armyworm
FNU	Fiji National University, Fiji
ICM	Integrated Crop Management
IPDM	Integrated Pest and Disease Management
IPM	Integrated Pest Management
KGA	Kastom Gaden Association
MAF	Ministry of Agriculture & Fisheries, Samoa
MAFF	Ministry of Agriculture, Food & Forests, Tonga
MAL	Ministry of Agriculture & Lands, Solomon Islands
MoA	Mode of action (of pesticides)
MoAW	Ministry of Agriculture & Waterways, Fiji
NARI	National Agriculture Research Institute
NGO	Non-Government Organisations
PHC	Plant health clinic
PHS	Plant health system
PICs	Pacific island countries
PNG	Papua New Guinea
PPE	Personal Protective Equipment
PPM	Parts per million
RNA	Ribonucleic acid
SINU	Solomon Islands National University, Solomon Islands
SPC	Pacific Community
SROS	Scientific Research Organisation of Samoa
UoG	University of Goroka, Papua New Guinea
USDA	United States Department of Agriculture
WHO	World Health Organization

Units of measurement

Volume

- L: litre
- ml: millilitre
- Liquids are often measured using bottle tops (lids):
  - Coca-Cola top = 5 ml
  - beer top = 4 ml
- Powders are often measured using bottle tops (lids):
  - Coca-Cola top = 2.5 g
  - beer top = 2 g

Weight

- g: gram
- kg: kilogram

Length/area

- m: metre
- m^2: square metre
- ha: hectare (1 ha = 10,000 m^2)

Acknowledgement

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Chapter 1

Plant Health Clinics

1.1 An Introduction

Many of you reading this chapter will have heard of plant health clinics (PHCs), and some of you may have experienced them firsthand. You will know that they are an attempt to help extension officers and farmers work together to reduce crops losses from pests, diseases and weeds, which FAO estimates to be between 20 to 40 percent annually. Certainly, if you include poor crop growth due to nutritionally deficient soils or damage from modern agricultural practices, the reduction is probably nearer the higher end.

But what you might not know is how PHCs started and why they have spread so quickly around the world. Looking at the origin of PHCs – why they were established in the first place and how they have developed – may give useful insights and ideas for use in the Pacific region. Here we give a brief account of how they started, taken from a story told by one of the people who was there at the beginning and, later, how they have developed in Pacific island countries[1] [2].

Let's set the scene. It's a small town, Tiraque, about 2 hours from Cochabamba, in Bolivia, South America, in December 2001. Next day is the weekly market (a so-called agricultural fair) when farmers come to town. Staff from two non-government organisations, one local (PROINPA[3]), the other international (CABI[4]) are discussing how to bring agricultural diagnostic and advisory services closer to farmers to play their part in reducing global poverty, an objective of the United Nations Millennial Development Goals, which had appeared the previous year. For this, they needed a new approach.

After much deliberation, it was decided to give an unannounced public demonstration of a diagnostic test for a crop disease to as many farmers as were interested. The test they chose was for root-damaging nematodes of potato, and what to do if the nematodes were present — crop rotation. Root nematodes are a major problem of potato, the staple food crop of the region.

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1 Boa E (2009) How the Global Plant Clinic began. Outlook on Pest Management: 112-116.

2 Bentley, Jeffery W., Eric Boa, Solveig Danielsen, Pablo Franco, Olivia Antezana, Bertho Villarroel, Henry Rodríguez, Jhon Ferrrufino, Javier Franco, René Pereira, Jaime Herbas, Oscar Díaz, Vladimir Lino, Juan Villarroel, Fredy Almendras & Saúl Colque (2009) Plant Health Clinics in Bolivia 2000-2009: Operations and Preliminary Results. Food Security 1(3):371-386.

3 PROINPA — Promoción e Investigación de Productos Andinos.

4 CABI – Intentional, inter-governmental, not-for-profit organisation, previously Commonwealth Agriculture Bureau International, now Centre for Agriculture and Bioscience International.

At this point, we should introduce the two representatives from CABI, as they appear later in this chapter. One was Eric Boa, head of the Global Plant Clinic that provided diagnostic and advisory services to developing countries, and Jeff Bentley, a CABI associate and resident of Bolivia. The representatives from PROINPA were agricultural technicians, experts in extension, both at ease with farmers and fluent in the local language, but neither were expert plant pathologists.

Although there was no warning that demonstrations would be held, large number of farmers came to hear about the diagnostic tests for potato nematodes. A similar interest was shown a few days later when diagnosis and advice were given on fruit crop diseases in a town close by. On that occasion, there was no market day, so talks were held at the bus station using a borrowed table!

So, the idea of mobile plant health clinics as they became known was born. Soon after, one of the international research organisations, CIAT[5], also became involved. CIAT already had an office in Bolivia and gave daily advice to farmers at a permanent building in a town not far from Cochabamba, which has a laboratory, so mobile PHCs were a natural extension to their on-going work. The connection between the so-called 'mobile' and 'fixed' clinics is important; they can be mutually supportive. Mobile clinics need expert diagnostic support, and labs can take advantage of mobile clinics with their access to crops of the neediest farmers, and any new problems as they arise.

The early success in Bolivia was sufficient for the Global Plant Clinic to partner other countries in trying out PHCs. The first countries were Bangladesh, Nicaragua and Uganda, followed by many more countries in Asia, Africa and Latin America. By 2009, there were 21 countries holding PHCs either regularly or testing them in pilot schemes. In some, NGOs took the lead, as had happened initially in Bolivia, in others, it was national governments, and sometimes a partnership between the two. Not all were successful, with some countries unable to find a suitable organisation to host the PHCs[6], but overall, the output has been extremely rewarding[7].

In 2011, the CABI plant clinics program, previously under the Global Plant Clinic, was transferred to Plantwise under Plant Health Systems Development, together with two other components: The Plantwise Knowledge Bank and Monitoring and Evaluation. By the end of 2018, approximately 3000 PHCs had been established in 30 countries, and more than 10,000 people trained to hold them[8]. Apart from PHCs, rallies were also held at town squares or in large streets providing farmers with information on topics that were known to be of interest to them.

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5 CIAT, Centro Internacional de Agricultura Tropical, Peru.

6 Ibid p. 115.

7 Impact Report 2011-2018. CABI Plantwise. pp. 58.

8 Plantwise Impact Report 2018. CABI, UK.

An idea, formulated on the eve of a market in Bolivia in 2003 to provide farmers with information on how to protect their crops against an important local pest, had become worldwide within 15 years. Today, we would say it had gone viral! Wherever PHCs were held, the format was similar: venues were farmer-friendly places, farmers brought samples of their crops with pest and disease damage, and locally trained extension staff — 'plant doctors' — made a diagnosis and provided verbal and written recommendations on management. Written instructions were given to farmers to retain, just like the prescription we get from a medical doctor. The similarity to clinics and health centres for humans was readily understood by farmers. It was an idea worth testing in Pacific island countries.

1.2 Plant health clinics in the Pacific — a start

Just as in many countries of Asia, Africa and Latin America, PHCs provided Pacific islands with a new approach. Technical support services for farmers with pest and disease problems were often ineffective, with farmers left without advice and having to deal with them as best they could. This often resulted in either nothing being done and the problem getting worse, or the use of inappropriate control measures. Further, as noted elsewhere, it had been challenging to create effective collaboration between all those involved in plant protection to build an effective plant health system that was so badly needed. This was of concern, especially at a time when agricultural production for local and export markets was being emphasised, demands for home use were growing, and more than 70 percent of the population in many Pacific island countries were relying on agriculture for their livelihood. A climate crisis with the potential to create epidemics of pests and diseases could only make matters worse.

News of plant health clinics reached the Pacific soon after they became established in Bolivia, and were being tested in Bangladesh, Nicaragua, and Uganda. At about that time, an ACIAR project to re-establish a plant protection capability in Solomon Islands, IPPSI[9], had started with the objective of increasing community awareness and understanding of plant pests and diseases, leading to improved and sustainable crop management. PHCs seemed an ideal way to achieve this, and with funding promised later, IPPSI began writing fact sheets on the most important pests and pathogens of the country in preparation, realising that if a sub-regional project eventuated, many of the fact sheets would have a wider significance.

The project did eventuate with the support of ACIAR. Phase 1, *Strengthening integrated crop management research in the Pacific islands in support of sustainable intensification of high-value crop production* (HORT/2010/090) began in 2011, implemented by the University of Queensland in association

[9] IPPSI, Improved Plant Protection for Solomon Islands (ACIAR funded).

with the Pacific Community (SPC). Along with Solomon Islands, the project partners were Fiji, Samoa and Tonga.

With agreement between the partners, the PHC program began as a pilot phase in Solomon Islands in May 2012 (Fig. 1.1). Eric Boa from CABI conducted the initial training, bringing experience in establishing PHCs elsewhere. He presented Module 1, Field diagnosis and plant clinic operations, a three-and-a-half-day course given to workshop participants who came from research and extension divisions of all four project partners. The idea being that at the end of the pilot phase, they would return to Solomon Islands and take part in an evaluation; this would help with the uptake of PHCs in their own countries. After the initial training given by Eric Boa, everyone took part in PHCs at markets to practise their newly-developed skills as plant doctors[10]. There was a short reflection where plant doctors shared samples brought by farmers and the diagnoses and recommendations that they had made.

Subsequently, more than 20 clinics were held in Solomon Islands on the islands of Guadalcanal and Malaita, followed by a three-week evaluation after 16 months. Jeff Bentley was the evaluator, visiting both islands and seeing clinics in operation. Jeff's report made interesting comments and recommendations.

The evaluation of the pilot phase showed that farmers face challenges in managing plant health problems and extension workers have difficulties giving advice. Biotic (pests and diseases) and abiotic (non-biological) causes lead to regular and often significant losses in crop production and quality. Diagnosis is difficult because of the diversity of symptoms and possible causes, meaning that choosing the best management options needs skill and careful consideration. On a more positive side, the pilot phase showed that there was high farmer satisfaction with the PHCs, and the plant doctors' knowledge and confidence improved substantially over the period.

Recommendations from the evaluation suggested:

- pilot phases in other project countries for 18 to 24 months before widespread establishment of PHC programs
- a 'champion' with enthusiasm and commitment to PHCs should be selected within each country
- more pest and disease fact sheets should be written
- the sustainability of PHCs beyond the funding period should be a consideration at the outset, with clinics incorporated into department policies and workplans
- PHCs should be written into extension staff terms of reference, they were not to be thought of as unpaid extra work.

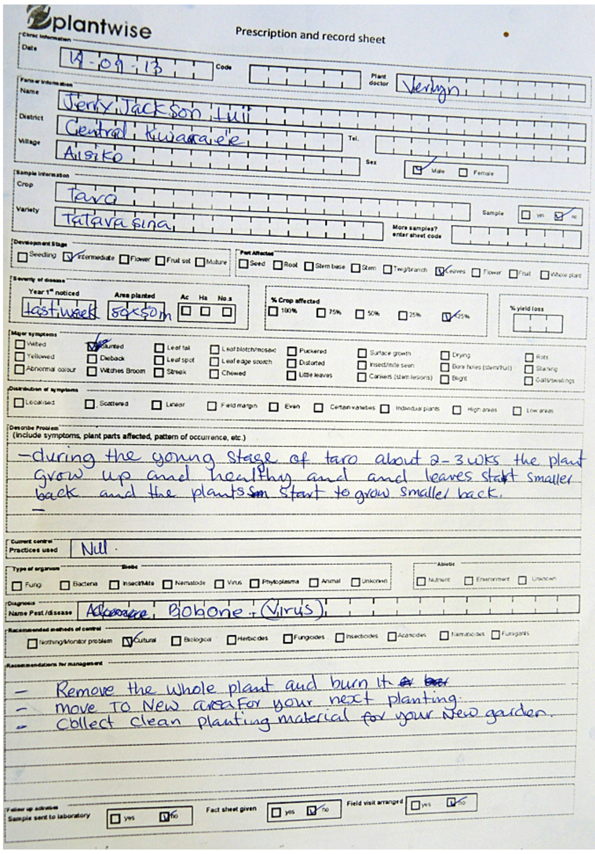
[10] Module 2 is on giving good management advice to farmers, Module 3 on writing pest fact sheets, and Module 4 Monitoring plant clinics.

Fig. 1.1 Introduction to the PHC, May 2012, Henderson, Guadalcanal.

An evaluation at the Honiara market with Jeff Bentley. Source: authors

A plant doctor giving advice to a farmer. Source: authors.

Representatives from Fiji, Samoa, Solomon Islands, Tonga (and Eric Boa). Source: authors.



plantwise

Prescription and record sheet

Clinic information
Date: 14-09-13 | Code: | Plant doctor: Verlyn

Farmer information
Name: Jerry Jackson Lui
District: Central Kwara'ae | Tel.:
Village: Aisiko | Sex: ☑ Male ☐ Female

Sample information
Crop: Taro
Variety: Tatava sina | Sample: ☐ yes ☑ no | More samples? enter sheet code:

Development Stage: ☐ Seedling ☑ Intermediate ☐ Flower ☐ Fruit set ☐ Mature
Part Affected: ☐ Seed ☐ Root ☐ Stem base ☐ Stem ☐ Twig/branch ☑ Leaves ☐ Flower ☐ Fruit ☐ Whole plant

Severity of disease
Year 1st noticed: last week | Area planted: 50x50m | Ac ☐ Ha ☐ No.s ☐
% Crop affected: ☐ 100% ☐ 75% ☐ 50% ☐ 25% ☑ <25% | % yield loss:

Major symptoms: ☐ Wilted ☐ Yellowed ☐ Abnormal colour ☑ Stunted ☐ Dieback ☐ Witches Broom ☐ Leaf fall ☐ Leaf spot ☐ Streak ☐ Leaf blotch/mosaic ☐ Leaf edge scorch ☐ Chewed ☐ Puckered ☐ Distorted ☐ Little leaves ☐ Surface growth ☐ Insect/mite seen ☐ Cankers (stem lesions) ☐ Drying ☐ Bore holes (stem/fruit) ☐ Blight ☐ Rots ☐ Staining ☐ Galls/swellings

Distribution of symptoms: ☐ Localised ☐ Scattered ☐ Linear ☐ Field margin ☐ Even ☐ Certain varieties ☐ Individual plants ☐ High areas ☐ Low areas

Describe Problem (include symptoms, plant parts affected, pattern of occurrence, etc.)
- during the young stage of taro about 2-3 wks the plant grow up and healthy and and leaves start smaller back and the plants ~~sm~~ start to grow smaller back.

Current control Practices used: Null.

Type of organism
Biotic: ☐ Fungi ☐ Bacteria ☐ Insect/Mite ☐ Nematode ☐ Virus ☐ Phytoplasma ☐ Animal ☐ Unknown
Abiotic: ☐ Nutrient ☐ Environment ☐ Unknown

Diagnosis
Name Pest/disease: ~~Alomae~~, Bobone. (Virus).

Recommended methods of control: ☐ Nothing/Monitor problem ☑ Cultural ☐ Biological ☐ Herbicides ☐ Fungicides ☐ Insecticides ☐ Acaricides ☐ Nematicides ☐ Fumigants

Recommendations for management
- Remove the whole plant and burn it ~~or bur~~
- move To New area For your next planting.
- Collect clean planting material for your New garden.

Follow up activities
Sample sent to laboratory: ☐ yes ☑ no | Fact sheet given: ☐ yes ☑ no | Field visit arranged: ☐ yes ☑ no

CABI Plantwise prescription form (now replaced)

Overall, the pilot phase was considered a success. Clinics continued in Solomon Islands, Fiji and Samoa, all of which had sent representatives to the first workshop in 2012, and decided to start their own programs, even though support had not been budgeted under Phase 1. In Tonga, a start was made in 2018, and PHCs continued in all countries under a second phase of the sub-regional project, *Responding to emerging pest and disease threats to horticulture in the Pacific islands* (HORT/2016/185) (Fig. 1.2).

After three years, and during the COVID-19 pandemic, Vanuatu joined the program. Further, three regional universities: Fiji National University (FNU), University of Goroka (UoG) in PNG and Solomon Islands National University (SINU) undertook to include PHCs in their agriculture courses. This is a significant step forward for the sustainability of PHCs after funding ceases.

1.3 Plant health clinics take shape

So far, we have told the story of the beginnings of PHCs in Bolivia, their spread worldwide and their start in Pacific island countries. We have stressed they were different from the 'fixed' clinics that had gone before, and that are still practised in many countries to this day. Our interest is in the 'mobile' kind that are held at places where farmers normally meet, at markets, bus stands, fairs, shows, and the like. This is unique, just as is having trained plant doctors, and record keeping prescriptions, with copies going to the farmers. And we have said how much farmers welcome PHCs.

What we have not yet said is that there are two major concepts playing out as overarching themes that guide PHCs. One involves their relationship to human and animal health services, and the other is their link with IPDM[11] (integrated pest and disease management). Understanding the importance of these connections is explained next.

[11] The letter D has been included for 'diseases' as pests are often considered to be insects alone, not all the organisms that attack plants, i.e., insects, pathogens, weeds, birds, slugs, snails, etc.

Fig. 1.2 A plant health clinic.

Farmers come with samples to have their problems diagnosed and to receive recommendations for management from plant doctors – trained extension staff.

A table, a chair (some shade) and a prescription form are essential equipment.

The summary form gives location, date, how many farmers attended, and information on the main insect pests, diseases and weeds.

Source: Ministry of Agriculture & Water, Fiji.

LABASA PHC - DREKETILAILAI, FIJI

MINISTRY OF AGRICULTURE

11th MAY, 2023

This Plant Health Clinic was held at Deketilailai about 20 minutes drive from Labasa town. The clinic started at 9am and concluded at 12pm. Nineteen (19) farmers attended; 3 females. Farmers came from Dreketilailai and Lekutulevu. A few farmers brought samples and some came with more than one problem There were 25 problems diagnosed including 1 unknown.

The problems include kava dieback , anthracnose on eggplant and chilli, scales on cassava and eggplant, bacterial wilt on eggplant, wilting of amaranthus, leaf spots on eggplant, leafminer on bele, snails and slugs on tomato and pumpkin, mealybugs on eggplant, red spider mites on bele, cluster caterpillar on dalo, powdery mildew on eggplant, banana bunchy top, ladybird beetle on eggplant and plaintain not bearing fruit (unknown).

Plant doctors from Crop Extension were Reshmi Lata, Saula Tavitani, Beren Teresia, Rajneel Lal, Sera Tuiwainunu Leweniqila, Nikhil Chand, Losana Nakato, Swastika Devi, Jocami Soronamata and Alefina Matagasau. Those from Crop Research include Toloi Vasuidreketi, Lusiana Seru, Takala Talacakau, Paula Koroikata, Anare Caucau, Vilikesa Tokaduadua and Semi Seruvakula from SPC. Alefina Matagasau was the clinic manager.

Prepared and reported by the Ministry of Agriculture. For more information, contact Alefina Matagasau Extension Labasa. Mob: 9571478; amatagasau@gmail.com. Plant Health Clinics are held as part of a sub-regional ICM/IPDM project (HORT/2016/185) – *Responding to emerging pest and disease threats to horticulture in the Pacific islands*, with support from the Australian Centre for International Agricultural Research, Canberra.

1.3.1 A medical model for PHCs

PHCs have done well in a short time, but many see them progressing further. They could underpin the development of plant health systems, bringing together extension, research, biosecurity services, regulatory bodies, education institutions, and agricultural input suppliers[12]. After all, each of these is involved in, or provides support to, PHCs.

To develop the collaboration that is required for an effective plant health system, different models have been considered, and the one used by medical services is an obvious candidate. After all, such services contain practices that are just as appropriate to plant health as they are to human or animal health. The notion has become more compelling with the development of the One Health concept. But more about that in Chapter 3 on soils.

Processes and practices based on human health systems are useful for thinking about the role of PHCs as part of an effective plant health system. Although there are obviously major differences between human and plant health there are also many similarities.

They can be summarised in six stages as follows:

- **prevention** — growing healthy plants that are less likely to be affected by pests depends on building a healthy agricultural ecosystem with fertile soil and the use of cultural controls, rather than toxic chemicals
- **personal** — a good plant doctor can give accurate, personalised advice to suit each farmer's situation, instead of the same solution for everyone
- **predictive** — an effective plant health system uses monitoring to predict the likelihood of pest and disease outbreaks based on weather conditions or biosecurity breaches (farmers are on the front line, bringing new or unrecognised pests and diseases to the attention of extension staff through the PHCs)
- **participatory** — accepting that the farmer is an active participant, attending PHCs to alert extension staff but also to find solutions together, rather than accepting recommendations with little explanation.
- **partnerships** — an effective plant health system relies on the cooperation of all relevant agencies — particularly extension, research, biosecurity, training divisions, farmers' organisations and pesticide retailers
- **treatment** — when a problem arises, depending on its seriousness, the plant doctor at a PHC starts by giving management advice that is least harmful to the agricultural ecosystem, such as those based on IPDM methods, before resorting to pesticides.

12 Eric Boa, Javier Franco, Malvika Chaudhury, Patrick Simbalaya, and Elna Van Der Linde (2016) Note 23: Plant health clinics. Global Forum for Rural Advisory Services (GFRAS). Lausanne, Switzerland.

In 2007, the WHO established a health system framework based on six basic 'building blocks',[13] namely:

i. a sustainable financing mechanism, which averts impoverishment of people due to healthcare costs
ii. a sufficiently healthy workforce having the right skills and motivation
iii. a reliably healthy information system for policy and program decision making
iv. well-maintained facilities with adequate medicines and appropriate technologies
v. robust mechanisms to deliver quality health services, and
vi. a robust stewardship to lead and steer the health systems[14].

The WHO framework seems an ideal way of evaluating PHCs in Pacific island countries. It also shows the connection between the two systems of plant and human health. This is, perhaps, not surprising, we want to build a plant health system that is properly financed, well led, underpinned by PHCs, supported by farmers, extension services, regulatory bodies, education and research institutions, and agricultural input suppliers. We want to be able to monitor pest outbreaks and forecast any threats to come.

To quote the WHO, but having plants in mind not humans, we can say our goal is:

> *"A [plant] health system [that] consists of all organizations, people and actions whose primary intent is to promote, restore or maintain plant health[15]"*

Interestingly, the framework in a slightly modified form has been applied at the PHC level to assess performance of PHCs in Uganda. A set of variables (i.e., sub-components) was used to define each of the WHO components, allowing the identification of 'key' features that affected PHCs and their context[16]. This could also be used to evaluate PHCs in Pacific island countries.

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13 WHO (2007). Everybody's business: strengthening health systems to improve health outcomes: WHO's framework for action. Geneva: World Health Organization.

14 A slightly modified wording of the framework appears on the WHO website for South-East Asia https://www.who.int/india/health-topics/health-systems-governance

15 Ibid.

16 Solveig Danielsen, Eric Boa, Moses Mafabi, Emmanuel Mutebi, Robert Reeder, Flavia Kabeere, Robert Karyeija (2013) Using plant clinic registers to assess the quality of diagnoses and advice given to farmers: Uganda. Journal of Agricultural Education and Extension 19(2): 183-201.

1.3.2 Integrated pest and disease management

In recent years, IPDM has become a popular method of plant pest and disease control. It is considered healthier and more environmentally sustainable as it does not rely solely on the use of synthetic pesticides. IPDM involves cultural practices and pays attention to biological control – the natural way that insects (and pathogens) are controlled by predators and parasites.

Cultural control practices are integral to IPDM. There are many that can be used, for instance, healthy soil, healthy planting material, crop rotation, isolation of crops, crop hygiene, time of planting, resistant varieties. When several are applied together, the cumulative effect is often far greater than when applied individually, resulting in lower insect damage and incidence of disease.

Biocontrol by natural enemies is also an important aspect of IPDM. It works by convincing farmers to avoid using broad-spectrum pesticides that kill all insects, both 'good' (beneficial) and 'bad' (pest). Control by natural enemies is also increasingly applied to plant pathogens. There is growing use of fungi, bacteria and nematodes, species that are naturally antagonistic to plant pathogens — *Trichoderma, Beauveria, Bacillus, Pseudomonas, Steinernema,* although many need to be reapplied repeatedly.

However, IPDM does not prohibit the use of pesticides: it suggests they are used only as a last resort when other methods have been tried and found insufficient to obtain the desired level of control. IPDM also maintains that pesticides should be used at levels that are economically and ecologically justified, according to the manufacturer's instructions, and at minimal risk to human health and the environment.

The last point is particularly important: in all situations it is best to avoid the use of pesticides that are broad-spectrum nerve toxins, gut poisons or hormone mimics, and are a danger to beneficial organisms as well as human and other animals. So-called biorational products — botanicals (neem, chilli, garlic, vegetable oil), microbial pesticides (Bt, spinosad, *Beauveria* and other examples mentioned above), minerals (kaolin clay, ash, insecticidal soap) and insect growth regulators — that are relatively non-toxic, are considered a better fit for an IPDM strategy.

1.4 PHC Resources

1.4.1 The manual

This manual forms part of a PHC program that trains extension staff (and others) to identify pests and diseases and to give advice to farmers in a local context through a PHC. In addition to providing advice, plant clinics capture on-the-ground intelligence about what is happening in a particular region, thus giving PHCs a unique ability to contribute to early warning of new pests. The databasing of clinic information is also essential here, and the use of KoboToolbox and KoboCollect in this regard can be found in Chapter 4.

The need for the manual was first recognised at a project advisory group meeting in April 2018[17]. If a group of regional trainers was to be formed, they needed technical information relevant to PHCs and, importantly, how to teach it based on what we know about adult learning. Few of the trainers had teaching experience, although it was their task to train national trainers.

However, although everyone at the April meeting realised that a training manual was key to the training of extension staff, previous experience in the region suggested that manuals were written but often not used. This being the case, the regional trainers decided they should design and develop the manual themselves. In doing so, they were guided by the needs of those who would potentially receive the training, and how they would deliver it (Fig. 1.3). They considered this would ensure a strong degree of relevance, and likely a sense of ownership. At the April meeting, an outline was agreed, and chapters allocated to volunteer authors.

Once drafted, the manual was workshopped in each country by members of the regional team, together with extension and research personnel, who had not been involved in its development, to see if it worked. The first workshop was in Samoa in October 2018, after which revisions and amendments were once again made. This was followed by workshops in Tonga (November 2018) and Solomon Islands (May 2019), by the end of which, the revised manual was finalised and printed.

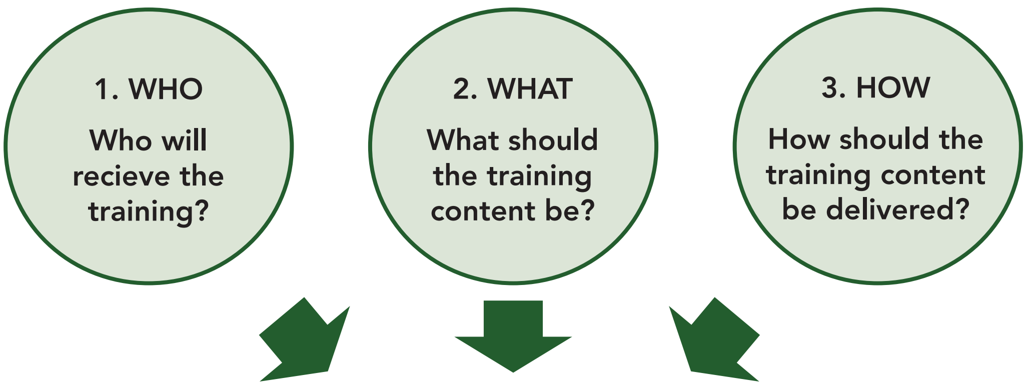

Fig. 1.3 PHC training manual design.

[17] Caroline Smith *et al*. Developing a training system for Plant Health Clinics in the Pacific region by and for regional trainers.

1.4.2 Layout of the manual

The manual consists of nine chapters and an appendix. It is written for trainers of plant doctors and aims to build on the PHC concept:

- **Chapter 1:** Introduction to PHCs, and how they developed
- **Chapter 2**: Pest and disease identification and diagnosis
- **Chapter 3**: Soils
- **Chapter 4**: The treatment of 'unknowns' using digital applications
- **Chapters 5 & 6**: IPDM
- **Chapter 7**: The planning and running of PHCs.

Each of these chapters contains a list of materials that trainers will need, technical information, and a range of exercises, practical work and quizzes designed to facilitate learning.

- **Chapter 8** contains information for trainers on effective teaching strategies and practices.
- **Chapter 9** contains the answers to the exercises and quizzes.
- **The appendix** contains forms and other resources for trainers.

1.4.3 The Pacific Pests, Pathogens & Weeds app

The Pacific Pest, Pathogens and Weeds app is in its 12th edition. The premise behind its development is that when crop pests occur, farmers want help and advice immediately. They don't want to wait, and in many cases they cannot wait. If they do not act quickly, they may lose the crop.

The app has 555 fact sheets, the majority are focused on pests and pathogens from the region, and the weeds are exclusively so. However, it includes some pests and pathogens not yet present but near enough to the region and important enough not to be ignored. Apart from full fact sheets, there are also mini ones, summaries, especially written for extension staff for occasions when they need concise information when discussing a pest, pathogen or weed with farmers at a PHC and there's no time to read a full account. Details of the app and how to use it efficiently can be found in Chapter 4.

In addition to new pests, the app has country translations of common pests and diseases, those that farmers frequently bring to the PHCs.

Each country, Fiji, Samoa, Solomon Islands, Tonga and Vanuatu, has chosen 20 mini fact sheets and translated these into local languages. In the case of Fiji, translations are both in Fijian and Hindi.

CHAPTER 2

Identification and Diagnosis of Plant Pests and Diseases

In this chapter you will learn the meaning of biotic and abiotic (and what may confuse you), what a pest is, how insects (and mites) can be good or bad, the life cycles they have, and consider the symptoms that help to identify them. You will also learn about plant pathogens, the diseases they cause, and their symptoms.

What equipment do I need?

- ❑ pre-prepared PowerPoint presentation to cover Sections 2.2-2.8
- ❑ plastic bags
- ❑ marking pens
- ❑ hand lenses
- ❑ samples of pests and diseases, enough for one per trainee
- ❑ laminated pictures of plant pests and diseases:
    - A, B & C (pp. 19-26)
- ❑ Pacific Pests, Pathogens & Weeds app:
    - fact sheets
    - mini fact sheets
- ❑ 3 tables marked A, B & C
- ❑ brown or butchers paper
- ❑ sticky tape.

2.1 Introduction to diagnosis

Many farmers and extension staff find it hard to identify pests and diseases that attack crops[1]. However, without knowing the cause of the damage seen in the field, it is difficult to know what to do for the best. Often, damage from disease is mistaken for damage from insects, and vice versa. Sometimes the cause is not even a pest or disease, but an abiotic factor. Without good identification and diagnosis, guesses may be made which can result in the wrong management being suggested, such as too much pesticide or the wrong pesticide. Or, perhaps, nothing is done because of the confusion.

> *The damage to crops caused by pests and diseases and other factors appear as symptoms (or signs). These are very important as they help identify the cause of problems.*

So, what can we do? We can get an idea of the cause of crop pest and disease problems by looking at the damage — the symptoms or signs on the plant. This is exactly what the doctor does when you go to a clinic. The doctor examines you, looks at the symptoms and asks questions. In a similar way, a plant health doctor must find the cause of a problem by examining the plant, looking at the symptoms and asking questions. Obviously, in this case the farmer answers the questions as plants cannot speak for themselves!

To become proficient plant health doctors, trainees need to spend a lot of time becoming familiar with the plant pests and diseases in their countries. There is no substitute for experience! The trainees need to know how to examine plants carefully with the help of a hand lens, recognise symptoms, and make use of resources, such as the Pacific Pest, Pathogens & Weeds app, their country social media groups, and other resources. More on these resources in Chapter 4.

2.1.1 Diagnosing using A, B or C

After looking at damaged plants during farm visits or those brought by farmers to PHCs, the next step is to think of A, B and C. Trainees need to sort the causes of the problem (or think of them) fitting one of three categories.

The causes they have to choose from are:

i. non-living
ii. living and
iii. not sure or confused.

---

[1] Sometimes the terms 'pest', 'disease' and 'pathogen' are confused or used interchangeably. Diseases in plants are caused by pathogens (infectious organisms), as well as environmental conditions (abiotic or physiological factors). Pests, such as insects and mites, affect plant health by chewing or sucking. Weeds are also sometimes included as 'pests'. In this manual we use the word 'pest' to include insects, mites, other animals and weeds, and the word 'disease' to include pathogens, i.e., fungi, oomycetes, bacteria, viruses, nematodes, phytoplasmas and viroids

We can call these causes:

- abiotic (A) for non-living
- biotic (B) for living and
- confused (C) for not sure (confused).

A, B or C, respectively (Table 2.1).

Abiotic

Abiotic factors are non-biological. Just like people and animals, plants get sick, not just from pests and diseases but also from non-biological factors; these we call 'abiotic'. For plants, these can include unhealthy environments such as poor soil, devastating weather, chemical poisons, or damage during cultivation. Sometimes, it is difficult to differentiate between abiotic and biotic damage on symptoms, as they can look quite similar. For example, a variegated but healthy leaf can be diagnosed as having a disease or a nutrient deficiency, whereas variegation can be a genetic condition where chlorophyll is absent from part of the leaf.

Table 2.1 shows the main abiotic factors that can cause problems in plants.

Of these, perhaps the most important are poor soil structure and composition, and nutrient deficiencies. These will be covered in Chapter 3.

Biotic

Biotic factors form a very large section, so we split them into smaller groups in the hope that the symptoms (signs) we see in the field will give us clues to the type of organisms that are causing the damage. For instance, insects and mites can be split into those that chew, those that suck, and those that pierce (see Table 2.2 and Figs. 2.50-2.101).

Table 2.1 **Different categories that make up abiotic and biotic causes. 'Confused' can be when there could be more than one cause, or you do not know what it is.**

Abiotic — non-biological causes	Biotic – biological causes
Nutrient deficiencies	Insects
Drought (water stress)	Mites
Water-logging	Birds
Root damage from ploughing, hilling up, etc.	Snails and slugs
Fertiliser burn	Rats and mice
Herbicide damage	Parasitic plants, e.g. Cuscuta (dodder), mistletoe
Salt spray	Weeds
Lightning Frost, e.g. in the highlands of PNG Sunscald Very hot weather Senescence (old age)	Pathogens: • fungi • oomycetes • bacteria • nematodes • phytoplasmas • viruses and viroids
Chimaera (variegation)	

Pathogens, too, can be split into those that cause spots, blights, rusts, wilts, mildews, and more (Figs. 2.111-2.136). The idea is to match the symptoms we see with the damage we associate with different types of organisms as closely as possible.

Of course, we must have some idea about the different symptoms these groups cause in the first place, and that comes down to experience and practice. The manual Sections 2.3.2 (Insect life cycles), 2.4 (Symptoms of insect and mites), 2.5 (What is a plant disease?), and 2.6 (Symptoms of pathogens), will help you by providing information, and 2.8 (Making a diagnosis: symptoms, possibilities, and probabilities) will give you the opportunity to put the learning into practice.

Once we have identified the likely cause of the damage, we say we have made a diagnosis. Then we can go on to recommend a treatment.

Confused

But what do we do if we are confused? That is, we can not decide between abiotic and biotic? A plant health doctor might be confused because the farmer presents a plant with symptoms that:

- may be caused by more than one pest or disease, so the symptoms are not clear or he or she is not sure which is the more important
- is present in the country, but unknown to the plant health doctor as he or she is new to the job and does not know the symptoms well enough to give a diagnosis with certainty
- is new to the country, i.e. the problem is unknown previously.

It takes much time and experience to become good at diagnosing symptoms, and even experts do not always know the cause of a plant problem. There are a lot of resources to help, and this manual will help your trainees to become familiar with:

- using a WhatsApp group, or other social media group
- Pacific Pests, Pathogens & Weeds app — full and mini fact sheets
- PestNet Community.

If the problem is still confusing or unknown, samples will need to be sent to the agencies in each country that deal with pest and disease identification, i.e., to research or biosecurity. It may even mean that samples (or photographs of samples) need to be sent overseas for examination. Further information on these aspects is given in Chapters 4 and 6.

Some examples of C, confusing symptom, are given in Fig. 2.1. This is followed by exercises on A, B or C, a section on abiotic factors and then longer sections on biotic pests and pathogens.

Fig. 2.1 Examples of confusing symptoms.

Dead and dying coconuts similar to the damage caused by lightning strike, although in this case due to Bogia disease associated with a phytoplasma disease (Papua New Guinea).

Sooty mould on soursop associated with a soft scale infestation and ants.

Honeydew excreted by the scales falls on the leaves and is then colonised by a black fungus which grows superficially on the leaves.

The ants protect the scale from predation and parasites.

Banana fingers with thickened skin possibly mistaken for a fungal rot.

A natural variegation on cassava leaves.

Capsicum infested by broad mite, often mistaken for a virus symptom.

EXERCISE 2.1: A, B, C?

This exercise helps your trainees to begin to apply their learning to describe plant damage as abiotic (A), biotic (B) or confused (C) — either a mixture of symptoms or unknown.

- **in groups**, allocate one or two sets of photo sheets of Pacific island pests and diseases
- **for each photo**, trainees should decide whether the damage is caused by abiotic (A) or biotic (B) factors, or if unsure, confused (C)
- **fill in the table** for the A, B, C photo sheets
- trainees will need to draw a **separate table** for each photo sheet
- trainees should **give reasons** and present their answers to the rest of the class
- go through the answers first before asking them to fill in the last column.

Your answers

Crop	Photo	A, B or C?	Reasons	Correct answer (fill in after class discussion)
	1			
	2			
	3			
	4			
	5			
	6			
	7			
	8			

EXERCISE 2.1: Banana

Are these symptoms caused by something abiotic [A], biotic [B] or confusing [C]?

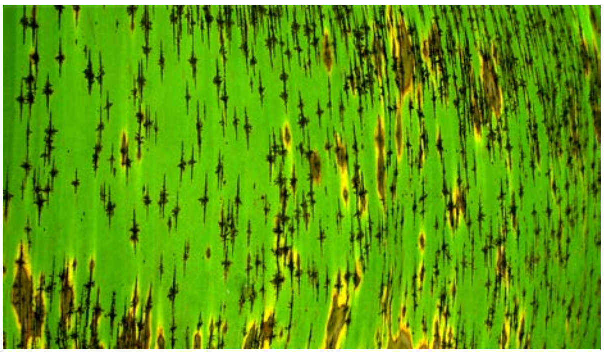

Photo 1: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 2: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 3: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

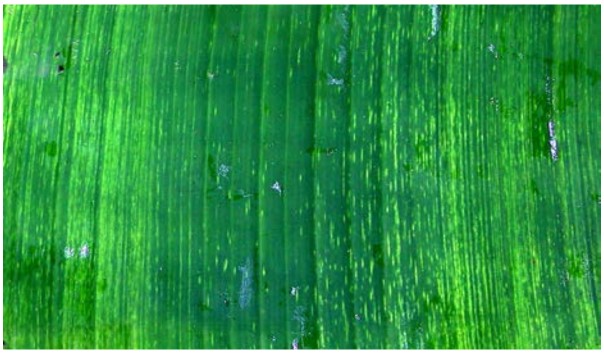

Photo 4: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 5: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 6: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 7: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 8: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Source: Photo 3: Wikimedia commons. Mokkie. Musa x paradisiaca 'Ae Ae'. Hawaii. Source: Photo 8: Richard Markham, Fiji. Source: Photos 1,2,4,5,6,7: authors

EXERCISE 2.1: Bele

Are these symptoms caused by something abiotic [A], biotic [B] or confusing [C]?

Photo 1: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 2: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 3: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 4: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 5: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 6: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 7: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 8: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Source: Photos 1-8: authors.

EXERCISE 2.1: Cabbage

Are these symptoms caused by something abiotic [A], biotic [B] or confusing [C]?

Photo 1: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 2: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 3: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 4: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 5: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 6: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 7: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 8: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Source: Photos 7 Source: Gerald Holmes. Cal Poly San Luis. Bugwood.org. Source: Photos 1,2,3,4,5,6,8: authors.

EXERCISE 2.1: Cassava

Are these symptoms caused by something abiotic [A], biotic [B] or confusing [C]?

Photo 1: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 2: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 3: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 4: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 5: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 6: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 7: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 8: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Source: Photos 1-7: authors. Source: Photo 8: Central Tuber Crops Research Institute, India.

EXERCISE 2.1: Citrus

Are these symptoms caused by something abiotic [A], biotic [B] or confusing [C]?

Photo 1: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 2: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 3: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 4: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 5: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 6: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 7: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 8: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Source: Photo 3: Citrus greening (Huanglongbing). UF/IFAS Citrus Research and Education Center. Source: Photo 4: Richard Davis, Northern Australia Quarantine Strategy. Source: Photo 5: JM Bové. INRA. Bugwood.org. Source: Photo 7: HD Catling. Bugwood.org. Source: Photos 1,2,6,8: authors.

EXERCISE 2.1: Coconut

Are these symptoms caused by something abiotic [A], biotic [B] or confusing [C]?

Photo 1: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 2: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 3: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 4: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 5: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 6: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 7: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

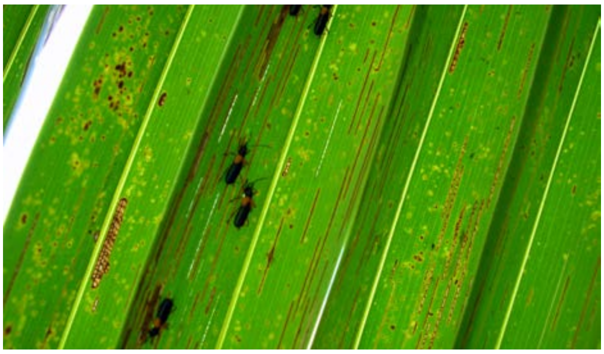

Photo 8: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Source: Photo 1: John Randles. Waite Agricultural Research Institute. Source: Photo 2: Tim Broschat. USDA APHIS PPQ. Bugwood.org. Source: Photo 4: Luigi Guarino, Crop Trust. Source: Photo 5: Gerald McCormack. Cook Islands Biodiversity & Natural Heritage. Source: Photo 6: Jean-Pierre Labouisse. CIRAD. Source: Photos 3,7,8: authors.

EXERCISE 2.1: Tomato

Are these symptoms caused by something abiotic [A], biotic [B] or confusing [C]?

Photo 1: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 2: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 3: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 4: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 5: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 6: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 7: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 8: Is the symptom caused by something
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Source: Photo 4: Gerald Holmes. Cal Poly San Luis. Bugwood.org. Source: Photos 1,2,3,5,6,8: authors.

EXERCISE 2.1: Mixed

Are these symptoms caused by something abiotic [A], biotic [B] or confusing [C]?

Photo 1: Maize
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 2: Tomato
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 3: Cocoa
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 4: Maize
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 5: Cocoa
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 6: Maize
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 7: Coconut
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Photo 8: Tomato
❑ abiotic [A] or ❑ biotic [B] or ❑ confusing [C] ?

Source: Photo 2: Missouri Botanical Garden. Source: Photo 6: Wikimedia Commons. Alandmanson. Maize plants with severe zinc deficiency. Source: Photo 7: George Wall. University of Guam. Source: Photos 1,3,4,5,8: authors.

EXERCISE 2.2: Speed dating

This exercise is fun and helps your trainees practise identifying and describing symptoms on plants carefully and accurately. Ensure that they have enough samples of pests and diseases for one per trainee, and that you have set up three tables marked A,B and C (Abiotic, Biotic, Confused).

- **trainees should form two lines** facing each other so they are standing opposite a partner
- give each person a **sample** of a plant pest or disease
- one trainee carefully **describes the symptoms** to their partner ('date') opposite, and then both try to decide whether the cause is abiotic (A), biotic (B), or confused (C)
- trainees have two minutes — when you say **'Stop'**, the other partner has to repeat the process with another sample
- next, **everyone in one line moves to the left to a new partner**, and repeats the process of describing the symptoms
- trainees now **place their samples on a table** marked A, B or C, depending on what they think the cause is.

Now go through the next Sections 2.2–2.8 of the manual with your trainees.

You could create a PowerPoint slide show if you have the facilities for this. Alternatively, if they have access to the manual, ask your trainees to read the sections for homework.

When you have completed this, your trainees will have a chance to change their minds about A, B or C, abiotic, biotic, or it is confused (Exercise 2.1).

2.2 Abiotic factors

This short section takes the abiotic factors listed in Table 2.1 and provides information to help trainees understand the symptoms they cause. It's imperative that they take them into account when they diagnose samples brought by farmers to PHCs. They are relatively common, and sometimes confusing, as more than a single factor may be present. For these reasons, abiotic factors are often overlooked. A useful summary of abiotic factors can be found here[2].

First, we introduce trainees to unhealthy plant growth due to poor soil conditions. This is done briefly, remembering that Chapter 3 contains a more detailed account of soils, and illustrations of nutrient deficiencies.

While plants have different soil requirements, there are some basic needs for optimum growth. In general, what we call 'healthy soil' is soil that can hold water and air, is not too fine or too coarse so it avoids water-logging, or drying out too quickly, and contains a good amount of organic matter and some clay to hold nutrients. It also has many macro- and micro-organisms, such as earthworms to keep it aerated, and bacteria, fungi, nematodes and protozoa to maintain a supply of nutrients. Healthy soil has a pH of around 6 to 7, which is best for most plants, although many require a lower or higher pH (see Chapter 3, Section 3.7).

Although they make their food (sugars) through photosynthesis from carbon dioxide and water, to be healthy, plants also need a range of other nutrients which they must get from the soil though their roots. If some of these nutrients are missing, the plant will show nutrient deficiency symptoms. These can be confusing; usually, they appear as yellowing or discoloured patches on the leaves. The veins might also be discoloured, or the fruit might be small, misshapen or fail to ripen. Sometimes, there are no symptoms at all except a reduction in yield. In general, nutrient deficiency symptoms on the leaf form a pattern that is evenly spread, whereas disease symptoms, especially those caused by viruses, tend to be patchy.

The most common nutrient deficiencies in Pacific islands are lack of nitrogen, potassium, sulphur, phosphorus, calcium, and magnesium[3]. These are the macronutrients — needed in quite large amounts. Boron, copper, iron, molybdenum, and zinc are micronutrients and, as their name suggests, they are only required in small amounts. Some nutrient deficiency symptoms are illustrated (see Chapter 3, Figs. 3.20-3.30). Boron deficiency is illustrated in Chapter 3, Fig. 3.27 in papaya and broccoli.

Sometimes, it is difficult to know if the problem is a lack of a particular mineral in the soil or it is present, but unavailable for some reason. The way

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[2] Hennelly M, et al. (2012) Introduction to abiotic disorders in plants. The Plant Health Instructor. (DOI: 10.1094/PHI-I-2012-10-29-01).

[3] Some scientists say it's easier to think about three groups of nutrients (i) primary macronutrients (N,P,K), needed in largest amounts; (ii) secondary macronutrients (Mg, Ca, S) needed in smaller amounts, and (iii) micronutrients (Cu, Mo, Mn, Zn, etc.) needed in very small amounts.

that pH (the acidity or alkalinity of soil) affects availability of nutrients is explained in Chapter 3, Section 3.7

A somewhat different situation occurs where nutrients are immobile within a plant. Blossom end rot of tomato and zucchini is a condition that is common when rapidly developing fruits are exposed to drought. The roots cannot obtain enough water with sufficient calcium to build cell walls, and as calcium inside the plant does not move from old to young growth, the developing fruits rot from the flower end. This is illustrated in Chapter 3, Fig. 3.24 on page 147.

More rarely, symptoms occur if there is an oversupply of macronutrients, for instance, if too much fertiliser or manure is applied. In this case, water moves out of the roots into the soil in response to the high concentration of salts in the soil, known as an osmotic effect. This is when fertiliser burn occurs (Fig. 2.2). Plants are more susceptible to fertiliser burn in dry times, with leaves turning brown and dying.

For healthy plant growth, not only is a range of nutrients required and in the correct amounts, but also in a narrow range of pH — a measure of the H^+ ion concentration of the soil. Generally, the optimum range is slightly acidic, pH6-7. Outside of this range, the availability of nutrients may be affected; for instance, below pH5.5, calcium, magnesium and phosphorus may be at low availability, whereas aluminium, boron and iron availability may reach levels that cause toxicity. At the other end of the pH scale, soils over pH7.5 have low availability of phosphorus, boron, iron, manganese, zinc and copper.

If possible, have a soil test done to find out what is missing in the soil. Then fertilisers (or manures) can be applied that add the missing nutrients. Some Pacific island governments provide soil analysis, if farmers make requests through extension services.

Too little or too much water can also have serious consequences on plant growth. Symptoms vary depending on whether the deficit or excess is short-

Fig. 2.2 Cucumber recovering from earlier excessive amount of fertiliser causing what is known as a 'fertiliser burn'.

Fertilisers contain salts and if these are too high concentrations then water is drawn out of the roots (by osmosis). Burns can also occur if fertiliser is given at the right amounts but water levels are low in the soil.

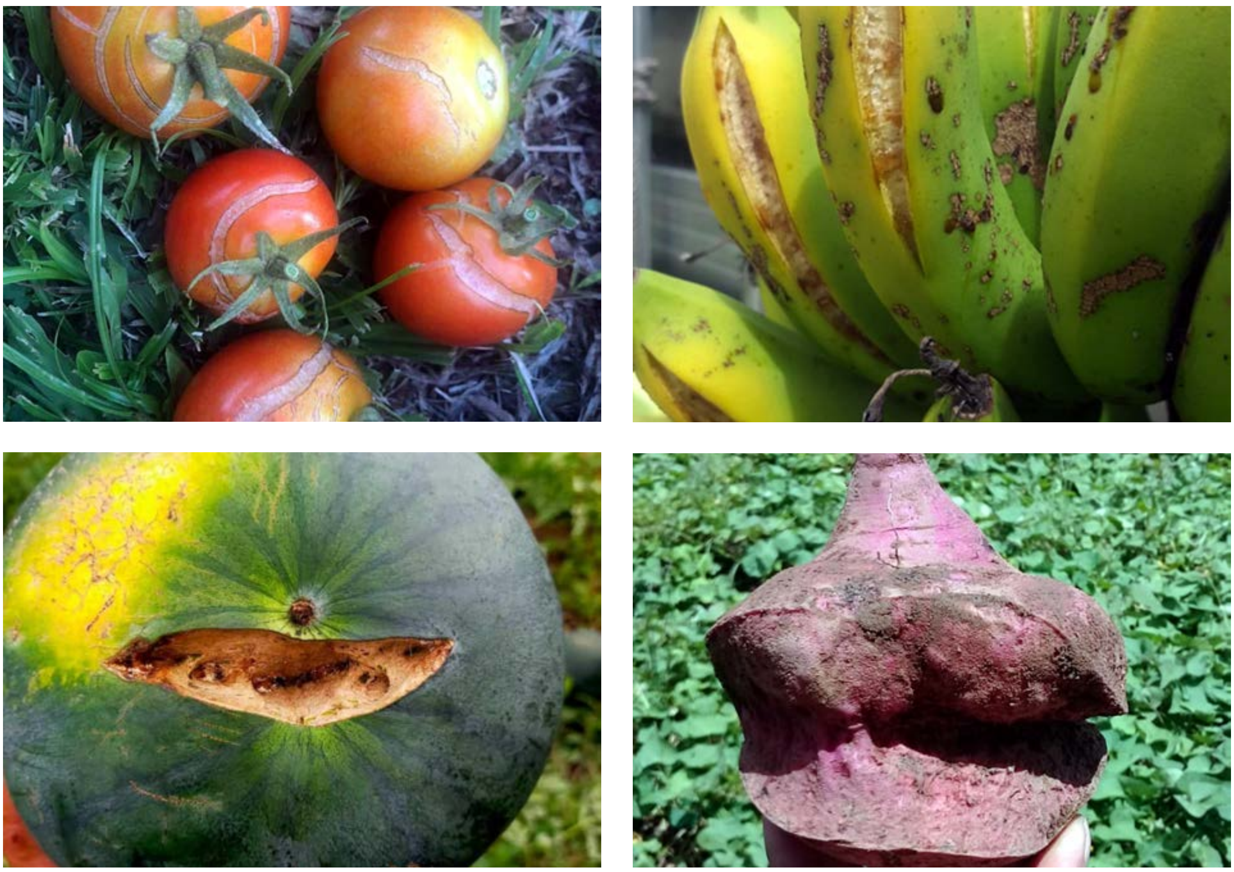
Source: authors.

or long-term. For instance, when soil water is low, plants may wilt during the hottest part of the day and recover towards evening. As long as water is applied, and the deficit is short-term, normal growth will resume when rain occurs, or the plants are irrigated. Where the water deficit is over long periods, as during droughts, plant growth is slow or not at all, and leaves may lose their colour, show marginal scorching, fall, and the plants may die. Where there is excessive water or flooding, it forces out air, and roots become devoid of oxygen, and cannot respire, leading to root death, or to increased susceptibility to soil pathogens.

Another symptom associated with both fruit and some root crops is splitting. Although reasons are debated, a common cause is prolonged dry conditions followed by heavy rains during the later stages of fruit development. Other suggestions involve fertiliser levels, temperatures, and humidity, in various combination or all of them. Often, the splitting is most pronounced at the stem end, but this differs between species as well as varying within and between varieties. (Fig. 2.3). A regular water supply, it seems, is the solution, avoiding large fluctuations in stress, which might otherwise result in fruit with weak rind or skin unable to withstand sudden pressure.

Fig. 2.3 Top left, clockwise — splitting in fruits of tomato and banana, the storage root of sweet potato and a fruit of watermelon.

It is assumed that the damage has occurred due to drought conditions followed by an unusually long period of rain. *Source: authors.*



Low soil oxygen not only occurs when soils have too much soil water, but also if they become compacted. This is related to soil structure, which is determined by the relative amounts of the three types of mineral particles of soil – sand, silt and clay – and how they are bound together by 'glues' from plant roots and microorganisms (bacteria and fungi in particular). In turn, the binding influences the size of pore spaces which contain air, and oxygen. Clay soils with relatively small particles have small pore spaces – these soils are at greatest risk of becoming compacted by tilling operations, heavy rains, or cattle treading on them. Consequently, plant growth is affected by a lack of water because it runs off rather than into the soil, and from a lack of oxygen because of restricted pore size. Plant health doctors should query farmers if they bring stressed plants to the clinic, and not assume immediately that biotic factors are the cause.

Physically damaged plants are sometimes brought to PHCs. Most frequently, in Pacific islands, damage occurs when plants are hilled-up, and mechanical injury occurs. Bullocks or horses are used to pull ploughs that heap soil around leaf bases of taro, and the wayward tread of these animals' hooves damage corms and their roots, stunting the plants or providing entry to soil-borne pathogens. Hilling up sweet potato to bury exposed roots that might otherwise become hosts of weevil is another example. Increasingly, trimmers are used to cut grass or for weed control, and young trees are damaged in the process (Fig. 2.4), leading to stem canker and/or stunted growth. And, as the climate crisis intensifies, we see storms and cyclones causing increased damage to trees and shrubs, withering leaves (Fig. 2.5), removing branches, splitting trunks and stretching roots as trunks are buffeted by winds.

Fig. 2.4 Apart from the damage that occurs when crops are hilled-up, mechanical damage also occurs as mechanisation replaces the use of hand tools.

Here, a grass trimmer has damaged the bole of the tree when young, cankers followed, and stunting resulted.

The guard was only placed after the damage was done!

Source: authors.

Fig. 2.5 It is expected that storms will increase in severity, if not in occurrence, as oceans warm and yields of banana, but also other food crop staples, taro, yam and cassava will decrease.

Source: authors.

An indirect consequence of storm damage and loss of leaves is damage to fruits, often seen on capsicum and tomatoes. The damage, known as sunscald, presents as a large blister on the side facing the sun due to the fruit's exposure. Sunscald is also the cause of dieback on plants that prefer shade. Cocoa, for instance, grows naturally as an understory tree in the forests of the Amazon, and most varieties do not tolerate growing without shade, unless bolstered by high levels of fertilisers. If they are exposed to excessive amounts of sun, leaves become yellow and fall, and shoots die back. Examples of scald and dieback can be found among the A, B or C (e.g. see MIXED on page 26).

Finally, among causes associated with atmospheric phenomena, there is lightning damage[4] (Fig. 2.6). This is occasionally seen in forests, but more commonly among mature coconut palms in plantations or even urban areas. Lightning strikes cause heat and shock-waves due to the electrical currents that are generated, and symptoms appear rapidly. Distinguishing features of lightning strike are their association with recent storms, blackened leaves (progressing from old to young), loss of nuts and, when damage affects small groups of trees, symptoms occur in a circular fashion[5]. However, damage is not too dissimilar from phytoplasma or virus diseases or attacks by rhinoceros beetles (from a distance at least).

Rising sea levels are affecting coastal areas of Pacific island countries. Plants are at risk of increased salinity caused by periodic incursions of seawater, saltwater spray from oceans, and erratic or reduced rainfall associated with the climate crisis. Salinity can have profound effects on plant development, including toxicity, water imbalance and nutrient deficiency. Apart from nutrient imbalances (e.g. reduced phosphorus uptake, and sodium, chlorine

4 Brown SH (Undated) Lightning strikes on coconut and royal palms. University of Florida. IFAS Extension. https://studylib.net/doc/18169959/lightning-strikes-on-coconut-and-royal-palms#google_vignette

5 Nelson SC (2008) Lightning injury of plants. Plant Disease. Cooperative Extension Service, College of Tropical Agriculture and Human Resources, University of Hawai at Manoa. https://www.ctahr.hawaii.edu/oc/freepubs/pdf/PD-40.pdf

Fig. 2.6 Lightning strike on coconuts. In this example, it appears that the progression of death of leaves is from young to old, on the two nearest palms at least. Look for signs of blackened leaves and trunks.

Source: Stephen H Brown. UF/IFAS.

and boron toxicity), osmotic effects occur, and water moves out of the plant into the soil, causing stunted growth, yellowing, and ultimately death. Similarly, salt spray can cause salt burn on buds, leaves and small twigs.

Pesticides (insecticides, fungicides, and herbicides) are well known to damage plants if not applied properly. It is commonly called phytotoxicity. For this reason, it is important to apply the products at the application rate specified on the packet. It is also important not to mix products – i.e. products of different kinds, or an insecticide with a fungicide, unless you know they are compatible. Farmers should always be asked about what they used, and the concentration used, if herbicide damage is suspected. Phytotoxicity is well known to occur with sulphur and oils, especially in hot weather, and copper fungicides can cause leaf bronzing.

However, plant health doctors will find most difficulty diagnosing problems associated with herbicide damage[6] for several reasons: herbicides can have long residual effects in the soil, resulting in damaged crops in subsequent seasons; for many, there is an interval between application and time for safe planting, which may not be adhered to; and for all, drift is a potential risk, causing symptoms on the non-target crop that are similar to virus infection – both produce chlorotic spots, mottles, mosaics, distortions, and vein-banding (Fig. 2.7). Apart from these reasons, perhaps the most common cause of herbicide damage occurs when the same sprayer is used for the application of herbicides and other chemicals. A failure to wash the spraying machine adequately after use leaves residual herbicide, which is later applied to crops when used for other pesticides.

Lastly, senescence, or aging[7] (Fig. 2.8). It is a natural process in plants evolved to break down compounds produced during the growth phase and to

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6 Joey Williamson, @2015, HGIC, Clemson Extension. https://hgic.clemson.edu/factsheet/glyphosate-damage-on-tomatoes/

7 Buchanan-Wollaston V (Undated) Senescence in plants. University of Warwick. Wellesbourne, UK. https://www.esalq.usp.br/lepse/imgs/conteudo_thumb/mini/Senescence-in-plants.pdf

redistribute the components later. Senescence may be induced at a particular development stage, for instance, with the formation of flowers or seeds, or as a response to changing environments, such as when leaves at the base of the plant become shaded by those further up the stem, resulting in reduced photosynthesis. It may also be initiated by a slowing of the rate of growth due to environmental stresses — changes in light or temperature as the season progresses, drought, or attack by pathogens. At first, leaves turn yellow with loss of chlorophyll, which in the autumn of temperate climates is associated with anthocyanin production as a way of protecting against damage and to maintain viability as senescence progresses. But senescence may not be uniform: colour changes show first at the tips and margins of leaves where the major veins stay green: they are needed to transport the components of senescence. Such symptoms may seem like nutrient deficiencies and plant health doctors need to weigh up the cause before making a diagnosis.

Fig. 2.7 Tomato showing yellow patches at the distal end of leaflets (at the stalk end), a condition associated with herbicide contamination.

Damage of this kind results most often from spray drift, and severity depends on the level of exposure, environmental conditions, variety, age and stage of plant development.

Source: Joey Williamson, @2015 HGIC, Clemson Extension.

Fig. 2.8 Leaves of Hydrangea, a shrub, showing three stages of senescence: early (left), middle (centre) and late (right). The challenge for the plant doctors is to assess the stage of maturity of the leaves, considering nutrient deficiencies as well as infections from pathogens. *Source: authors.*

2.3 Biotic causes

2.3.1 What is a pest?

In this manual we treat pests as organisms that you can see with the eye or with a hand lens. This includes insects, mites, slugs and snails, as well as larger animals, such as birds, mice, rats and even humans! Weeds are also regarded as pests. Most pests that farmers are concerned with are insects and mites. They usually cause problems by chewing, sucking or, more rarely, piercing when laying eggs. When they are on leaves, stems or flowers, they are quite easy to identify. It is more difficult to identify them on roots, unless there is obvious chewing, or the roots are decayed. For this reason, farmers often bring only the leaves to the clinic because that is where they see the symptoms.

Note: Insects[8] have six legs, except for some uncommon butterflies that have four. Mites belong to the arachnid class, along with spiders, scorpions and ticks, and have eight legs. Here are some important facts about insects/mites/spiders that will help identify them as plant pests.

The taxonomy of mites is still being researched. Of the six or so orders, the plant parasitic mites belong to the order Trombidiformes; this contains the spider mites (tetranychid) and those smaller mites (eriophyid) living in galls and buds.

There are 30 orders of insects, but only eight orders contain pests.

The insects in these eight orders are listed below:

1. Grasshopper, crickets and katydids (Order: Orthoptera)
2. Moths and butterflies (Order: Lepidoptera)
3. Beetles and weevils (Order: Coleoptera)
4. Flies (Order: Diptera)
5. Termites (Order: Blattodea)
6. Ants, bees, wasps and sawflies (Order: Hymenoptera)
7. Thrips (Order: Thysanoptera)
8. Aphids, ‘bugs’ (true bugs), leafhoppers, planthoppers, psyllids, mealybugs, scales and whiteflies (Order: Hemiptera).

[8] The word ‘bug’ to many people is an insect, but as the Australian Museum notes, not all insects are bugs. There are many different forms, including aphids, hoppers, scale insects, cicadas and, confusingly, the 'true' bugs – stink bug, assassin bug, coreid bug, and many more. The ‘true bugs’ are a sub-order known as the Heteroptera.
https://australianmuseum.net.au/learn/animals/insects/bugs-order-hemiptera/
https://australianmuseum.net.au/learn/species-identification/ask-an-expert/what-do-true-bugs-look-like/

There are both 'good' and 'bad' insects

Insects that are considered 'good' for humans are those that pollinate flowers, e.g. flies, bees, butterflies, moths and beetles. These are necessary for seed and fruit crops. There are also insects that prey on other insects. These predators can be generalists, e.g. some wasps and beetles, or specialists, e.g. parasitoids – wasps and flies that lay their eggs on or in a pest, and whose larvae eventually kill it.

'Bad' insects are those that are bad for humans. These include:

- crop feeders — many
- carriers of human diseases, e.g. mosquitoes that carry the malaria parasite or the dengue fever virus
- carriers of plant diseases, e.g. aphids, mealybugs, whiteflies and planthoppers transmit viruses, phytoplasmas and bacteria
- nuisances, e.g. fire ants that 'sting' people with secretions of formic acid, or mosquitoes, bed bugs and lice that bite.

Some insects and mites are both good and bad

Some insects and mites can be both good and bad. For example, some ants keep generalist plant-feeding insects away — they prevent butterflies and moths from laying eggs, and their larvae (caterpillars) from developing. At the same time, they leave sap-sucking insects like aphids and scales alone, as the ants feed on their sugary secretions (honeydew). In this way, ants defend the aphids and scales from predators. They are usually used in greenhouses against spider mites.

Spiders are almost entirely beneficial, mites less so

There are some 45,000 species of spiders and, unlike insects, none of them eats plants. Spiders hunt their prey or spin webs to trap them. Their effect on small caterpillars (e.g. on cabbages), on leafhoppers and planthoppers (e.g. on rice), and on insect pests feeding on many other crops, is often overlooked. The only bad thing about spiders is that they also prey on honeybees, butterflies and other beneficial insects.

Mites are related to spiders, but some are bad. The so-called spider mites are plant pests that cause silvering on many plants. They live commonly on the underside of leaves along the main veins. Webs are often present. The other bad mites are the plant parasitic eriophyid mites; some cause galls and others feed in buds, causing distortions to developing leaves and flowers. Rarely, eriophyid mites spread viruses, but none are known to do so in the Pacific region.

However, as with insects, not all mites are bad. There are species of predatory mites, which are available for farmers to purchase in some countries. They are usually used in greenhouses against spider mites, and they also eat small insects.

Although many people don't like them, spiders are not insects and they are good for our crops, so should be left alone!

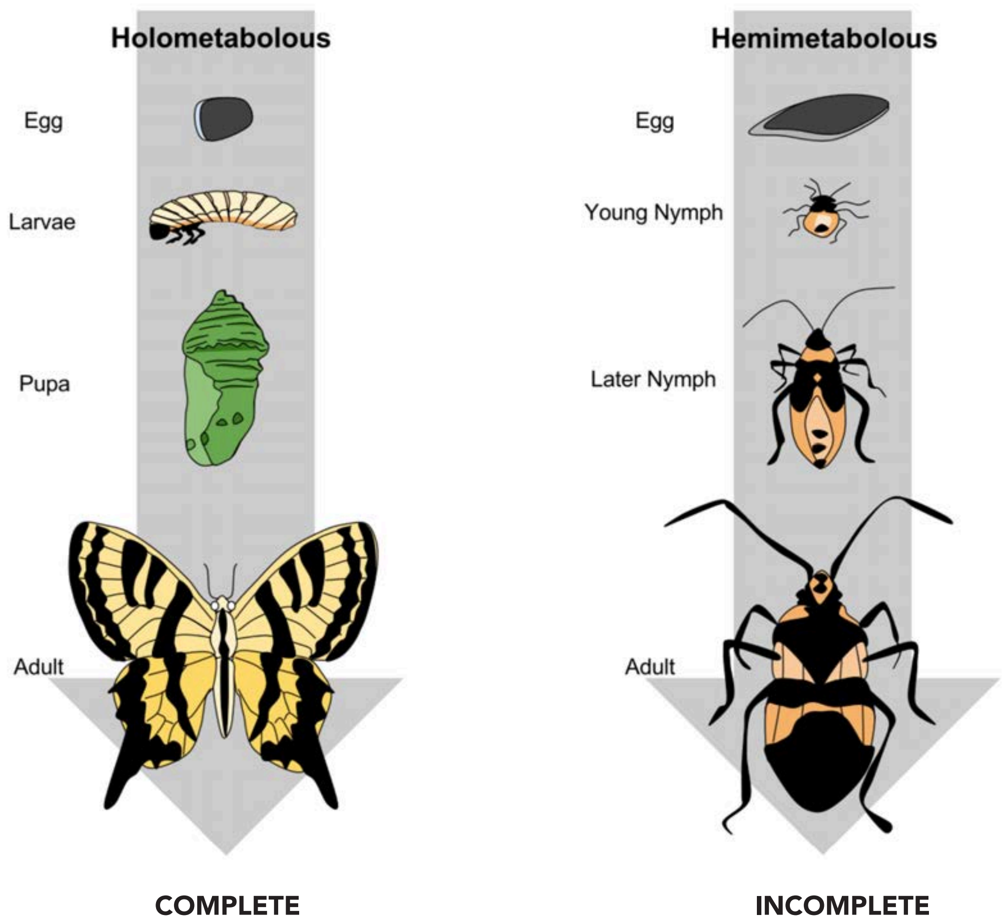
2.3.2 Insect life cycles

Insects have two different life cycles — either complete or complex metamorphosis ('holometabolous', where the immature stages are different from adults) or incomplete or simple metamorphosis ('hemimetabolous', where the immature stages are similar to adults).

Life cycles of insects with complete metamorphosis

Insect groups that undergo complete metamorphosis are: Coleoptera (beetles); Lepidoptera (moths and butterflies); Hymenoptera (wasps, ants and bees); and Diptera (flies). All these groups have a life cycle where the egg hatches into a larva (e.g. a grub, caterpillar or maggot) that develops into an inactive pupa stage (or puparium[9] in the case of flies) before emerging as an adult (e.g. a butterfly, beetle, wasp).

Fig. 2.9 Examples of complete and incomplete metamorphosis emerging as an adult (e.g. a butterfly, beetle, wasp). *Source: Wikimedia Commons. Username 1927. Holometabolous vs. Hemimetabolous.svg.*



[9] A puparium occurs in some fly families. It is the hardened skin of the last larval stage.

Life cycles of insects with incomplete metamorphosis

Typical insects that undergo incomplete metamorphosis are: Hemiptera (aphids, true bugs, cicadas, hoppers, mealybugs, scales and whiteflies); Orthoptera (grasshoppers and crickets); Blattodea (termites); and Thysanoptera (thrips). Immature stages of these insects are called nymphs, which gradually increase in size and change form. As the insects grow, they shed their skin (called moulting). After each moult, the nymphs look a little different or a little larger but, unlike a caterpillar of a butterfly or moth, the nymphs are not that different from the adults. After a final moult, the full adult form emerges (Fig. 2.9).

Life cycles of mites

Spider mites have four stages — egg, larva, nymph and adult. There is one larval stage with six legs and two nymphal stages that are small versions of the adult, with eight legs. The minute, carrot-shaped eriophyid mites have three stages - egg, and first and second nymph. They have two pairs of legs.

Why is it important to know the life cycle of an insect pest?

Once you know which group your pest belongs to, the next most important step is to determine its life cycle. This allows you to suggest ways to control the pest at its most vulnerable stage, or possibly suggest how to avoid it all together. This is one of the basic concepts behind integrated pest and disease management (IPDM).

As we have seen already, insects have different types of life cycle, incomplete (simple) and complete (complex). Those insects with incomplete life cycles have nymphs that are similar to adults, which gradually change. They usually occur in the same habitat and eat the same food. For these, control strategies are the same for both stages. However, those insects with complete life cycles have larvae, pupae and adults that appear very different from each other and, importantly, often live in different habitats, eat different foods or, in the case of the pupa, do not eat at all. This means that controlling these insects may require a different response from insects with incomplete, simple life cycles.

Life cycles of the eight insect and single mite orders that damage crops are as follows — Figs. 2.10-2.48.

Grasshoppers, Crickets and Katydids: Orthoptera [Figs. 2.10-2.12]

These have simple life cycles (see diagram). Eggs laid in the soil, hatch into small versions of the adult, gradually getting larger by successive skin shedding (moults).

Small wing-buds can often be seen, and these get larger after each moult. There is no resting stage. The adult has fully developed sex organs, and wings may be fully developed, but in many species wings, are short or absent.

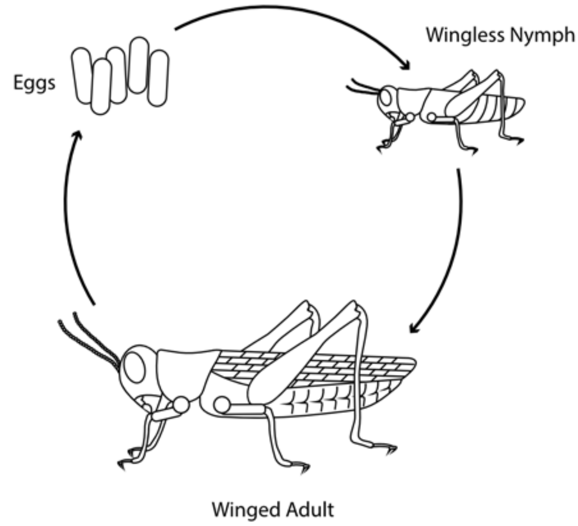


Fig. 2.10 Grasshopper (*Aiolopus* sp.)
Usually they have short antennae, shorter than the body length. They feed during the day. Most feed on plants.
Source: Dave Rentz. Kuranda. Queensland.

Fig. 2.11 Katydid (unknown species)
They have long antennae, longer than the body, and are often thin and threadlike. They also have very large hind legs. Most feed on plants.
Source: authors.

Fig. 2.12 Cricket (*Teleogryllus* sp.)
These have long antennae, but differ from katydids. They have long ovipositors, eat both plants and insects, and live in burrows in the ground during the day.
Source: Gerald McCormack. Cook Islands Biodiversity & Natural Heritage.

Moths and butterflies: Lepidoptera [Figs. 2.13-2.16]

These have complex life cycles (see diagram).

A larva hatches and gradually gets larger as it passes through several skin changes or moults. Finally, it forms the non-feeding pupa (resting stage).

The pupa may be on a plant or in the soil. The pupa stage ends with the emergence of the adult.

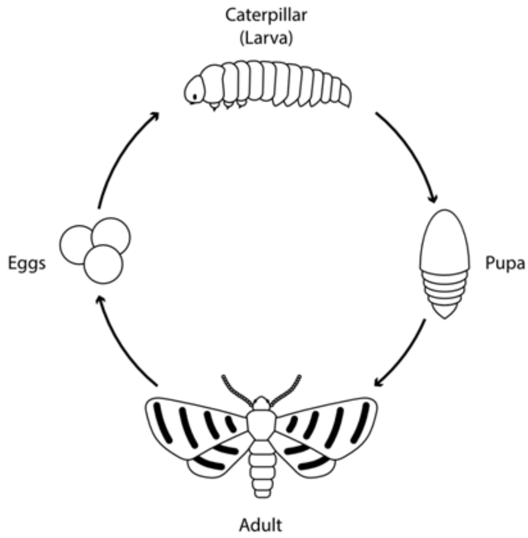


Fig. 2.13 Moth (*Diaphania* sp.) and butterfly adults usually feed on plant nectar, but there are rare exceptions, e.g. the fruit-piercing moth, which sucks juice from fruits.

Source: Gerald McCormack. Cook Islands Biodiversity & Natural Heritage.

Fig. 2.14 Caterpillars (*Diaphania* sp.) are not used by taxonomists to categorise them. Adults are used. Moths and butterflies differ:

i. while at rest, adult butterflies fold their wings, while moths spread their wings flat
ii. the antennae of adult butterflies end in club-like tips, while moth antennae are feathery
iii. moth pupae are wrapped in a silk-like covering, whereas butterflies' pupae are hard, smooth and without silk.

Source: authors.

Fig. 2.15 Caterpillars (e.g. *Agrius* sp.) mostly have three pairs of true legs on the thoracic (front) segments just behind the head and usually five pairs of fleshy prolegs on the third to the sixth and last abdominal segments. The last pair are the 'claspers', covered in hooks and used to hang onto leaves, stems, and bark.

Source: authors.

Fig. 2.16 Looper caterpillars (e.g. *Chrysodeixis* sp.) are different: they have three pairs of true legs, an anal or clasper pair, but fewer other pairs depending on the family. This reduction means that the caterpillars travel in 'loops' as seen in the image above. *Source: Don Herbison-Evans. Macleay Museum. University of Sydney.*

Beetles and Weevils: Coleoptera [Figs. 2.17-2.18]

These have complex life cycles (see diagram).

Eggs are laid on or in the soil, rotten wood, even animal faeces.

Larvae (grubs) hatch from eggs and develop into pupae, and then adults.

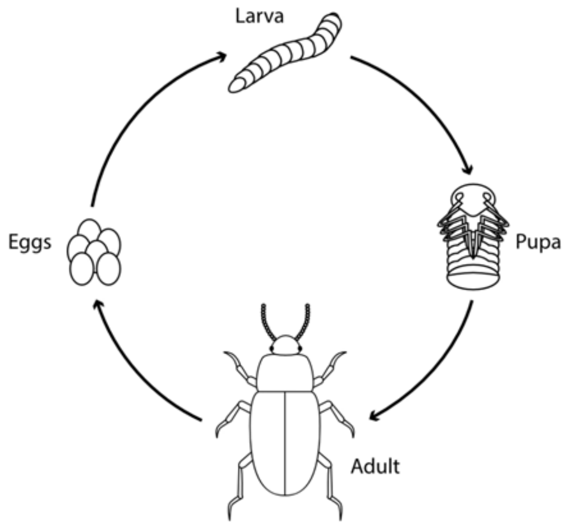


Fig. 2.17 Beetles (*Aulacophora* sp.) have two pairs of wings the first or front pair are hardened (the elytra) to protect the second pair which are used for flight; although not all beetles fly.

Note, the wings meet in the middle of the back (unlike the 'true bugs' – see below).

Source: authors.

Fig. 2.18 Weevils (*Cosmopolites* sp.) are a group within beetles.

They have characteristic snouts, although some are not as long as in the image above.

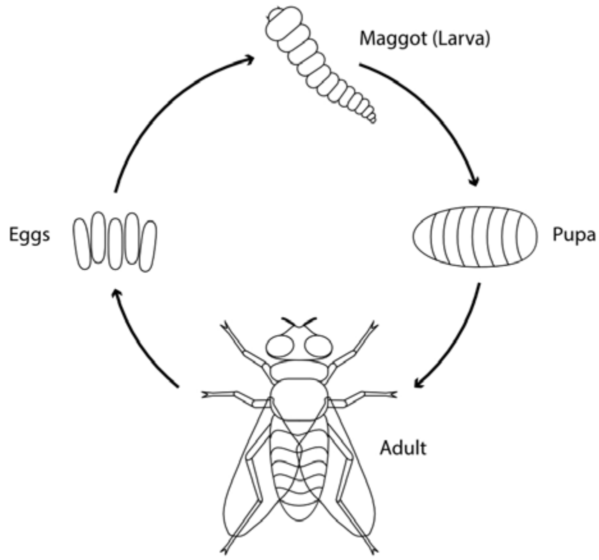
Source: Gerald McCormack. Cook Islands Biodiversity & Natural Heritage.

Flies: Diptera [Figs. 2.19-2.20]

These have complex life cycles (see diagram).

The eggs (many species do not have eggs but give birth to living young) hatch into legless larvae (maggots), which increase in size after successive moults.

They pupate within the dried skin of the larva, to form a small, walled 'puparium'. Some produce free-living pupae in water (e.g. mosquitoes) that hatch into adult flies. Adults may be useful pollinators of flowers, or fruit fly pests. Leafminers and fruits flies are common pests in the Pacific islands.



Note, whiteflies are not members of this order; they are members of the aphid, leafhoppers and planthopper, psyllid, mealybug, scale insect order (Hemiptera).

Fig. 2.19 Leafminer (*Liriomyza* sp.)

The adult fly is tiny and not easily seen. It is the larva (the maggot) that causes the damage as it mines the leaves. The pupa usually falls from the leaf and matures in the soil.

Source: Pest and diseases image library. Bugwood.org.

Fig. 2.20 Fruit fly (*Bactrocera* sp.)

Adult flies have a single pair of wings. In most cases, they lay 1-20 eggs into maturing fruits together with bacteria that provide food for maggots, either directly, or indirectly by causing fruits to rot. The fruit fall to the ground and the larvae enter the soil to pupate.

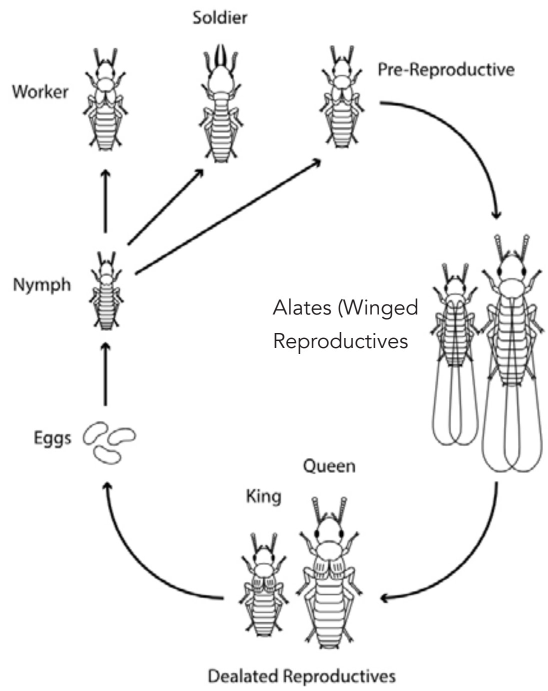
Source: Graham Teakle. Canberra.

Termites, Blattodea [Fig. 2.21]

These have simple life cycles (see diagram).

Unlike ants, termites have only egg, nymph and adult stages. They are social insects that are now placed in the cockroach order (Blattodea).
Like ants, and some bees and wasps, termite colonies have sterile males and female 'workers' and 'soldiers' (see diagram). They also have fertile 'reproductives' (with two pairs of wings) — producing males called 'kings' and one or more fertile females called 'queens'.

Termites mostly feed on dead plant material — wood, leaf litter, soil, or animal dung. In subtropical and tropical regions, their recycling of wood and plant matter is ecologically important. Termite colonies range from a few hundred to several million individuals.



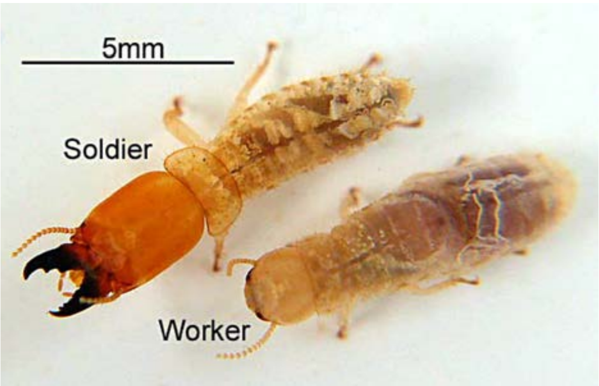


Fig. 2.21 Termite (*Neotermes* sp.)
The life cycle begins with the winged (they have two pairs) reproductives leaving the colony to swarm.

Females and males pair, they shed their wings, look for a place to start a new colony, and mate. The female lays eggs and both sexes (king and queen) take care of the offspring until there are enough workers to take over. Mating continues for life (unlike ants which mate only once).

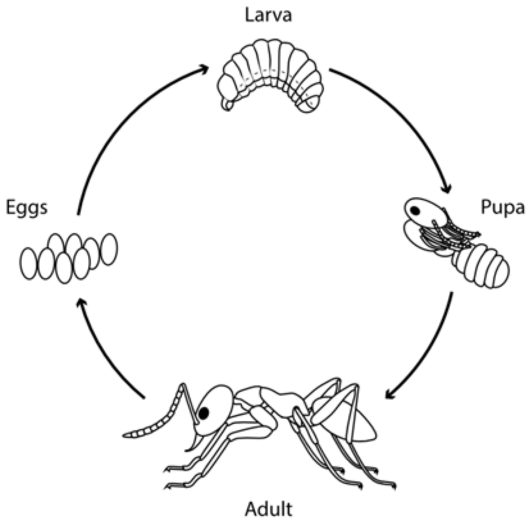
It may take up to 10 years before the king and queen have built a colony that produces reproductives once more.

Queens live for 20-50 years.

Unlike ants, termites have only egg, nymph and adult stages.

Source: Gerald McCormack. Cook Islands Biodiversity & Natural Heritage.

Ants, Bees (Leafcutting), Wasps & Sawflies: Hymenoptera [Figs. 2.22-2.27]



These have complex life cycles (see diagram). The eggs hatch into legless larvae, which increase in size as they moult before becoming pupae then adults. Those that are of interest because of their role as pests or in IPDM are as follows:

Ants (Figs. 2.22-2.23]

Within an ant colony there are one or multiple queens, a few sexually active males (from unfertilised eggs) and large numbers of wingless female workers (from fertilised eggs) that cannot reproduce.

Female workers have different tasks:

- caring for the eggs and larva
- gathering food, or
- defending the colony.

Adults feed on liquid foods (hence their attraction to honeydew) and parts of seeds rich in fat and protein. They are also predators or scavengers of insects and spiders that are fed to larvae. A new colony starts when a queen lays eggs and the resulting larvae develop into new winged queens and males, and they leave the nest and mate in the air. The males die and the queen finds a new place to start a colony by laying eggs which become workers.

Fig. 2.22 Weaver ant (*Oecophylla* sp.)
These ants have been used in biocontrol programs against pests of citrus, mango and cocoa, but this is unusual; they should never be imported for biocontrol purposes without thorough pest risk assessments as they are generalists, attacking crop pests as well as beneficial insects. Also, they bite people harvesting fruit. *Source: Muhammad Mahdi Karim. Bangalore. India.*

Fig. 2.23
Weaver ants tending mealybugs on cocoa.
Source: authors.

ANTS — lifecycle

Bees (Leafcutting): Megachile species [Fig. 2.24]

Bees and wasps have complex life cycles much like ants (see diagram for ants). The eggs hatch into legless larvae, which increase in size as they moult before becoming pupae then adults.

These are mostly solitary, occurring in countries throughout the world.

They cut discs from leaves to build nests, often in rotting wood.

The nest has a line of cells each with a single egg and a ball of pollen for the larva when it hatches. Adults feed on nectar and pollen, and are important pollinators of some crops, ornamentals and wildflowers.

They are regarded as pests where they spoil the aesthetic look of plants and take pieces from leaves.

Fig. 2.24 Leafcutting bee (*Megachile* sp.)
Source: Simon Hinkley & Ken Walker. PaDIL. Museums Victoria.

Wasps (Fig. 2.25)

Most are solitary, although some, such as the yellowjackets and hornets, live in colonies with queens and non-reproductive workers.

Social wasps have life cycles similar to ants and bees, except the workers hunt other insects and spiders to feed their carnivorous larvae. However, there is considerable difference between social and solitary wasps. Some solitary wasps lay eggs in other insects, and are important in biological pest control. They are similar to parasites but, importantly, they kill their hosts, and are known as 'parasitoids'.

All life stages — eggs, larvae, pupae or adults — of other insects (and some other arthropods) are targeted as hosts, depending on the parasitoid species.

Adult parasitoid wasps mainly feed on nectar, but only a very few species are involved in pollination.

Fig. 2.25 A parasitoid wasp (*Diadegma* sp.), laying its egg in a larva of diamondback moth.
Source: Mike Furlong. University of Queensland.

Sawflies [Figs. 2.26-2.27]

Many species have males, but many do not, and females produce eggs without fertilisation.

Sawfly larvae often feed on leaves (sometimes defoliating trees).

They look very much like the caterpillars of moths or butterflies – they have thoracic legs and prolegs.

Adults do not have a 'waist', typical of bees and wasps, and they feed on pollen, nectar and sap.

Females have long ovipositors that have a saw-like appearance used for cutting into plants to lay their eggs (hence their common name).

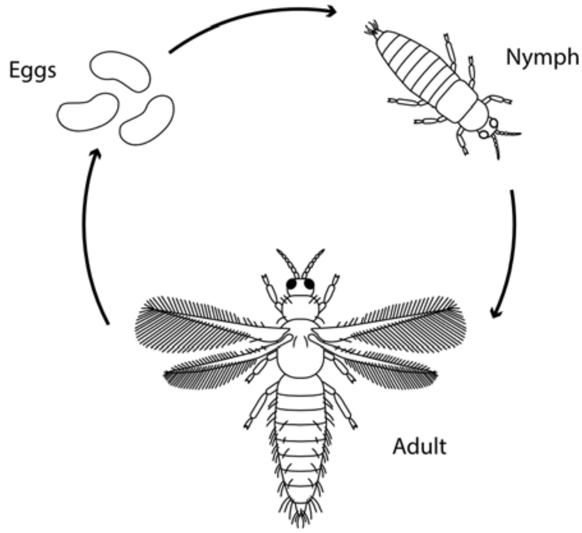
The ovipositor looks like a 'stinger'.

Fig. 2.26 Adult sawfly (*Neodipiron sp.)*
Source: Gerald J Lenhard, Louisiana State University, Bugwood.org

Fig. 2.27 Sawfly caterpillars
Note there are eight pairs of prolegs, greater than the number of pairs commonly seen on caterpillars of moths and butterflies.
Source: Gerald J Lenhard, Louisiana State University, Bugwood.org

Thrips: Thysanoptera [Figs. 2.28-2.30]

They have simple life cycles (see diagram).



Thrips are minute (usually 1-2 mm long or less), slender insects, with fringed wings. They feed mostly on plants by puncturing cells and sucking up the contents, although in a few cases they are predators of other thrips, other insects or mites. They are weak fliers, but are often spread on the wind.

Many thrips damage plants by feeding on them, and some cause important diseases by spreading viruses, such as *Thrips* and *Frankliniella* sp., which spread *Tomato spotted wilt virus*.

Other thrips species are beneficial pollinators.

Fig. 2.28 Thrips (*Gynaikothrips* sp.) Eggs, nymphs and adults. *Source: authors.*

Fig. 2.29 Eggs, nymphs of different ages, and adults. *Source: authors.*

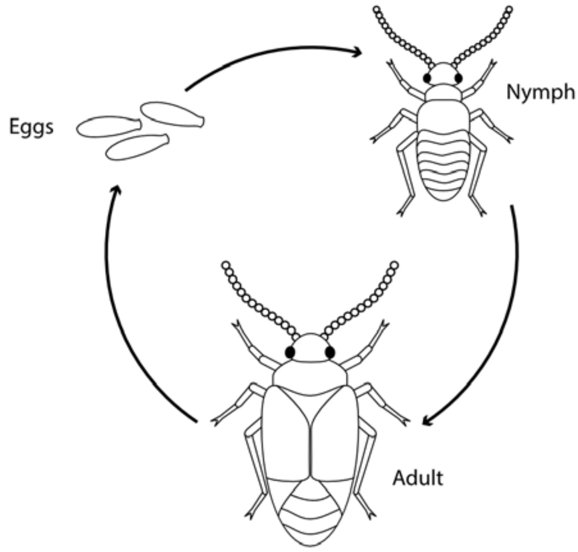
Fig. 2.30 Nymphs of the red-banded thrips, *Selenothrips* sp. on mango. *Source: Lyle Buss, University of Florida. Bugwood.org*

Aphids, Bugs ('True bugs'), Leafhoppers, Planthoppers, Psyllids, Mealybugs, Scales and Whiteflies: Hemiptera [Figs. 2.31-2.44]

Different members of this huge order have incomplete (simple) life cycles (see diagram), although mealybugs, scales and whiteflies are considered (by some taxonomists) to have a pupal stage.

It is an order of insects with very diverse life cycles. Many have two pairs of wings, although some species are wingless, and others only have forewings.

The wings are mostly membranous, but with some they are hardened at the base. All have piercing or sucking mouthparts and feed on plant.



Aphids [Fig. 2.31]

These have a simple life cycle.

Some species lay eggs, i.e. where they have to survive the winter in temperate or sub-tropical regions. In the tropics, females give birth to living young, without having to mate, producing more females.

The young are wingless versions of adults. Colony development is rapid. Later, when colonies become crowded or the host plants begin to die, winged forms develop for dispersal.

Aphids belong to the sub-order Sternorrhyncha.

Fig. 2.31 Citrus aphids (*Toxoptera* sp.)
Nymphs, winged and wingless adults. The two sausage-shaped objects in the lower half of the photo are the larvae of hoverflies, which are feeding on the aphids.
Source: authors.

APHIDS — lifecycle

True bugs (Figs. 2.32-2.33)

'True bugs' are members of the sub-order Heteroptera.

They have simple life cycles: they lay eggs or give birth to living young that get larger gradually by moulting. There is no resting (pupa) stage. Adults have fully developed sex organs and fully developed wings, if present – some species are without wings or have short wings). If present, the wings form an X-shaped pattern when folded at rest.

The word Heteropteran means 'different wings' as most have forewings that are part membranous and part hardened. Nymphs are generally softer and 'squishier' than adults.

Fig. 2.32 True bug (*Riptortus* sp.) nymphs. Notice in this insect the nymphs mimic ants as a way to prevent predation.
Source: Graham Teakle. Canberra.

Fig. 2.33 True bugs (*Riptortus* sp.) adult. Note, the X made by the folded wings when at rest
Source: authors.

Leafhoppers & planthoppers [Figs. 2.34-2.35]

These have a simple life cycle and are members of the sub-order Auchenorrhyncha.

There are males and females. Eggs produce nymphs, then short-winged nymphs occur; later, when crowded or food supplies are low, long-winged forms develop for dispersal.

Some members of both groups spread important plant diseases.

Figs. 2.34 Nymphs of a leafhopper (*Amrasca* sp.)
Source: authors.

Fig. 2.35 Planthoppers (*Tarophagus* sp.) showing winged adults and nymphs at different stages of development.
Source: authors.

Psyllids [Fig. 2.36]

These have a simple life cycle, and are members of the sub-order Sternorrhyncha.

They look like miniature cicadas.

Commonly called a plant louse (or plant lice for plural, or even jumping plant lice).

Eggs are laid on new shoots, and nymphs go through several moults.

Adults are about the size of winged aphids, but, in contrast, they have wings folded over their bodies. Nymphs and adults suck sap.

Many species produce strings of wax, or waxy covers over their bodies, e.g. the citrus psyllid that spreads Huanglongbing (citrus greening) disease.

Fig. 2.36 Asian citrus psyllid (*Diaphorina citri*)
The angle of the body relative to the surface that the insect is resting on is characteristic of this species. *Source: David Hall, USDA-ARS. Budwood.org*

Mealybugs [Fig. 2.37]

Mealybugs belong to the super family Coccoidea, and family Pseudococcidae.

The soft bodies of mealybugs are covered in mealy or cottony wax with waxy threads around them.

They are often found in groups and generally able to move short distances.

Eggs are laid singly or in clusters (often embedded in waxy threads), and hatch to produce 'crawlers' which have legs and are quite mobile; these wander around or are spread on the wind before settling down to feed by sucking sap.

Fig. 2.37 Mealybugs (*Phenacoccus* sp.), with mealy/waxy covering and immature nymphs. *Source: Whitney Crenshaw. Colorado State University. Bugwood.org*

They moult through several stages. In males, the last stage, called a 'pupa', produces a winged adult that looks like a tiny mosquito with one pair of wings, but without a mouth, whose function is only to mate.

Note, not all species lay eggs: some give birth to living crawlers, and some other species do not have males – females are produced without fertilisation.

Scale insects [Figs. 2.38-2.41]

Scale insects have similarities with mealybugs: (both are in the sub-order Sternorrhyncha):

- some lay eggs (and hatch as crawlers)
- some give birth to living crawlers
- some reproduce without mating and
- some have mosquito-like males.

As adults, scales are without legs, heads or wings. The covering or 'scale' of hard scales is not attached to the body, whereas it is with soft scales. In both cases, these waxy covers protect them from predators, parasitoids and pesticides.

Hard scales do NOT produce honeydew, so they are not associated with ants and fungal sooty moulds.

Three families are illustrated below. They are common scales of Pacific island countries:

- cushion scale *(Icerya* species — family Monophlebidae)
- armoured scale *(Pseudaulacaspis* sp. — family Diaspididae)
- soft scale *(Saissetia* sp. — family Coccidae).

Fig. 2.38 Adult breadfruit scale (*Icerya seychellarum)* Presently, a large infestation of the scale occurs in Fiji after the introduction of a white-footed ant *(Technomyrmex albipes)* which tends the ant protecting it from natural enemies. *Source: authors.*

Fig. 2.39 Adult fluted scale *(Icerya purchasi)*
The scale is a hermaphrodite, able to self-fertilise, which is unusual in insects. The fluted part is an egg sac with many red eggs. Adults are covered in white wax. *Source: authors.*

Fig. 2.40 Adult coffee brown (soft) scale *(Saissetia* sp.)

Females reproduce without mating, i.e., parthogenetically. Males are unknown. Eggs are laid under the female. *Source: authors.*

Fig. 2.41 White peach scale (*Pseudaulacaspis* sp.)
A hard scale. The white areas on the branches on the left are cocoons of the minute winged males; the females are the circular discs-shaped bodies on the branch in the centre *Source: authors.*

Whiteflies [Figs. 2.42-2.44]

The whitefly life-cycle is similar to that of mealybugs and scales. However, there are males and females, with females being slightly larger. Eggs are laid in circular or spiral patterns on the underside of leaves. Crawlers emerge and pass through another three nymph stages. Both sexes have an intermediate pupal stage.

Note, the word 'pupa' is disputed by some authorities.

Some species reproduce without mating, and in others females mate with their offspring. The pupal stage is used for identification.

Whiteflies produce honeydew which leads to sooty moulds on foliage.

Fig. 2.42 Not all whiteflies are white!
Orange spiny whitefly (*Aleurocanthus* sp.) on citrus, lays eggs in a spiral, and produces black nymphs, and white-fringed pupae.
Source: authors.

Fig. 2.43 Orange spiny whitefly (*Aleurocanthus* sp.) pupae and adults. *Source: authors.*

Fig. 2.44 Sweet potato whitefly (*Bemisia* sp.)
Adults and pupae with slits from which they have emerged. *Source: Scott Bauer. USDA-ARS. Bugwood.org*

Plant mites (Figs. 2.45-2.48)

Tetranychid spider mites are less than 1 mm long, they lay relatively large, round, transparent eggs, and spin webs to protect themselves. Eggs hatch producing a larvae and this moults into 1st-stage (proto) and 2nd-stage (deuto) nymphs, and then matures into an adult (see diagram). In hot, dry conditions populations enlarge rapidly.

Eriophyid mites are smaller, and usually found living in the buds of plants, or in galls. The life cycle is relatively simple:

- egg
- first and second nymphs, and
- adult.

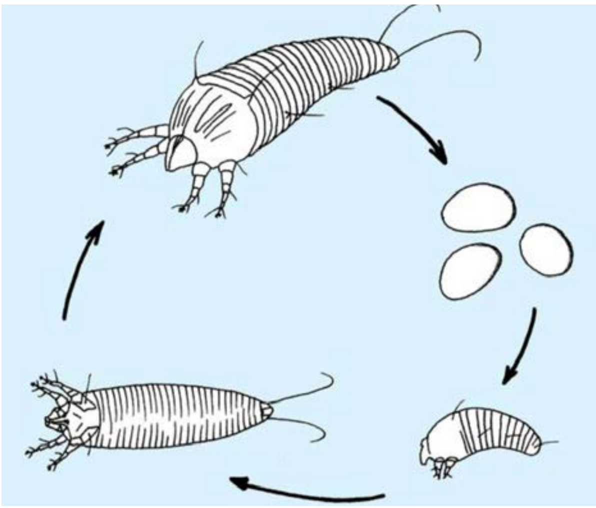


Fig. 2.45 Lifecycle of an eriophyid mite.
Source: Science Literacy and Outreach. University of Nebrasks-Lincoln.

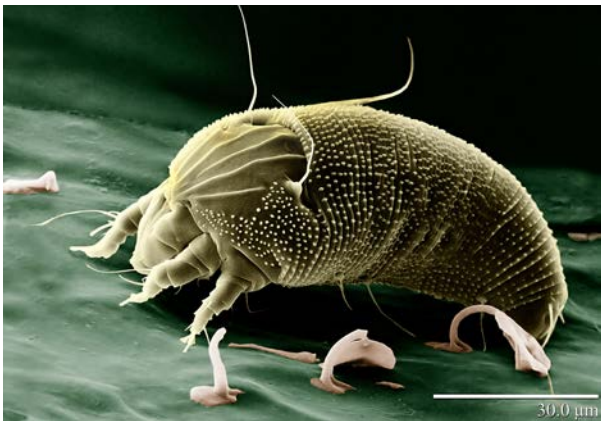


Fig. 2.46 Appearance of eriophyid mite.
Source: Wikimedia Common. Gilles San Martin. Louvain-la-Neuve. Belgium.

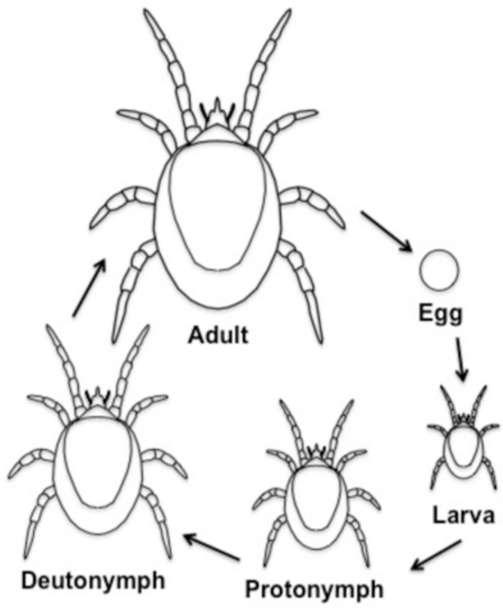


Fig. 2.47 Lifecycle of an tetranychid mite. Eggs, 1st-stage (proto), 2nd-stage (deuto) and adult.
Source: University of North Carolina Extension.

Fig. 2.48 Tetranychid mite.
Source: Eric Erbe. USDA-ARS. Bugwood.org

2.4 Symptoms of insects and mites — what can they tell us?

Pests can be divided into those with mouthparts that chew, those that suck, and those that pierce when laying eggs (Fig. 2.49). Thrips are often said to rasp, but it is now agreed that they pierce and suck, with different mandibles (mouthparts) adapted for the tasks. See the damage they cause in Figs. 2.82-2.84.

Fig. 2.49 Three ways insects cause damage on plants — chewing, sucking and piercing.
Source: David Trinklein. Extension. University of Missouri (left & centre).

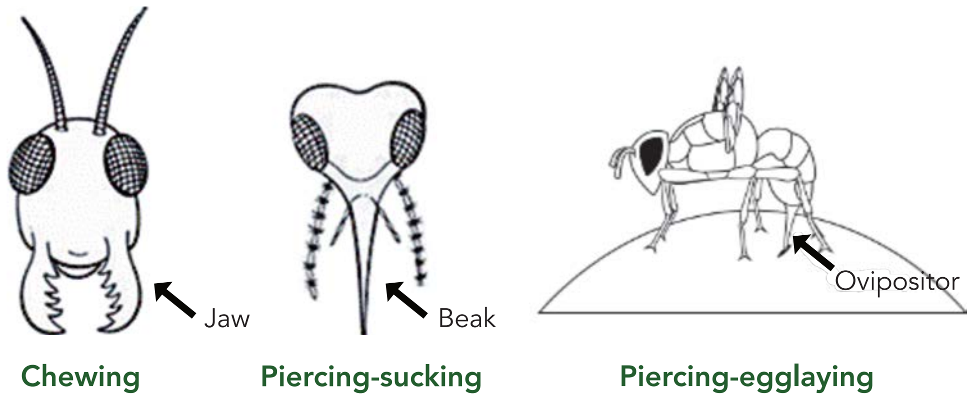


Table 2.2 **Variety of ways pests can damage crops, with examples and an explanation of which stages of the lifecycle are most likely to produce particular types of damage.**

Mouthparts	Pests	Sign of damage	Stage of lifecycle causing damage	Comments
Chewing	Grasshoppers, crickets & katydids (Orthoptera)	▪ chewed leaves, flowers & stems	adults & nymphs	
	Moths & butterflies (Lepidoptera]	▪ chewed leaves, flowers & stems ▪ boring or tunnelling into stems and trunks	moth & butterfly larvae (caterpillars), rarely adults (e.g. fruit-piercing moths)	
	Beetles & weevils (Coleoptera)	▪ mining of leaves ▪ chewed leaf surface or holes through the leaf ▪ boring or tunnelling in bark, trunks & roots, leaving frass ▪ mining of leaves	adults & grubs (larvae)	frass is insect excrement Leaf-mining less common than Lepidoptera and Diptera
	Flies (Diptera)	▪ rots in fruit ▪ mining of leaves	maggots (larvae)	
	Termites (Blattodea)	▪ chewed trunks & roots	adults & nymphs	in PICs: coconut (atolls); Formosan subterranean (Marshall Is.) & Asian subterraneum (Fiji, Micronesia)
	Ants, bees, wasps & sawflies (Hymenoptera)	▪ some bees cut out pieces of leaves ▪ some wasps cause galls ▪ ants protect aphids, scales, mealybugs from parasitoids & predators	larvae of sawflies, adults of leaf-cutting bees & larvae of gall wasps	ants do not damage plants directly; they protect other insects from natural enemies so they can take their honeydew. Excessive honeydew leads to leaves blackened by sooty moulds
Sucking	Thrips (Thysanoptera)	▪ scars on fruits, especially from the stalk end ▪ curled leaves ▪ 'silvering' of leaves and flowers	adults & nymphs	'silvering' is caused by air entering the leaf when the insect (or mite) pierces the leaf to suck the sap
	Moths & butterflies (Lepidoptera)	▪ fruit-rots (round at first)	adults (rare)	the fruit-piercing moth is an example of an adult in this group
	Aphids, bugs, leafhoppers, planthoppers, psyllids, mealybugs, scales & whiteflies (Hemiptera)	▪ small spots on leaves, flowers fruits (leading to rots) & also on seeds ▪ sooty moulds (fungi) ▪ wilts, stunted foliage & dieback ▪ galls	adults & nymphs	sooty mould fungi grow on the honeydew excreted from aphids, mealybugs, planthoppers, soft scale & whiteflies
	Mites (Trombidiformes)	▪ speckling and/or 'silvering' of top surface of leaf, with mites & webbing beneath ▪ severe leaf distortions and/or galls	adults & nymphs	two types of mites: those living on leaves (tetranychids) & those in buds or galls (eriophyid)
Piercing	Flies, beetles & weevils	▪ small spots or holes on fruits with surrounding bruising ▪ dark liquid oozing from fruit	adults	the damage is called a 'strike' when done by fruit fly

2.4.1 Chewing pests

Examples of chewing pests follows — Figs. 2.50-2.81.

Grasshoppers, crickets and katydids [Figs. 2.50-2.52]

Adults and nymphs eat large areas of leaves and soft stems, e.g. grasshopper attack on sugarcane and katydid damage to banana and oil palm. Note, leaf damage is similar to that caused by caterpillars, but there is no frass (i.e. faeces).

Often, damage from grasshoppers and katydids starts from the margin of the leaf, but not always. Crickets are different in their eating habits from the other two; they are 'omnivorous', meaning they eat many different kinds of food - plants, other insects including eggs, larvae and pupae, and also the remains of dead animals.

Fig. 2.50 Damage on long bean by small grasshopper (identity unknown) that eats through young leaves causing irregular holes; sometimes only the leaf surface is eaten, similar to damage ('windows') caused by other groups (see Figs. 2.54–2.57. *Source: authors.*

Fig. 2.51 Grasshopper (unknown) damage on sugarcane shows a solitary insect, and clearly the damage started at the edges of the leaf, where the grasshopper continues to feed. Note, lack of frass, which might otherwise suggest caterpillar damage. *Source: authors.*

Fig. 2.52 Katydid (*Sexava* sp.) on oil palm and banana can be devastating, where the entire leaf is stripped, leaving only the midrib. *Source: authors.*

Moths and butterflies (caterpillars) [Figs. 2.53-2.63]

Caterpillars chew all plant parts, but most commonly leaves.

They also bore into succulent stems and fruits. In many cases, the damage they cause is diagnostic for a particular type of insect on a particular crop e.g. cluster caterpillars on taro, but symptoms can also be similar to those of other groups.

For example, moths, flies, sawflies and beetles all have larvae that produce leafmines and blotches — although in terms of numbers, moths have the greatest number of species that feed in this way.

Similarly, holes in leaves are caused by caterpillars, but also by grasshoppers (nymphs and adults) and beetles (adults and larvae). Larvae of both moths and beetles also bore into stems, producing wilts and leaving frass.

The following examples show the variety of damage done and, importantly, show that by comparison with other groups, the damage is not exclusive. The symptoms illustrated are: chewing surface layers of leaves; eating entire leaves, mining leaves, making holes in leaves, folding leaves, rolling leaves and boring stems and fruits.

Fig. 2.53 Surface layers eaten by young, gregarious taro armyworm (*Spodoptera* sp.) called a taro cluster caterpillar at this stage. *Source: authors.*

Fig. 2.54 Later, solitary caterpillars eat the entire leaf, leaving only the petioles. *Source: authors.*

Fig. 2.55 Surface layers eaten by the coconut flat moth (*Agonoxena* sp.) from the underside of the leaf. *Source: authors.*

Fig. 2.56 Mines (blotches) made under the leaf surface by the cowpea leaf miner (*Phodoryctis* sp.). Compare this symptom with the mines made by leafminers of flies (Fig. 2.76) and beetles (Fig. 2.67). *Source: authors.*

Fig. 2.57 Holes in leaves

At first, caterpillars of diamondback moth (*Plutella* sp.) make 'windows' in the leaves of cabbages by eating the surface layers; later, the larger caterpillars eat through the leaf making holes. *Source: authors.*

Fig. 2.58 Folds and holes in leaves (*Herpetogramma* sp.). The caterpillars fold the leaves, presumably for protection, and eat holes in the leaves as they mature. The red sweet potato beetle (*Candezea* sp.) makes similar holes in leaves, although it does not fold them. *Source: authors.*

Fig. 2.60 Roll leaves

In a similar way to the banana skipper, the cotton leaf roller (*Haritalodes* sp.) on bele has rolled the leaves, although less spectacularly. *Source: authors.*

Fig. 2.59 Rolled leaves

Banana skipper (*Erionota* sp.) caterpillars have rolled the leaves to live and eat inside. *Source: Richard Markham. Fiji.*

Fig. 2.61 Wilt caused by a caterpillar (*Erias* sp.) boring into a stem, *bele. Source: authors.*

Fig. 2.62 Wilt caused by a caterpillar (*Erias* sp.) Internal boring of a bele stem, rot, caterpillar and frass. *Source: authors.*

Fig. 2.63 Bored fruit.

A common symptom of capsicum caused by the caterpillar of the corn earworm (*Helicoverpa* sp.). It also attacks fruit of tomato and eggplant. *Source: Haidee Brown, Deanna Chin. Plant Industries. Northern Territory.*

Beetles and weevils [Figs 2.64-2.75]

Symptoms caused by beetles and weevils vary, and some are similar to those made by caterpillars of moths and butterflies.

Adults in or on leaves may make straight lines, wavy lines, circles from stripping surface tissues on one side of leaves, holes through leaves, and holes into stems and trunks. Some larvae (called 'grubs') mine leaves.

Weevils – a large sub-group of beetles, some with long snouts – attack fruits, leaves, trunks, roots and stored products, as well as causing many other symptoms similar to those of beetles. Many weevils are also biocontrol agents of weeds and therefore beneficial to human beings.

Fig. 2.64 Feeding grooves cut parallel to the veins of ornamental ginger caused by unknown beetle. *Source: authors.*

Fig. 2.65 Feeding grooves cut into sweet potato leaves by flea beetles (*Chaetocnema* sp.) stripping the surface and making wavy lines. *Source: authors.*

Fig. 2.66 Outer layers of a cucumber leaf stripped away by a phytophagous ('plant-eating') 28-spot ladybird beetle (*Epilachna* sp.). The adults and larvae have 'skeletonised' the leaf in patches. *Source: authors.*

Fig. 2.67 Mines (blotches) made by the larvae of the coconut leafminer (*Promecotheca* sp.), a beetle. *Source: authors.*

Fig. 2.68 Small holes in leaf of *bele* caused by the flea beetle (*Nisotra* sp.). *Source: authors.*

Fig. 2.69 Holes in cucumber cut by the pumpkin beetle (*Aulacophora* sp.). It is thought that the beetle cuts out leaf circles in order to reduce toxic substances from entering them. *Source: authors.*

Fig. 2.70 Boring in oil palm fronds by the coconut rhinoceros beetle (*Oryctes* sp.). Similar holes are bored through the base of coconut fronds. *Source: authors.*

Fig. 2.71 Boring by larva (grub) of the cocoa weevil borer (*Pantorhytes* sp.). Gum is often produced by the tree in response to the presence of the larva, and there may be frass at the opening of the hole. *Source: authors.*

Fig. 2.72 Wilt of *Amaranthus* caused by a stem weevil (*Hypolixus* sp.). A symptom similar to that of *bele* (Fig. 2.62). Several larvae bore into the stem eating the interior and filling it with frass. Cankers form on stems and branches as fungi take advantage of the damaged plants. *Source: authors.*

Fig. 2.73 Boring into the corm of taro by adult taro beetle (*Papuana* sp.). *Source: authors.*

Fig. 2.74 Boring into storage roots by larvae of sweet potato weevil (*Cylas* sp.). *Source: authors.*

Fig. 2.75 Bored grain in storage damaged by the lesser grain weevil (*Sitophilus* sp.). Both adults and larvae do the damage, by feeding inside the grains. *Source: Clemson University. USDA Cooperative Extension Slide Series. Bugwood.org*

Flies [Fig. 2.76]

Leaf-mining fly maggots burrow just beneath the outer leaf layers similar to leaf-mining caterpillars. Note that larvae of leaf mining moths deposit frass down the middle of the mine, whereas leaf-mining fly maggots tend to leave the frass alternating between the sides of the mine. The reason for these alternating deposits is that the fly larva feeds on its side, and from time to time rolls over. Larvae of moths (and beetles and sawflies) feed either belly-up or belly-down, and frass is deposited down the middle of the mine.

Fig. 2.76 Mines made by the larva (maggot) of a fly leafminer (*Liriomyza* sp.) on tomato. The mines are very similar to those made by larvae (caterpillars) of moths. *Source: Dr J Poorani. ICAR- National Bureau of Agricultural Insect Resources (NBAIR). India.*

Termites [Figs. 2.77-2.78]

Crop damage by termites is unusual in Pacific islands, although damage to buildings is common. Serious damage on coconuts does occur, but this appears to be confined to atoll countries.

If symptoms are seen similar to those of Fig. 2.77, they should be reported immediately to agricultural authorities.

The presence of the coconut termite in Rotuma (Fiji) is thought unlikely, but another species is damaging both coconut and citrus (Fig. 2.78).

Fig. 2.77 It is not common for termites in the region to attack living plants or trees, but there are exceptions.

The coconut termite (*Neotermes* sp.) attacks living palms in some atoll countries. It makes grooves into the bark for reasons unknown, but their appearance is considered diagnostic for the species. *Source: Gerald McCormack. Cook Islands Biodiversity & Natural Heritage.*

Fig. 2.78 Surface termite tunnels and a nest in the trunk of a living coconut (Rotuma, Fiji).

An unknown termite species is attacking coconuts and citrus on the island. *Source: authors.*

Ants, bees, wasps and sawflies [Figs. 2.79-2.81]

Within this group there are relatively few examples of damage caused directly by chewing adults or larvae. There are leaf-cutting bees that spoil ornamental flowers, gall wasps, e.g. *Quadrastichus* larvae on *Erythrina* trees, and sawflies that occasionally strip leaves.

However, for the most part, bees and wasps are considered beneficial and important, wasps especially so, as they are parasitoids, natural enemies of plant pests. Where problems exist they are of different kinds. Introduced Asian bees compete with honey bees, and wasps (and hornets) may be a nuisance as they sting humans and animals.

Fig. 2.79 Leaf cutting bee (*Megachile* sp.)

The adult causes the symptoms. The bees live in burrows; they make cells from the leaf pieces, place eggs and pollen inside for the young and then seal the cell.

Source: Whitney Cranshaw. Colorado State University. Bugwood.org

Invasive ants especially are a major problem in Pacific islands, some out-compete native species, seriously disrupting ecosystems. Further, they feed on honeydew from scale insects, mealybugs, aphids, psyllids and planthoppers, protecting them from their natural enemies. Plants are weakened as honeydew supports mould fungi which blacken leaves, restricting photosynthesis.

See also Section 2.4.2 on aphids and related examples under sucking pests.

Fig. 2.80 Sawfly larvae (*Nematus* sp.) are similar to moth caterpillars except for a greater number of prolegs. The damage by sawflies and caterpillars can be similar.

Source: Wikimedia Commons. Charles James Sharp. Sharp Photography.

Fig. 2.81 Galls produced by the larvae of the Erythrina gall wasp (*Quadrastichus* sp.)

The larvae feed on the leaves and the tree responds by producing swollen deformed leaf galls. Note, insects of many orders as well as mites, produce galls.

Source: Albert (Bud) Mayfield. USDA Forest Service. Bugwood.org

2.4.2 Sucking pests

Examples of sucking pests follow — Figs. 2.82-2.99.

Thrips [Figs. 2.82-2.84]

Silvering on fruits and leaves is a common symptom on plants in Pacific island countries; this is seen commonly on capsicum, onion, mango and eggplant. On capsicum and eggplant, thrips enter the fruit buds when they are very young. Symptoms also occur on the flowers of some plants.

Most thrips feed by puncturing plant cells and sucking up the contents.

The damage is done early, but becomes noticeable only later when the leaves and fruits expand: they become discoloured, silvery, and distorted. Some thrips are beneficial predators.

Symptoms of thrips are similar to those caused by spider mites. However, often the thrips have disappeared by the time that the leaves and fruits emerge. In some species, populations of thrips can be found within the folded, rolled leaves (e.g. *Ficus*) or on the underside of leaves (e.g. taro). Note, some species of thrips spread viruses.

Fig. 2.82 Thrips on shallot *(Thrips tabaci)*
Thrips have unusual mouth parts: one side cuts or hammers the leaf surface to rupture the cells, while the other part has a tube to suck up the contents. *Source: authors.*

Fig. 2.83 *Thrips* sp. silvering of leaves is a typical symptom of thrips. *Source: Haidee Brown, Deanna Chin. Red-banded thrips on fruit trees. Plant Industries. Northern Territory.*

Fig. 2.84 *Thrips* sp. Scarring on fruit of capsicum (left) and eggplant (right). On both, the thrips have entered the bud at an early stage, fed on the fruit as it developed creating the 'dragged-out' symptom as the fruit expanded (especially noticeable on eggplant). By this stage, the thrips have moved to younger fruit. *Source: authors.*

Moths and butterflies [Fig. 2.85]

Sucking damage by moths and butterflies is rare.

The one important example in Pacific island countries is the fruit-piercing moth, a pest of citrus and many vegetables, especially tomato.

The caterpillars develop on *Erythrina* trees.

Fig. 2.85 Fruit piercing moth (*Eudocima* sp.) on orange. The moth has sucked juice from the fruit and secondary invasion by rotting-causing organisms has caused the fruit to drop. *Source: authors.*

Aphids, true bugs, leafhoppers, planthoppers, psyllids, mealybugs, scale insects and whiteflies [Figs. 2.86-2.96]

All these groups suck sap to feed, and symptoms vary:

- aphids, leafhoppers and planthoppers, and psyllids cause distortions and wilting
- true bugs cause spotting and stem cankers and
- mealybugs and scales can cause leaf distortion and dieback.

Many produce honeydew (aphids, leafhoppers and planthoppers, phyllids, mealybugs, soft scales, whiteflies), which promotes sooty moulds, reduces photosynthesis, stunts growth and causes early leaf fall. Ants tend these insects for their honeydew and protect them from natural enemies. Aphids, psyllids, leafhoppers and planthoppers, mealybugs and whiteflies spread pathogenic bacteria and viruses.

Fig. 2.86 Distorted young leaves of basil caused by aphids (*Aphis* sp.) feeding on the underside. Mealybugs can produce similar symptoms on other plants (Fig. 2.87). *Source: authors.*

Fig. 2.87 Distorted young leaves of tomato caused by mealybugs (species unknown) on plants grown under protected cropping. The white fluffy waxy growth often covers eggs and young stages and is typical of mealybug infestations. *Source: authors.*

Fig. 2.88 Spotting on fruits by the feeding of the fruit spotting bug (*Amblypelta* sp). A related species causes premature nut fall of coconuts, and dieback of cassava (Figs. 2.89 & 2.90). *Source: Haidee Brown, Deanna Chin. Plant Industries. Northern Territory.*

Fig 2.90 Feeding by *Amplypelta* results in leaf wilt, dieback, and cankers on the stem. *Source: authors.*

Fig. 2.89 Cankers on stem of cassava from 'true' bug (*Amblypelta* sp.) feeding. The scars on the stem have been invaded by a (secondary) fungus — notice black pin-point size dots in the cankers which, most likely, will contain fungus spores. *Source: authors.*

Fig. 2.91 Psyllid galls on Malay apple, common in Pacific island countries, caused by the Malay apple gall psyllid (*Trioza* sp.). Eggs are laid on the underside of the leaf and the nymphs enter the leaf, stimulating the leaf to develop galls on the upper surface. *Source: authors.*

Fig. 2.92 Wilt of rice due to planthopper attack (*Nilaparvata* sp.). Large numbers cause 'hopper-burn' as the plants become dehydrated, wilt and collapse. This is a common symptom in rice when pesticides are used and natural enemies are destroyed, and the planthoppers increase in number as a result. *Source: authors.*

Fig. 2.93 Sooty mould, an indirect result from soft scale infestations (*Ceroplastes* sp.). The scale produces 'honeydew', a waste liquid from feeding on plant sap which falls onto the foliage and is colonised by fungi, resulting in characteristic black growth. *Source: Haidee Brown, Deanna Chin. Plant Industries. Northern Territory.*

Fig. 2.94 Ants (*Technomyrmex* sp.) tend scale insects for their honeydew, and in the process protect them from their natural enemies, allowing large infestations to occur This has happened in Fiji with the introduction of the white-footed ant. *Source: Randy R Thaman. Fiji ant-mealybug bioinvasion: threat to food, health, livelihood, cultural and environment security in the Pacific islands. USP.*

Fig. 2.95 Lesser snow scale (*Pinnaspis* sp.), an armoured scale on oil palm fruit. The female scale can be seen as pale brown round objects on the fruits in the centre; the white areas are the cocoons of the male scale. *Source: authors.*

Fig. 2.96 Spirals and adults of the spiralling whitefly (*Aleurodicus* sp.). Eggs are laid in the waxy spirals. *Source: authors.*

Mites (Figs. 2.97-2.99)

There are two types of mites that are common pests in Pacific island countries.

One is represented by the two-spotted mite, that causes white/ greyish speckling on the top of leaves and webbing on the underside.

The other is represented by the much smaller broad mite that lives inside buds and causes yellow patches and distortions on leaves and fruits. It is common on capsicum and tomato.

A hand lens or microscope is useful to see mites.

Fig. 2.97 Speckling symptom on taro caused by the feeding of two-spotted mites (*Tetranychus* sp.), most often on the under surface of leaves. The silvering is said to be caused by air entering cells punctured by the mites as they feed. *Source: authors.*

Fig. 2.98 Distortions on capsicum, commonly caused by broad mite (*Polyphagotarsonemus* sp). Symptoms can be mistaken for distortions caused by virus infection. *Source: authors.*

Fig. 2.99 Galls formed by the sweet potato gall mite, an eriothyid mite (*Eriophyes* sp.). *Source: authors.*

2.4.3 Piercing pests

Examples of piercing pests follows — Figs. 2.100-2.101.

Weevils and flies [Figs. 2.100-2.101]

Some insects pierce fruits when laying eggs.

In Pacific island countries, fruit flies are a common example of this.

At the same time as they insert eggs, they inject bacteria that cause rots and provide food for the maggots. Weevils also lay eggs in fruit.

Fig. 2.100 Eggs laid by the mango seed weevil (*Sternochetus* sp.) cause sap to be released which dribbles down the fruit before hardening.
Source: Haidee Brown, Deanna Chin. Plant Industries. Northern Territory.

Fig. 2.101 'Strikes' on tomatoes where fruit has been pierced by fruit flies (*Bactrocera* sp.) in the process of laying eggs.
Source: Haidee Brown, Deanna Chin. Plant Industries. Northern Territory.

2.4.4 Similar symptoms, different groups

It is not surprising that different groups of pests may cause similar symptoms, as they have only two methods of feeding on plants (chewing and sucking) and one method of laying eggs (piercing). For instance, among the chewing insects it can be hard to tell whether the damage was done by an adult chewing beetle, an adult (or nymph) katydid, the larva (caterpillar) of a moth, or a leaf-cutting bee (Table 2.3). All have mandibles, which are hardened and tooth-like for cutting and crushing.

When it comes to sucking insects and mites, again buds, leaves and stems are damaged, but the symptoms differ from those caused by chewing insects. Again, this should not surprise us as the method of feeding is quite different — sucking insects tap into vascular systems for liquid food. This kind of feeding causes distortions, galls, stippling/silvering, wilting, and dieback.

In only two cases do we see different groups causing similar damage. Galls are produced by some aphids, psyllids, thrips and broad mites, and speckling/silvering can be caused by thrips, true bugs, and both kinds of mites (Table 2.3). Of interest though, is that within the large grouping, order Hemiptera, similar symptoms are produced by insects that appear quite different, for instance, compare the sub-order containing scale insects/ mealybugs/aphids (order Sternorrhyncha) to the other sub-orders containing the true bugs (sub-order Heteroptera), and the leafhoppers/ cicadas (sub-order Auchenorrhyncha.)

The fact is, they may look very different, but their common underlying biology binds them together taxonomically, and results in pest species producing similar symptoms when feeding on plants.

To plant health doctors, all this information can be quite confusing. It is provided here as a warning to doctors not to assume that a particular symptom can always be interpreted as the result of the feeding of a particular kind of insect or mite. A smart plant health doctor, when given a sample with symptoms but without any likely cause, will always have questions to ask! Table 2.3 summarises similar symptoms caused by different orders of pest.

Table 2.3 Similar symptoms but different orders: examples from the Pacific Pests, Pathogens & Weed app. (N/A = there are no fact sheets in the Pacific Pests, Pathogens & Weeds app.)

Plant part attacked / symptom	Order (common name)	Stage causing damage	Insect or mite (example)	Crop (example)	Fact sheet #
Type of damage: chewing					
Leaf, make holes or stripping	Coleoptera (beetle)	Adult	*Candezea*	Sweet potato	53
	Lepidoptera (moth)	Larva	*Plutella*	Cabbage	20
	Orthoptera (katydid)	Adult, nymph	*Sexava*	Oil palm	246
	Hymenoptera (bee)	Adult	*Megachile*	Ornamentals	N/A
Leaf, mining (serpentine or blotch)	Coleoptera (beetle)	Larva	*Promecotheca*	Coconut	60
	Diptera (fly)	Larva	*Liriomyza*	Tomato	110
	Lepidoptera (moth)	Larva	*Phodoryctis*	Cowpea	378
	Hymenoptera (sawfly)	Larva	*Phylacteophaga*	Eucalytus	N/A
Leaf, scraping top layer	Coleoptera (beetle)	Adult, larva	*Epilachna*	Eggplant	58
	Lepidoptera (moth)	Larva	*Spodoptera*	Taro	31
	Orthoptera (grasshopper)	Adult, nymph	*Aiolopus*	N/A	N/A
Stem/trunk, boring	Coleoptera (weevil)	Larva	*Pantorhytes*	Cocoa	61
	Coleoptera (beetle)	Adult	*Oryctes*	Coconut	108
	Diptera (fly)	Larva	*Ophiomyia*	Cowpea	291
	Isoptera (termite)	Adult	*Neotermes*	Coconut	116
	Lepidoptera (moth)	Larva	*Earias*	*Bele*	23
Fruit, boring	Coleoptera (weevil)	Larva	Cryptorhynchus	Mango	437
	Lepidoptera (moth)	Larva	*Deanolis*	Mango	281
Seed, boring	Coleoptera (weevil)	Adult, larva	*Sitophilus*	Rice	338
	Lepidoptera (moth)	Larva	*Sitotroga*	Rice	337
Tuber/corm/ storage root, boring	Coleoptera (weevil)	Larva	*Cylas*	Sweet potato	29
	Coleoptera (beetle)	Adult	*Papuana*	Taro	30
	Lepidoptera (moth)	Larva	*Phthorimaea*	Potato	298
Type of damage: sucking					
Leaf, sooty mould	Hemiptera (aphid)	Adult, nymph	*Rhopalosiphum*	Maize	330
	Hemiptera (leafhopper)	Adult, nymph	*Idioscopus*	Mango	263
	Hemiptera (scale)	Adult, nymph	*Ceroplastes*	Gardenia	271
	Hemiptera (psyllid)	Adult, nymph	*Diaphorina*	Citrus	185
	Hemiptera (whitefly)	Adult, nymph	*Aleurocanthus*	Citrus	244
Leaf distortions	Hemiptera (aphid)	Adult, nymph	*Aphis*	Basil	38
	Hemiptera (scale)	Adult, nymph	*Aspidiotus*	Coconut	104
	Hemiptera (mealybug)	Adult, nymph	*Phenacoccus*	Tomato	373
Leaf, galls	Hemiptera (aphid)	Adult, nymph	*Eriosoma*	Apple	N/A
	Hemiptera (psyllid)	Nymph	*Trioza*	Malay apple	366
	Trombidiformes (broad mite)	Adult, nymph	*Eriophyes*	Sweet potato	138
	Thysanoptera (thrips)	Adult, nymph	*Gynaikothrips*	Acacia	N/A
Leaf/fruit, speckling	Thysanoptera (thrips)	Adult, nymph	*Thrips*	Capsicum	49
	Hemiptera (true bug)	Adult, nymph	*Corythucha*	Eggplant	253
	Trombidiformes (Eriophyid)	Adult, nymph	*Phyllocoptrata*	Citrus	344
	Trombidiformes (2-spotted)	Adult, nymph	*Tetranychus*	Taro	24
Leaf, wilt, dieback	Hemiptera (true bug)	Adult, nymph	*Amblypelta*	Cassava	19
	Hemiptera (scale	Adult, nymph	*Icerya*	Citrus	343
	Hemiptera (planthopper)	Adult, nymph	*Tarophagus*	Taro	41
	Hemiptera (mealybug)	Adult, nymph	*Phenacoccus*	Cassava	329
Type of damage: piercing					
Fruit, egg laying (stike)	Coleoptera (weevil)	Adult, larva	*Cryptorhynchus*	Mango	437
	Diptera (fly)	Adult, larva	*Bactrocera*	Tomato	425

EXERCISE 2.3: Similar symptoms, different groups

Table 2.3 shows that pest symptoms can be confusing as similar symptoms can be caused by very different types of pests. Exercises 2.3 and 2.4 will help your trainees to think about symptoms of pest damage and the range of possible causes. This is a challenging exercise, but the purpose is for your trainees to recognise that similar symptoms can have many causes. It is not necessary for them to learn the names of every pest.

By thinking about and discussing the possible answers in their groups and then with the whole class, your trainees will have a deeper understanding of the complexity of pest diagnosis, so they do not immediately jump to one answer when they see symptoms.

- in pairs or threes, ask your trainees to **draw and complete the table below** by filling in the blank cells — they will need access to the Pacific Pests, Pathogens & Weeds app facts sheets
- then ask them to **compare their answers** with another group and make changes if they need to. Also, they should check their answers with Table 2.3
- **discuss their answers** with the whole class, especially paying attention to symptoms that are confusing. An example is given in the first row.

Your answers

Symptom	Damage type *	Possible causes (pest orders — common names)	Life stage of pest	Confirmed by fact sheet #
Holes (stem/trunk)	Chewing	1. Fly 2. Moth/butterfly	Larva (maggot) Larva (caterpillar)	291 23
Speckling (leaf/fruit)				
Mines (leaf)				
Galls (leaf)				
Holes (seed)				
Wilt, dieback (leaves/ branches/ plants)				
Sooty mould (leaf)				
Distortions (leaf)				
Scraping (leaf)				
Egg-laying strike (fruit)				

* chewing, sucking or piercing.

EXERCISE 2.3: similar symptoms, different groups

EXERCISE 2.4: Understanding chewing, sucking and piercing damage

For this exercise, try to find samples of leaves, fruit or roots that show symptoms of chewing, sucking or piercing, but with no visible pests.

- give each pair or group of trainees a **different sample of pest damage** (or a photograph if you cannot find field samples)
- your trainees should **examine their sample** carefully with a hand lens and answer the following questions
- then they should **share their answers** with the whole class and discuss the diagnosis process.

Plant part (leaf, fruit, root):

1. Describe the symptoms:

2. Are the symptoms typical of:
   i. chewing
   ii. sucking or
   iii piecing?
   Explain your answer:

3. List all possible causes of these symptoms, including the life cycle stage of the pest:

4. What further information would you need to find out the actual cause?

2.5 What is a disease?

Plant diseases are caused by fungi, oomycetes, bacteria, nematodes, viruses, viroids and phytoplasmas.

Together they are known as pathogens. The causes of many diseases are difficult to identify, as the pathogens are mostly hidden inside the leaves, stems, seeds, roots or soil.

Sometimes, damage caused by pests and diseases looks similar, e.g. virus and mite damage, but this is rare. More commonly, viruses are spread by insects, sucking ones in particular, so if you suspect a virus, look for an insect too!

Fungi

Fungi (singular, fungus), vary in size from single cells to masses of thin, branched, cottony growth (called hyphae). A single strand is called a hypha (plural, hyphae), and a mass of hyphae a mycelium. Fungi feed on dead organic material or on living organisms by releasing enzymes which break down the food they are growing on into chemicals that they can absorb. Unlike plants, they are without chlorophyll so do not carry out photosynthesis, and their cell walls are of chitin (the same as the exoskeleton of arthropods – insects, spiders and crustaceans) not cellulose, which is used by plants. They reproduce by spores, either asexually (without mating) or sexually. Spread occurs in wind and rain, on and in seeds and in other propagation materials, often associated with the domestic and international trade in plants.

Oomycetes

Oomycetes (singular, oomycete) were once thought to be fungi; now they are classified with some kinds of algae. They are known as water moulds as most exist in fresh or brackish water or in wet soils living on dead or decaying organic matter. Some are pathogens of plants, fish and other life forms. Differences from fungi include that their cell walls are made of cellulose not chitin; the branching cottony growth (filaments) do not have cross walls; and they produce asexual spores (sporangia), each of which releases tiny spores (zoospores) with two whip-like hairs (flagella), allowing them to swim short distances in soil water. Like fungi, sexual spores are produced, and methods of spread and survival are also similar.

Many are important pathogens, including the following groups:

i. *Phytophthora* species

ii. *Pythium* species

iii. downy mildews and

iv. white blister rusts.

There are examples of these in the Pacific Pests, Pathogens & Weeds app.

Bacteria

Bacteria (singular, bacterium), are microscopic, single-celled organisms, found in all environments on Earth. They range in shape from spheres to rods to spirals, have a rigid cell wall, a single, circular chromosome of DNA, and some have flagella, whose whip-like actions provide movement. Nutrition is by photosynthesis or by breaking down chemical compounds using enzymes. Reproduction is by binary fission: the cell DNA duplicates, the cell content increases and the cell splits in two. Bacterial root infections can sometimes be identified by putting a cut root into water. Milky streams of bacteria may be seen streaming from the root.

Viruses

Viruses (singular, virus) are single-celled microscopic parasites of many different shapes and sizes, with a core of DNA or RNA surrounded by a protein coat or shell (called a 'capsid'). They are mostly much smaller than bacteria. They need cells of other organisms for reproduction, and that is why many scientists say they are not living. They have been on the earth for billions of years, and are found in all other organisms, including bacteria and fungi. Viruses are important in transferring genes between species, so-called 'horizontal genetic transfer', which is important in the evolution of species.

Viroids

Viroids (singular, viroid) are the smallest pathogens known, and are simpler than viruses. They consist of a piece of circular RNA without a protein coat or shell. They can only reproduce within a host cell and are only found in plants, where they may cause diseases. Like viruses, viroids are thought to be non-living by many scientists.

Phytoplasmas

Phytoplasmas (singular, phytoplasma). The previous name was mycoplasma-like organism. They are similar to bacteria but do not have a cell wall, and because of that their shapes vary. They occur in the phloem of plants and are spread by sap sucking insects, mostly leafhoppers. A little-leaf or witches' broom symptom is common, with small yellow leaves on bushy shoots. Flowers may become leaf-like. They are usually detected by electron microscopy or by molecular methods.

Nematodes

Nematodes (singular, nematode) are tiny worms that live in the soil. Males mate with females which produce eggs and the young, called 'juveniles', moult several times before becoming adult. Most are free-living, feeding on bacteria, fungi and protozoans (single-cell organisms). Some are plant parasites and have a spear in their mouth used to enter and move through plants. Commonly, they damage root tips, causing excessive root branching or galls.

Here are five important facts about pathogens, that will help you to understand them:

2.5.1 Most pathogens are small

Of all the pathogens, only fungi can be seen with the naked eye, and then only those that produce masses of cottony growth, or the large fruiting bodies we call mushrooms, toadstools or brackets. However, when the length of all the cottony growth of some soil fungi is measured, they may not be so small — some are thought to be the largest organisms in the world as their growth extends over many hectares.

The spores of fungi are also small, and a microscope is needed to see them. A microscope is also needed to see nematodes, and especially the plant pathogens. Fig. 2.102 shows the relative size of various pathogens compared with humans.

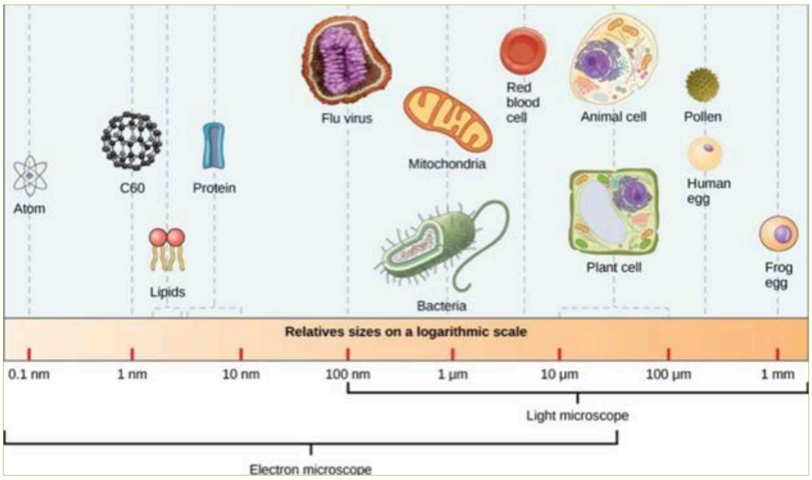


Fig. 2.102 The relative size of bacteria and viruses compared with plant and animal cells (on a logarithmic scale). (Note, I nm is a billionth of a metre, and each unit of increase in a logarithmic scale represents a 10-fold increase in the quantity being measured). Fungal spores (not shown) are in the 2-100 µm range. *Source: Wikimedia Commons. Charles Molnar and Jane Gair, OpenStax.*

2.5.2 Pathogens reproduce very quickly

Fungi make spores of many shapes and sizes in open or closed structures (Figs. 2.103-2.104).

Bacteria make copies of their DNA and then split into two. If conditions were right, it is estimated that starting with one bacterium that divides after 30 minutes, and the progeny maintain this rate of division over every generation, it would take only 48 hours to cover the world!

Viruses enter plant cells and direct the cell to make their components, which are assembled into new viruses and released.

Plant parasitic nematodes have a spear in the mouth to damage cells of roots (Fig. 2.107) and to feed on them. In some cases, they produce chemicals that stimulate plants to make galls. Nematodes reproduce rapidly too. Most lay eggs that pass through immature stages (the juveniles) before becoming adult. Life cycles can be as rapid as 3-7 days depending on the soil conditions. Some nematodes produce chemicals that stimulate plants to make galls (e.g. root knot nematodes).

2.5.3 Fungi and bacteria need water for infection

Fungal spores need water for germination and infection either above or below ground. Germination produces a germ tube that penetrates either directly or through natural openings (mostly stomata), taking a few hours to

Fig. 2.103 Fungal spores are produced in sacs through which they emerge during times of rain. *Source: authors.*

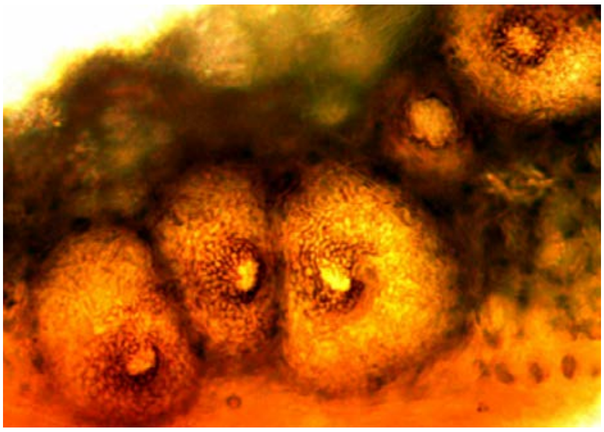


Fig. 2.104 A close-up of the sacs is shown from a similar fungus to that in Fig. 2.103. *Source: MSU Extension. Michigan State University.*

Fig. 2.105 Fungal spores are produced on the underside of the tomato leaflets. The spores are on stalks (conidiophores) that emerge through the leaf, bearing the spores, the conidia.
Source: authors.

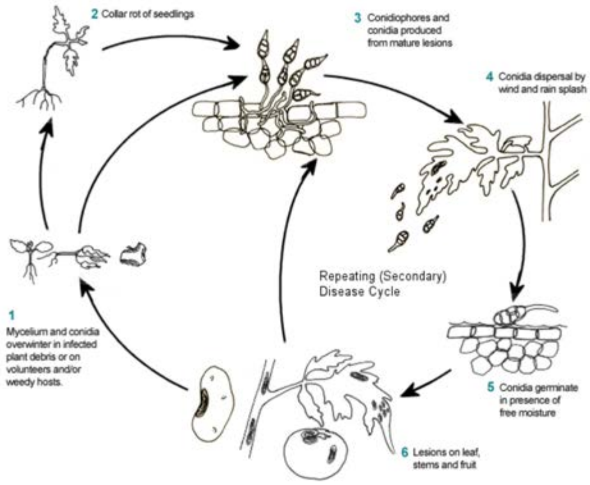


Fig. 2.106 This diagram shows how fungus emerges through the plant leaf to produce spores. In contrast to Figs. 2.103 and 2.104, the spores are not enclosed in sacs.
Source: American Phytopathological Society. G Kemmitt. Early blight of potato and tomato. The Plant Health Instructor.

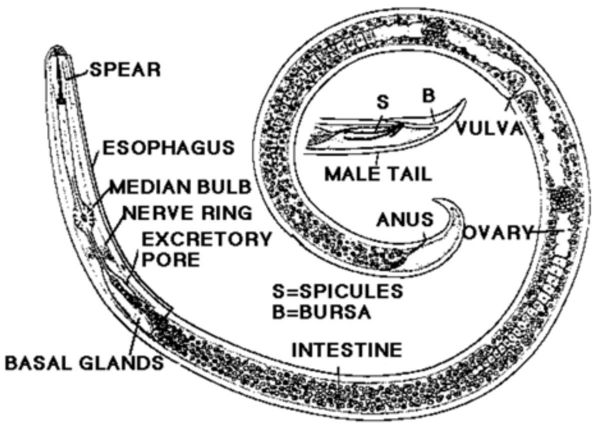


Fig. 2.107 Diagram to show the spear in the mouth of a nematode. Note that these minute organisms, mostly smaller than the naked eye can see, have a complex structure, with intestine, male and female reproductive and nervous systems. *Source: By kind permission, PH Putnam. UC Davis.*

do so. Powdery mildews are an exception: they do not need free water, but they do need high humidity. Most powdery mildews grow over the surfaces of plants, putting down short tubes to draw out nutrients. Bacteria enter through natural openings, assisted by wind-driven rain. In the soil, wounds made by nematodes or fungi assist them. Occasionally, bacteria are injected into plants by insects as they feed, in the same way that plants are infected by viruses.

2.5.4 Pathogens have many ways of spreading

A majority of fungi, oomycetes and bacteria are spread above-ground in rain-driven wind (Fig. 2.108). For the most part their spores or cells are delicate and cannot withstand dehydration. However, there are instances where wind is the main agent of spread. There is also involvement of insects in the spread of these groups above ground, but this is less common.

Below ground, too, water plays a role, with movement of fungal and oomycete spores and bacterial cells in ground water, which also spreads nematodes. In some oomycetes, however, there are motile spores (Fig. 2.109).

Although insects play a minor role overall in the spread of fungi, bacteria and nematodes, this is not the case for viruses. Here, they are the main agent of spread. To be successful, a virus needs assistance to break through the cellulose wall of plant cells, and do it in such a way that the cells remain alive, in order to manufacture more virus. In the act of feeding by piercing and sucking, or less often by chewing, on succulent leaves and stems, insects place viruses where they need to be (Fig. 2.110).

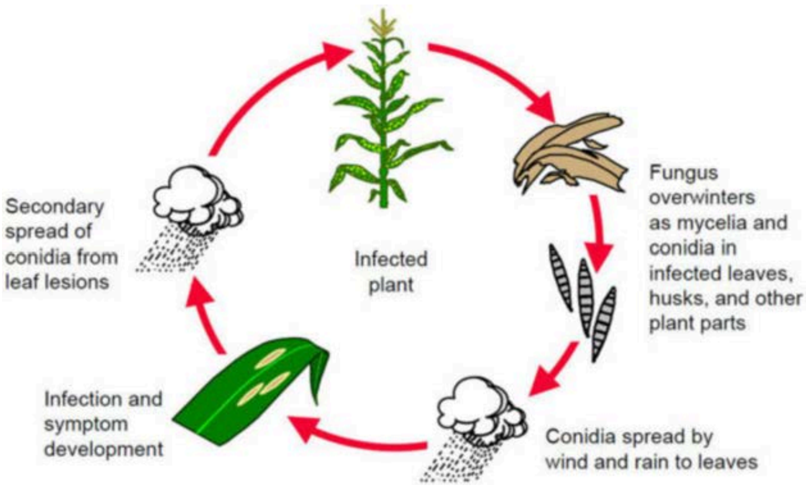


Fig. 2.108 In this fungal disease of maize, spores called 'conidia' are spread by wind and rain. In the soil, the situation is different: some pathogens, for instance, fungi, oomycetes, bacteria and nematodes, move (or are moved in water). *Source: Northern Corn leaf blight. By kind permission Pioneer. USA.*

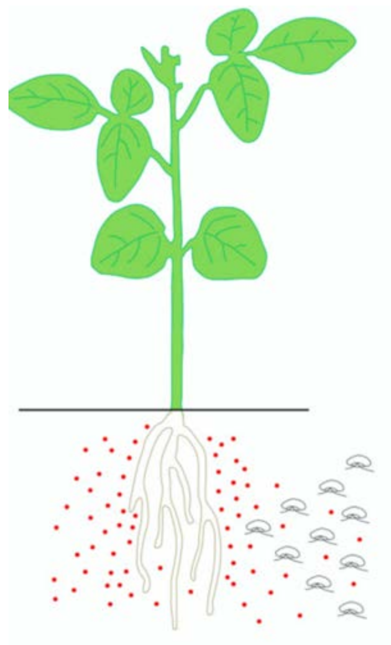


Fig. 2.109 Pathogens that have the ability to self-propel in the soil water are attracted by chemicals from the roots of plants. *Source: authors.*

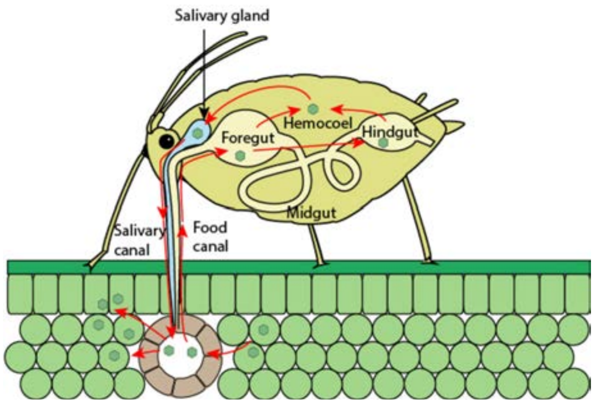


Fig. 2.110 Aphids and many other sap-sucking insects infect plants with viruses as they feed. The viruses may be:

i. attached to the stylets and quickly transferred or
ii. passed out through the stylets after a lengthy period of multiplication within the insect and during a feed on a new host.

Source: ViralZone.

Insects are not the only organisms that transfer viruses in this way; fungi also do it and so do nematodes, but the number of examples is very small.

It is unfortunate to note that in addition to the many natural methods of pathogen spread, human beings are also involved, and this association is now occurring at rates not seen previously. Much of it is associated with the international trade of plants and plant parts, whether as ornamentals or for propagation as seeds or cuttings. Local spread occurs too. Farmers often unwittingly spread pathogens in or on planting materials - the cuttings of *bele* or cassava, the corms of taro and banana, vines of sweet potato, or sets of yam. Careless use of agricultural machinery harbouring pathogen-contaminated soil is yet another way that human beings assist pathogens to spread.

2.5.5 Pathogens have many ways of surviving

To survive and pass their genes to the next generation is clearly an aim of all pathogens. Many methods are used by the groups described in this manual to ensure that it occurs. Your trainees should become acquainted with the methods associated with some of the main diseases in the region where PHCs are held. It is important to discuss survival of plant diseases with farmers because IPDM relies heavily on disrupting pest life cycles to achieve success. For instance, healthy planting material is a must, as is the destruction of harvest remains if they are likely to harbour pathogens for future crops.

Some methods of survival are listed below:

- in or on seeds (fungi, bacteria and viruses)
- in plant trash on or in soil (fungi and bacteria)
- on weeds — all
- on ‘volunteer’ (self-sown or those remaining from the previous harvest) plants — all
- on over-lapping crops — all
- as dormant spores or eggs in soil — fungi and nematodes
- inside insects — viruses, phytoplasmas, some bacteria.

2.6 Symptoms of pathogens — what can they tell us?

Fungi, oomycetes (fungus-like *Phytophthora, Pythium* and relatives), bacteria, phytoplasmas, viruses, viroids and nematodes which collectively we call pathogens, commonly cause symptoms when they infect plants. These symptoms are important in helping us to diagnose plant diseases, so here we look at the type of symptoms that they produce.

Spots and shot-holes [Figs. 2.111-2.114]

Leaf spots are common and mostly caused by fungi. The spots grow to a particular size and then stop (Fig. 2.111-2.114). Spores develop on the underside of the leaves as furry patches, or inside black sacs embedded in the top surface. In both types, the spores are spread by wind and rain.

When the centre of the spots fall out, which is typical of some diseases, we call it a shot-hole (Fig. 2.112). It is hard to tell fungal spots from those caused by bacteria (Fig. 2.113) without studying them in the laboratory. Viruses occasionally develop ringspots (Fig. 2.114) but, as with bacterial spots, they are rare.

Fig. 2.111 Spots (fungus) on coconut. Uniform ovals with clear margins, unlikely to expand further now leaf has reached maturity.
Source: authors.

Fig. 2.112 Spots (fungus) on taro. The centre of some of the spots has fallen out, giving a 'shot-hole' symptom.
Source: authors.

Fig. 2.113 Spots (bacteria) on tomato with a possible bacterial infection. *Source: Gerald Holmes. Cal Poly San Luis. Bugwood.org*

Fig. 2.114 Spots (virus) on sweet potato. *Source: authors.*

Blights [Figs. 2.115-2.117]

Some spots do not stop growing and the symptoms develop into a blight.

Blights are typically wet-weather diseases, such as taro leaf blight (Fig. 2.115), watermelon gummy stem blight (Fig. 2.116) and yam anthracnose (Fig. 2.117).

Spots develop, expand and form masses of spores, which spread rapidly, infecting and defoliating leaves and killing stems.

Fig. 2.115 Taro leaf blight. This blight can totally destroy the crop in a few days of wet weather. *Source: authors.*

Fig. 2.116 Gummy stem blight on watermelon. This blight, too, can totally destroy the crop in a few days of wet weather. *Source: authors.*

Fig. 2.117 Yam anthracnose. Leaf spots of *Colletotrichum gloeosporioides* expand and lead to a blight (and often dieback). *Source: authors.*

Dieback [Figs. 2.118-2.119]

Many fungal and some bacterial and viral diseases cause dieback symptoms. Leaves are first infected, and then a progressive death of the stem or branch.

Many early yams *(Dioscora alata)* are susceptible to dieback caused by *Colletotrichum*, the common anthracnose fungus. But dieback is not confined to above-ground infection. It occurs if roots are infected, too, for instance, when avocado roots are attacked by the oomycete *Phytophthora*, and citrus by the fungus *Ganoderma.*

Bacteria also cause dieback symptoms (e.g. citrus canker and Huanglongbing), so too do viruses (e.g. tristeza and vanilla viruses, and kava dieback), and even nematodes when roots are damaged, e.g. by root-knot *Meloidogyne* species.

When you consider that insects can cause dieback symptoms (e.g. *Erythrina* gall wasp, citrus psyllid, cocoa weevil borer) you realise that it is a very common symptom and can be caused by pathogens and insects alike.

However, it can be useful as a symptom. If you put 'dieback into the search engine on the Pacific Pest, Pathogen & Weeds app you will get 55 results, and then all you have to do is go through each to match dieback with your crop of concern!

Fig. 2.118 Vanilla dieback. Mosaics, distorted leaves, blackened stems, typical of dieback and collapse of plants following infection by Vanilla necrosis virus. *Source: Mike Pearson. University of Auckland.*

Fig. 2.119 Kava dieback. Collapsed blackened stem typical of dieback caused by infection of *Cucumber mosaic virus. Source: Richard Davis, Northern Australia Quarantine Strategy.*

Mildews [Figs. 2.120-2.121]

There are two kinds of mildew — powdery and downy.

Powdery, as the name suggests, causes white growths over leaves, common on cucurbits and okra in Fiji (Fig. 2.120), and rose in Tonga, during dry weather. The fungus forms long chains of oval spores that stand erect from the leaf, giving it a powdery appearance. These mildews are unusual fungi as they grow on the outside of leaves and feed from organs that penetrate the leaf surface to feed on cells inside. Their spores do not germinate well in water, they just need high humidity.

Downy mildew is different. It is not a fungus, but an oomycete or water mould, related to algae. It needs water for the spores to germinate. Downy mildew of cucumber (Fig. 2.121a & 2.121b)) and squash (especially in Tonga) are the common examples in the Pacific region.

Typically, the mildew forms squarish or rectangular areas on the top of the leaf, that are yellow at first then turn brown. Patches of greyish/ brown occur below where the spores develop. *Phytophthora* and *Pythium* (common on taro causing blight and wilt, respectively), are also oomycetes.

Fig. 2.120 Powdery mildew on okra. *Source: authors.*

Fig. 2.121a Downy mildew on the underside of a cucumber leaf where spores are produced. *Source: Gerald Holmes. Cal Poly San Luis. Bugwood.org*

Fig. 2.121b Downy mildew on the upper surface has the same 'squarish' infection confined by the veins, but they are yellow. *Source: Gerald Holmes. Cal Poly San Luis. Bugwood.org*

Wilts [Figs. 2.122-2.123]

Wilts can be caused by fungi, oomycetes, bacteria and nematodes. It is difficult to tell which is the cause from symptoms alone, unless you are familiar with the disease on a certain crop. Experience will help you to know what diseases are common on different crops.

For instance, a wilting cocoa plant would suggest *Phellinus,* a soil-borne fungus (Fig. 2.122 & Fig. 2.123); a wilting taro, *Pythium,* an oomycete that destroys the fine roots (Fig. 2.124); and a wilting tomato would suggest a fungus (e.g. *Athelia)* or a bacterium (e.g. *Ralstonia,* bacterial wilt). Examination of the wilted plants would be needed to decide the cause.

Symptoms of wilt can be confusing to farmers. Usually, the roots are diseased and the leaves droop down or collapse, as they lack water. Farmers and plant health doctors might mistake the symptoms on the leaves for the cause of the problem, so suggest that if they see wilted plants they inspect the roots. Dig up the plant carefully, wash the roots and look for death and decay of the fine, side roots; these are the ones that take in water and nutrients from the soil. Without them, leaves collapse.

Remember, insects can damage roots, too. For instance, *Papuana* beetles cause a wilt when they attack the young roots and corms of taro (Fig. 2.125).

Fig. 2.122 The disease is caused by a fungus, *Phellinus,* common on cocoa, causing a wilt. In cocoa-growing countries in the Pacific islands, the fungus grows through the soil, infects the roots and kills them. *Source: authors.*

Fig. 2.123 Leaves wilt and the crust-like fungus grows up the cocoa trunk. *Source: authors.*

Fig. 2.124 One symptom, two causes possible: i. *Pythium*, an oomycete, attacks the fine roots of taro, and many other crops, and causes the leaves to wilt.
Source: authors.

Fig. 2.125 One symptom, two causes possible: ii. *Papuana* beetle attacks the corm of the taro planting piece, burrowing into the growing point, and causes the leaves to wilt.

Both this plant and that of Fig. 2.124 look similar above ground. *Source: authors.*

Damping-off [Fig. 2.126]

Damping-off is a special case of wilt that affects seeds and seedlings. There are two kinds of damping-off: pre-emergence, when seeds or seedlings are killed before they reach the soil surface; and post-emergence, when they die soon afterwards (Fig. 2.126). Often, fungi and oomycetes are involved. When the disease occurs in a nursery, it is likely that the soil has not been pasteurised.

Fig. 2.126 Damping-off showing both pre- and post-emergence symptoms where the seedlings are killed either before or after they have penetrated the soil surface. Fungi and oomycetes are usually the cause and are common in nurseries if the soil has not been pasteurised.
Source: authors.

Canker [Fig. 2.127]

A canker is an area on a branch or trunk that is dead in the centre and alive at the edges, where it expands slowly. There may be gum at the edges. Fungi, oomycetes or bacteria are the likely cause. Cankers on cocoa are often seen as a result of the oomycete *(Phytophthora)* that causes black pod disease growing back into the branch or trunk (Fig. 2.127).

Fig. 2.127 Canker on cocoa.
Phytophthora has grown from the pod into the branch. *Source: authors.*

Smuts [Fig. 2.128]

Smuts infect cereal crops and grasses.

They are not common in the Pacific Island countries, but boil smut might be seen (Fig. 2.128) in Solomon Islands and/or Papua New Guinea.

Spores of the fungus are in the soil; they germinate, infect and grow inside the plant, reaching the cob, where the seeds are transformed into a mass of black spores. Small galls occur on the leaves.

Fig. 2.128 Smut on maize.
The seeds in the cob have been transformed into masses of black spores. *Source: authors.*

Rusts [Figs. 2.129-2.130]

When leaves with rust are stroked with a finger, a brownish/orange colour is left behind, hence the name, rust.

The powder is a mass of spores formed by the rust fungus in numerous leaf pustules.

Rusts have complex life cycles; there are several stages and, for some, the life cycle involves two unrelated hosts.

Spores are able to travel high in the atmosphere and spread over large distances.

Breadfruit, yams, peanuts (Fig. 2.129), maize (Fig. 2.130) and many other plants have rust diseases in Pacific island countries.

Fig. 2.129 Rusts: pustules on the underside of peanut leaflets. *Source: authors.*

Fig. 2.130 Rusts: pustules on the top of a maize leaf. *Source: authors.*

Yellows and distortions [Figs. 2.131-2.134]

The word 'mosaic' is often applied to virus diseases that cause yellowing or distortions of the leaves.

It describes the patches of yellow or light green mixed with the normal green colour on infected leaves.

Mosaic symptoms occur commonly on yam, *bele,* sweet potato (Fig. 2.131), chilli, taro and beans (Fig. 2.132).

On monocotyledonous plants, mosaics occur parallel to the main veins, and therefore as stripes. They are commonly seen in maize infected with with *Maize mosaic rhabdovirus* where where bands of green and yellow occur from the base to the tip of the leaf.

Fig. 2.131 Mosaics: Small patterns of yellow amongst the green of sweet potato leaves. *Source: authors.*

Sometimes, colour changes are just seen along the sides of major veins, as in virus diseases of taro, or in stripes parallel to the veins, as in banana.

Often, viruses also cause distortions.

Taro infected with *Alomae* or *Bobone* is a good example (Fig. 2.133). In this case, infections can be caused by several viruses, and symptoms depend on the number and type present. Less severe are the crinkles and bumps that occur on leaves or fruits, such as those seen on zucchini.

Distortions are also produced by phytoplasma infections. Phytoplasmas are spread by insects (often leafhoppers) and cannot be grown in the laboratory on artificial media.

Different kinds occur on coconuts throughout the world, and in recent years, coconuts near Madang, PNG, have also been found infected with phytoplasmas causing Bogia disease.

It seems that the same phytoplasma also infects banana, causing leaves to yellow. Yellowing of leaves is just one symptom caused by phytoplasmas; more common is little leaf, for example on sweet potato (Fig. 2.134).

Fig. 2.132 Mosaics: Small yellow and green patterns with distortions on leaves of long bean, caused by a virus disease. *Source: authors.*

Fig. 2.133 Distortions: curled, twisted leaves of taro infected by the virus complex known as *alomae,* a lethal disease. *Source: authors.*

Fig. 2.134 Distortions: on young sweet potato leaves caused by a phytoplasma infection, showing a little-leaf symptom. *Source: authors.*

Post-harvest/storage diseases [Figs. 2.135-2.136]

Just as diseases infect plants in the field, they also occur after harvest.

They are especially common in corms, storage roots, tubers and many kinds of fruit and vegetables.

Few harvested crops stay uninfected for more than a few days after harvest.

Wounds caused at harvest make the produce susceptible to infection by fungi, bacteria and also nematodes.

Many species are involved.

In some cases, rots in the field continue in storage, for example, *Pratylenchus* (nematode) on yam, and *Pythium* (oomycete) on taro (Figs. 2.135-136).

Other rots, such as those on citrus (*Penicillium)* and mango (*Colletotrichum)* start after harvest.

Fig. 2.135 Post-harvest rots: dry caused by nematode. *Source: authors.*

Fig. 2.136 Post-harvest rots: taro with two rots: *Pythium* is the cause of the whitish rot at the base, and *Athelia* the white cottony growth on the left side. *Source: authors.*

A WARNING

Some symptoms can be misleading…

Example 1: Sooty mould is not a disease but is caused by fungi growing on honeydew from aphids, mealybugs and scale insects.

Example 2: Cassava roots blacken after harvest due to physiological (chemical) processes.

Example 3: Taro corms shrivel after harvest through water loss.

EXERCISE 2.5: Using symptoms to make a diagnosis

Now that your trainees have more information about pests and pathogens, they should collect their samples from Exercise 2.2 tables A, B and C and have another look at them using a hand lens.

- trainees should carefully and clearly describe all the symptoms (signs) on the plant and try to make a diagnosis
- trainees should copy and complete the table below and fill in the last column after discussion.

Crop	Plant part affected: leaf, stem, fruit, root, other	Symptom/sign: describe very carefully and clearly	Diagnosis: possible causes with reasons	Actual cause: fill in after class discussion
Example: Rose	Leaf, stem, flower bud	Grey/white powder on the stalk and bud of the flower. It is not present on the older parts of the plant.	Mildew — a fungus that grows on the outside of leaves and stems (and buds).	Powdery mildew *(Podosphaera pannosa).* Spores can be seen with the hand lens.

EXERCISE 2.6: What have you learned about pests and diseases?

In pairs or groups, trainees should complete this table.

- some cells have been filled in as an example
- they should check their answers with another group, then discuss the answers as a class.

	Fungi	Bacteria	Viruses	Nematodes	Insects
Size – can they be seen with the naked eye?		No			
How do they reproduce?	Spores				
How do they spread?					
How do they survive?			In living cells		
What are some typical symptoms/signs on plants?		Wilts			

2.7 Most common crops, pests and diseases in your region

It is very important that before the clinic, plant health doctor trainees become familiar with crops commonly grown in the area where the plant health clinic is to be held, so that they can be prepared. Once these crops are identified, they should use the Pacific Pests, Pathogens & Weeds app for those that they are not familiar with.

Some of the pests and pathogens of common crops in Samoa are given in Table 2.4 and in Tonga in Table 2.5.

Table 2.4 Some common pests and pathogens of crops in Samoa with Fact Sheet numbers

Crop	Fact Sheet (pest/pathogen or disease)
Banana	▪ Black Sigatoka (002) ▪ Bunchy top (121) ▪ Burrowing nematode (257) ▪ *Corynespora* leaf spot (309) ▪ Scab moth (017) ▪ Weevil (109)
Beans	▪ Lace bug (253)
Cabbage	▪ Diamondback moth (020) ▪ Centre grub (114) ▪ Cluster caterpillar (LCM) (078) ▪ Club root (283)
Carrot	▪ Black rot (204)
Chinese cabbage	▪ Diamondback moth (see under cabbage) (20) ▪ Centre grub (see under cabbage) (114) ▪ Cluster caterpillar (LCM) (see under cabbage) (78)
Citrus	▪ Tristeza disease (250) ▪ Fruit-piercing moth (113) ▪ Scab (048)
Cocoa	▪ Black pod (006) ▪ Pink disease (012)
Coconut	▪ Hispine beetle (059) ▪ Rhinoceros beetle (108) ▪ Embryo rot (070)
Mango	▪ Anthracnose (009) ▪ Seed weevil (353)
Papaya	▪ *Phytophthora* fruit and root rot (152)
Passionfruit	▪ Woodiness virus (156) ▪ Spots (153) ▪ Southern blight (011)
Peanut	▪ Southern blight (011) ▪ Rust (034) ▪ Leaf spots (036)
Pineapple	▪ Wilt disease (380)
Solanaceae (tomato, capsicum, eggplant)	▪ Bacterial wilt (081) ▪ Root-knot nematode (254) ▪ Frog-eye spot (092) ▪ Target spot (163) ▪ Fruit-piercing moth (113) ▪ Leaf mould (076) ▪ Spider mites (024) ▪ Broad mites (049) ▪ Southern blight (011)
Taro	▪ Root rot (044) ▪ Rhabdovirus diseases (089)

Table 2.5 Some common pests and pathogens of crops in Tonga with Fact Sheet numbers

Crop	Fact Sheet (pest/pathogen or disease)
Yam	▪ Rose beetle (107) ▪ Anthracnose (016) ▪ Scale (post-harvest) (093) ▪ Dry rot (nematode) (008)
Curcurbits (cucumber, melon, watermelon, squash, zucchini etc.)	▪ Cucumber moth (033) Watermelon gummy stem blight (007) ▪ Downy mildew (143) ▪ Powdery mildew (063) ▪ Leaf miner (262) ▪ *Corynespora* leaf spot (189) ▪ Zucchini mosaic virus (202) ▪ Papaya ringspot virus-W (392)
Cabbage	▪ Large cabbage moth (078) ▪ Diamondback moth (020) ▪ Damping-off (047) ▪ Basal stem rot (101)
Cassava	▪ Spiralling whitefly (025) ▪ White peach scale (052)
Banana	▪ Banana weevil (109) ▪ Banana scab moth (017) ▪ Black Sigatoka (002) ▪ Banana bunchy top virus (121) ▪ Banana burrowing nematode (257)
Coconut	▪ Coconut flat moth (065) ▪ Coconut rhinoceros beetle (057) ▪ Coconut stick insect (102)
Tobacco	▪ Frog-eye spot (304)
Sweet potato	▪ Weevils (029 & 119) ▪ Sweet potato whitefly (284) ▪ Little leaf (055) ▪ Scab (013)
Solanaceae (tomato, capsicum, eggplant)	▪ Fruit flies (171) ▪ Fruit-piercing moth (113) ▪ Anthracnose (177) ▪ *Corynespora* target spot (163) ▪ Bacterial wilt (146) ▪ Leaf moulds (045 & 076) ▪ Spider mites (024)
Taro, giant taro, Xanthosoma	▪ Cluster caterpillar (031) ▪ Taro hornworm (032) ▪ Aphids (038) ▪ *Pythium* wilt (044)
Kava	▪ CMV dieback (160) ▪ Nematode (254)
Papaya	▪ Papaya crown rot (172) ▪ *Phytophthora* fruit & root rot (152)
Bean	▪ Aphids (356) ▪ Bean pod borer (037) ▪ Green vegetable bug (098)
Maize	▪ Rust (042 & 225) ▪ Maize mosaic virus (074)

For Samoa, Tonga, and also Fiji, Solomon Islands and Vanuatu, 20 common pests and pathogens brought to PHCs by farmers have been selected, and descriptions made using the mini fact sheets in the Pacific Pests, Pathogens & Weeds app. Translations of these into local languages by national plant protection experts can be found in v12 of the app.

EXERCISE 2.7: Completing a 'stem' table (optional exercise)

This exercise helps your trainees to summarise their learning so far about pests and diseases. Trainees should do this on their own or in pairs.

- it is like **completing a sentence** (the 'stem' is the beginning of the sentence)
- **starting with the first column** (Insect Pests), they fill in the answers — then they fill in the second column (Nematodes) and so on, until the table is completed
- there will be many correct answers — a few cells have been filled in as examples.

	Insect pests	Nematodes	Nitrogen deficiency	Viruses	Fungi	Bacteria	Drought
Are:				very small			
Are not:		an insect					
Can:							
Cannot:	produce spores						
May cause:						wilting	
Does not cause:					chewing of leaves		
Can be controlled by:							
Cannot be controlled by			fungicide				fertiliser

EXERCISE 2.8: What am I?

This exercise can be as easy or as difficult as you decide to make it. Make a list of the words that you would like your trainees to understand. The exercise can be carried out at any point during the training to strengthen your trainees' learning.

- write **words associated with plant protection** (see below) on cards, and stick one on the back of each trainee with masking tape — they are not allowed to look at it!
- trainees then move around the room **asking other trainees questions** to find out what the word is — the other trainees can ONLY answer 'yes', 'no' or 'sometimes/maybe'

- if, after a while, people are having difficulty, **clues may be given**
- trainees should **sit down after** they have found the correct answer
- **discuss how difficult or easy** it was to find the right answer, and why.

Some examples of words you could use:

Bacteria | Rhinoceros beetle | Phytoplasma | Potassium deficiency | Rust | Aphid | Spore | Weed | Snail | Mite | Sooty mould | Fall army worm | Leaf spot | Wilt | Drought | Nematode | Mosaic | Abiotic | Soil | Variegation | Virus

2.8 Making a diagnosis: symptoms, possibilities and probabilities

It is very important for plant health doctors to be able to work through a process of 'possibilities and probabilities' in diagnosis to be able to give good advice to farmers. Some problems are easy to diagnose, especially pests that you can see; others are difficult. As well, some plant problems may have similar symptoms. For example, yellowing of leaves can be due to nutrient deficiency and can also be due to diseases caused by fungi, bacteria, phytoplasmas and viruses.

Do doctors need to know the names of everything?
No! Specific diagnosis, like that of the name of the insect or fungus, is not always possible and it is not really necessary.

Farmers do not need to know scientific names, but they do need to know the pest or disease type to give them an understanding of the information and management recommendations.

2.8.1 Using the possibilities and probabilities process to diagnose a problem

Now that your trainees have some knowledge of pests and diseases, they can look at symptoms to see if they are distinctive in any way in order to develop a diagnosis. The best approach to making a diagnosis is to think like a detective! What is likely or unlikely to be the cause; what is possible or what is probable?

Successful diagnosis can be difficult because there are so many insects, mites, pathogens and abiotic causes, and plants respond to them in different ways. However, diagnosis is essential for good management.

Use the examples and exercises below to build your trainees' confidence in their ability to make correct diagnoses. They should practise these steps as often as they can with a range of different pest and disease samples.

Work carefully through the following possible and probable causes process with your trainees, using eggplant as the example. Once you think they have understood the process, ask them to complete Exercises 2.9, 2.10 and 2.11.

EXAMPLE: Blotch symptoms on eggplant

Symptoms:
1. dark blotches on the fruit
2. the spots/blotches are roughly circular
3. minute black dots in the spots: possibly containing spores
4. spots dispersed over the fruit and merging together.

Possible causes	Possible? ✓✗	Probable? ✓✗	Why do you decide this?
BIOTIC			
Insect	✓	✗	No insects found and no frass, but could be secondary infection after sucking insects. But none seen.
Mites	✗	✗	No mites found and not typical of mite symptoms.
Fungi	✓	✓	Fungi cause spots/blotches on eggplant, and fungal fruiting bodies present.
Bacteria	✓	✗	Bacteria may cause spots/blotches on eggplant, so could be a new disease, but fungal fruiting bodies suggest not bacterial.
Virus	✗	✗	Not a typical symptom for virus. No irregular yellow patches (mosaic) & distortions on fruits. Leaves of plants normal.
Phytoplasma	✗	✗	Not a typical symptom for phytoplasma. Leaves of plants normal.
Nematode	✗	✗	Not a typical symptom and most nematodes are on roots.
Weeds	✗	✗	Not a symptom associated with weeds.
Parasitic plants	✗	✗	Not a symptom associated with parasitic plants.
Slugs & snails	✗	✗	None present, and not a symptom associated with slugs & snails. No slime trails.
Mammals	✗	✗	Not a symptom associated with mammals.
Birds	✗	✗	Not a symptom associated with birds.
ABIOTIC			
Nutrient deficiencies	✗	✗	Not a symptom of nutrient deficiency
Sun scald	✗	✗	Not a symptom caused by sunscald
Water (too much or too little)	✗	✗	Not a known drought symptom
Lightning	✗	✗	Not a symptom of lightning strike
Herbicide	✗	✗	Not a symptom of herbicide damage
It's natural	✗	✗	Not at all natural!

NOTE: These are likely to be anthracnose caused by *Colletotrichum* (or *Phomopsis).* There is a fact sheet in the Pacific Pests, Pathogens & Weeds app (no. 50). Yes, a bacterial cause is a possibility, but the probability for a fungus is higher. *Colletotrichum* spots are common on eggplant fruits, but bacterial spots are unknown. Also, inside the large black areas there are tiny round black structures which are likely to contain fungal spores.

EXERCISE 2.9: Using the possible and probable approach

In pairs or threes, now work though this example, following the steps above. Then check your answer with the Pacific Pests, Pathogens & Weeds app. Discuss with the rest of the class.

EXAMPLE: Cassava with mosaic and distortions

Symptoms:

1.
2.
3.
4.

Possible causes	Possible? ✓✗	Probable? ✓✗	Why do you decide this?
BIOTIC			
Insect			
Mites			
Fungi & oomycetes			
Bacteria			
Virus			
Phytoplasma			
Nematode			
Weeds			
Parasitic plants			
Slugs & snails			
Mammals			
Birds			
ABIOTIC			
Nutrient deficiencies			
Sun scald			
Water (too much or too little)			
Lightning			
Herbicide			
It's natural			

EXERCISE 2.9: continued…

Now check your answer with the Pacific Pests, Pathogens & Weeds app.

- What is your diagnosis?
- Do you still need more information? What information do you need and why?
- What would you ask the farmer who brought this sample?

Discuss with the class:

REMEMBER

When working with farmers, NEVER go straight to the Pacific Pests & Pathogens & Weeds app.

ALWAYS work through the ABC activity and then the possibilities and probabilities process in your mind first!

EXERCISE 2.10: Using the possible and probable approach

In pairs or threes, now work though this example, following the steps above. Then check your answer with the Pacific Pests, Pathogens & Weeds app. Discuss with the rest of the class.

EXAMPLE: Sweet potato with folding and collapsing leaves

Symptoms:

1.
2.
3.
4.

Possible causes	Possible? ✓✗	Probable? ✓✗	Why do you decide this?
BIOTIC			
Insect			
Mites			
Fungi & oomycetes			
Bacteria			
Virus			
Phytoplasma			
Nematode			
Weeds			
Parasitic plants			
Slugs & snails			
Mammals			
Birds			
ABIOTIC			
Nutrient deficiencies			
Sun scald			
Water (too much or too little)			
Lightning			
Herbicide			
It's natural			

EXERCISE 2.10: continued...

Now check your answer with the Pacific Pests, Pathogens & Weeds app.

- What is your diagnosis?

- Do you still need more information? What information do you need and why?

- What would you ask the farmer who brought this sample?

Discuss with the class:

REMEMBER

When working with farmers, NEVER go straight to the Pacific Pests & Pathogens & Weeds app.

ALWAYS work through the ABC activity and then the possibilities and probabilities process in your mind first!

EXERCISE 2.11: Using the possible and probable approach

In pairs or threes, now work though this example, following the steps above. Then check your answer with the Pacific Pests, Pathogens & Weeds app. Discuss with the rest of the class.

EXAMPLE: *Xanthosoma* wilt

Symptoms:

1.
2.
3.
4.

Possible causes	Possible? ✓✗	Probable? ✓✗	Why do you decide this?
BIOTIC			
Insect			
Mites			
Fungi or oomycetes			
Bacteria			
Virus			
Phytoplasma			
Nematode			
Weeds			
Parasitic plants			
Slugs & snails			
Mammals			
Birds			
ABIOTIC			
Nutrient deficiencies			
Sun scald			
Water (too much or too little)			
Lightning			
Herbicide			
It's natural			

EXERCISE 2.11: continued...

Now check your answer with the Pacific Pests, Pathogens & Weeds app.

- What is your diagnosis?
- Do you still need more information? What information do you need and why?
- What would you ask the farmer who brought this sample?

Discuss with the class:

REMEMBER

When working with farmers, NEVER go straight to the Pacific Pests & Pathogens & Weeds app.

ALWAYS work through the ABC activity and then the possibilities and probabilities process in your mind first!

CHAPTER 2 QUIZ: Test your knowledge

Multiple choice. Pick one answer only...

1. In ORDER, abiotic and biotic factors that cause damage on plants are:

A. a fungus and a mite
B. a bird and drought
C. potassium deficiency and bacteria
D. phytoplasma and poor soil

2. Symptoms on tomatoes and cabbages caused by bacteria are:

A. leaf spots and evenly spread leaf yellowing
B. wilt and V-shaped yellowing at the edges of leaves
C. rust spots and mosaics
D. dieback and with leaves going purple

3. A common disease of tomatoes in the Pacific is:

A. witches' broom
B. tobacco mosaic
C. early blight
D. ring spot

4. The smallest of these pathogens is:

A. virus
B. phytoplasma
C. bacterium
D. fungal spore

5. A plant doctor finds a plant with symptoms of wilt. The most unlikely cause would be:

A. bacteria in the soil
B. powdery mildew
C. nematodes
D. stalk borer

6. Pests with eight legs are:

A. mites
B. insects
C. nematodes
D. millipedes

7. Which of these diseases is caused by a fungus?

A. bunchy top on banana
B. blossom end rot on tomato
C. citrus canker
D. damping-off on cabbage seedlings

8. A plant doctor finds a cabbage with a lot of holes in the leaves. Which are not possible causes?

A. diamondback moth
B. large cabbage moth
C. leaf chewing nematodes
D. snails

CHAPTER 2 QUIZ: continued...

Multiple choice. Pick one answer only...

9. A virus cannot usually be spread between plants by:

A. nematodes

B. tools

C. true bugs

D. aphids

10. Two insects with complete life cycles are:

A. aphids and beetles

B. butterflies and bugs

C. grasshoppers and ants

D. bees and moths

11. Where do you find the eggs of this spiralling whitefly?

A. inserted into the leaf

B. whiteflies do not lay eggs, they give birth to living young

C. in the waxy spirals

D. underneath the female whiteflies

12. What is the most likely cause for this hibiscus wilt?

A. mites or thrips have attacked the young leaves, and they have wilted

B. it was planted on a slope, and there has been a long drought

C. old age

D. a fungus or an insect is destroying the roots.

CHAPTER 3

Soils

Note to trainers

This chapter is very long and contains a lot of information and exercises. You do not need to cover it all if you do not have time, or your trainees are familiar with some of the material. Choose the parts and exercises that suit your needs.

As there is a lot of information to cover, you could develop a PowerPoint presentation on the major points, as well as ask your trainees to read sections during class and/or for homework.

Some of the exercises require preparation and having the equipment ready before your workshop, e.g. collecting and preparing soil samples, finding worms, starting a compost heap and preparing agar plates. Check the 'what equipment do I need' section at the beginning of each practical exercise.

You will find a glossary of terms to do with soil in the Appendix.

3.1 What do we already know about soil?

Everyone knows what soil is, don't they? It is so common, it is everywhere, in all countries, on all continents, even Antarctica. And it is very important. In fact, some people have gone so far as to say that without soil there can be no life and, conversely, without life there can be no soil.

Some of the past great thinkers and political leaders have glorified soil and made large claims about it. One of the most famous statements is:

> "The nation that destroys its soil, destroys itself"
> *Franklin D Roosevelt, President of the USA, 1933-1945.*

This must be correct, as most plants get their water and nutrients from soil. Plants are the main source of food for humans and most animals, so we can say that most living creatures on land depend on soil for their existence.

Soil is not inert; it is a living, dynamic, natural ecosystem composed of living organisms that interact with non-living components in an environment that is always changing.

However, over recent decades, we have taken soils for granted, and now they are under stress from intensive farming, including tilling and ploughing, over-harvesting and the use of chemicals such as pesticides and inorganic fertilisers. We can say that soils are not as healthy as they should be.

In this chapter, we look at this dynamic world of soil and understand how healthy soil is important for plant health, and thus the health of humans and animals. This is the concept of 'One Health' which we will return to later. So let's dig in, and get started.

Your trainees probably already have some knowledge of soil. The first exercises are designed to focus your trainees on soil and find out what they already know. Where appropriate, answers to the exercises are provided in Chapter 9.

Exercise 3.1: Practical activity — describing soil

A good way to start examining soil is to use our senses.

What equipment do I need?

- ❑ soils
- ❑ paper
- ❑ tablespoons
- ❑ prepare the soil samples before the workshop.

- **trainees should place about a tablespoon** of the different soils on some paper or in a container
- for each, **in the table below**, they should describe its colour, texture (feel) and smell, and make a guess about how good each soil is for promoting healthy plant growth, with reasons
- **organic soil** from a vegetable garden in Tasmania, Australia, has been included for comparison
- trainees should **fill in the table** below:

Your answers — describing soils

Soil	Colour	Texture (feel): fine, smooth, coarse	Smell	So you think this soil is good for plant health? Your reasons
1				
2				
3				
4				
Tasmanian organic	Very dark brown	Little bit coarse, crumbly	Earthy	Yes, this looks like good soil for growing vegetables because of its dark colour and earthy smell. This suggests a lot of broken-down organic matter

Exercise 3.2: Traditional knowledge of soil

Many of your trainees will have some experience of working with farmers with different soils.

- ask them to **discuss what they know** from the people in their community, or through their work
- trainees should **describe the different types of soils**, types of planting or farming methods used, and the challenges the farmers face. If they are not sure, they should guess
- trainees should **complete the table below** then discuss the answers as a class. Source: Marvin Baekisapa, SINU.

Your answers — knowledge of soil

Location	Soil	Description of soil: colour, etc.	Suitable for which plants / crops	Planting: months	Farming methods	Challenges	Solutions for each of the challenges

3.2 The importance of soils to humans

Apart from the obvious benefit of anchoring plants, nourishing them, and indirectly providing food for humans and other creatures, soils have many other important functions, at least in terms of assisting humans. Many of those are shown in the diagram, Fig. 3.1.[1]

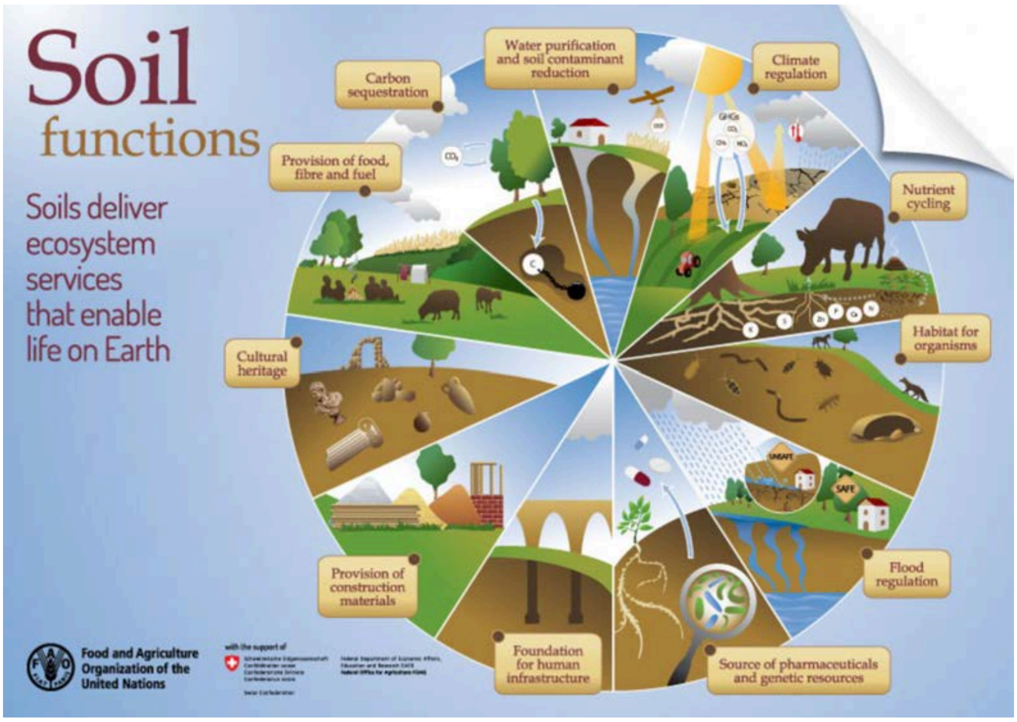
There are many functions given in that diagram, and all are of importance, but we are going to mention three in more detail to show not only how soil benefits humans, but also its very complex nature.

3.2.1 Regulation of water

First among our three choices is the regulation of water by allowing water to drain through the soil rather than flowing over land causing erosion and flooding. As water flows through the soil to the depths below, through pore spaces between clumps and along tunnels created by earthworms and insects, it is filtered and microorganisms and contaminants are removed, processes that are very important for human health.

1 FAO and UNEP (2021) Global assessment of soil pollution: Report. Rome. https://doi.org/10.4060/cb4894en

Fig 3.1 Functions of soils showing ways they support human life on the planet, providing what is termed 'ecosystem services'. Soil is vital to plant growth for the provision of water and nutrients, to animal diversity, above and below ground, for its role in purifying water and regulating flooding — by allowing seepage to deeper layers — and provides many of the materials used in constructing buildings and roads. Perhaps most importantly for our times, soil has a key role in mitigating the climate crisis. *Source: FAO Soil functions.*



3.2.2 Importance of soil microbes

The second important function is the interaction between plants and microbes, such as bacteria and fungi, resulting in mutually beneficial relationships. We use the word 'symbiosis' to describe the relationships between the two: plants provide the microbes with sugars formed by photosynthesis in their leaves in exchange for nutrients, water and other chemicals provided by soil microbes.

These important microbes live in the soil in contact with the roots in a region called the 'rhizosphere' (the zone of interaction between plant roots and microbes[2]). We said that microbes give plants nutrients, water and other chemicals. The importance of the major nutrients (nitrogen, phosphorus and potassium, NPK) and several minor ones, as well as water, is well known, but what other chemicals are involved in the interactions? Research shows that some of the other chemicals produced by bacteria especially, are antagonistic to (they work against) plant pests and pathogens, allowing plants to grow healthily (Fig. 3.2).

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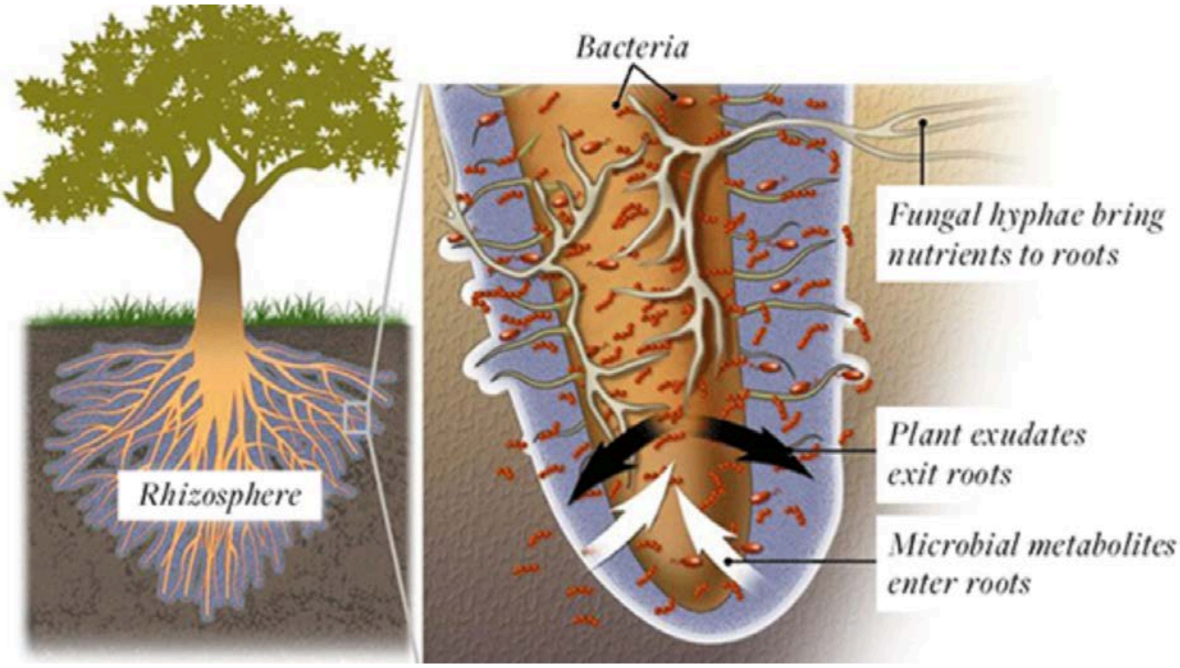
2 Montgomery DR, Biklé A (2016) The hidden half of nature. The microbial roots of life and health. Published by WW Norton & Company. https://www.sej.org/publications/sejournal-wi-2015-2016/hidden-half-nature

Fig. 3.2 Exchanges between plants and soil microbes (bacterial and fungi). Sugars from the leaves reach the roots, and some leak out into the rhizosphere, the narrow area of soil just behind the root tip. In exchange, chemicals from the microbes are taken up by the roots and used by plants for healthy growth. It is estimated that up to 20% of the sugars manufactured by plants are shared with microbes.
Source: The Hidden Half of Nature (David Montgomery).



It has also been found that chemicals from microbes enter roots, leading to plants increasing their disease resistance responses — rather like an immune response to a vaccine in humans.

Humans have also made use of soil-borne microbes for antibiotic production (e.g. species of *Bacillus, Micromonospora, Penicillium, Streptomyces)* and more recently, for less-harmful pesticides, for e.g. Bt *(Bacillus thuringiensis),* spinosad *(Saccharopolyspora spinosa)* and abamectin *(Streptomyces avermitilis),* all now in common use against crop-damaging insects. These are part of a new class of pesticide known as 'biopesticides' which are expected to do less harm to the user and the environment.

3.2.3 Soil is a carbon sink

The third important function of soil is that it is a carbon 'sink'[3]. In recent years, the climate crisis has focused attention on the way soils absorb carbon dioxide from the air and store it in other forms of carbon. The United Nations Food and Agriculture Organization (FAO) has published a map showing that the top 30 cm of the world's soils contain twice as much carbon as the entire atmosphere[4]. Soils are the second-largest natural carbon sink after the oceans.

So, we can see that there are many reasons we need to understand and look after soil to stay healthy, not just to feed us!

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3 Carbon Sink (2023). Wikipedia. https://en.wikipedia.org/wiki/Carbon_sink

4 FAO. Global soil organic carbon map. https://www.fao.org/3/i8195e/i8195e.pdf

3.3 Where does soil come from?

Soil is the thin layer of material covering the surface of the earth formed from the weathering or the breakdown of rocks by physical, chemical and biological processes (Fig. 3.3)[5,6]. Rocks split or break up due to changes in temperature, volcanic activity, rock collisions, and by the erosive power of water and wind. Chemicals in the rocks may be dissolved by water or react with air – acid rain is an example. This occurs when rain contains sulphuric acid or nitric acid derived from industrial processes. As well, carbon dioxide in the atmosphere dissolves in water and falls as carbonic acid in rain. Biological weathering refers to weathering caused by organisms — animals, plants, lichen (Fig. 3.4), algae, fungi and bacteria, as they burrow into or live on rocks, producing weak acids that convert some of the minerals to clay. This kind of activity contributes to further weathering by physical and chemical means.

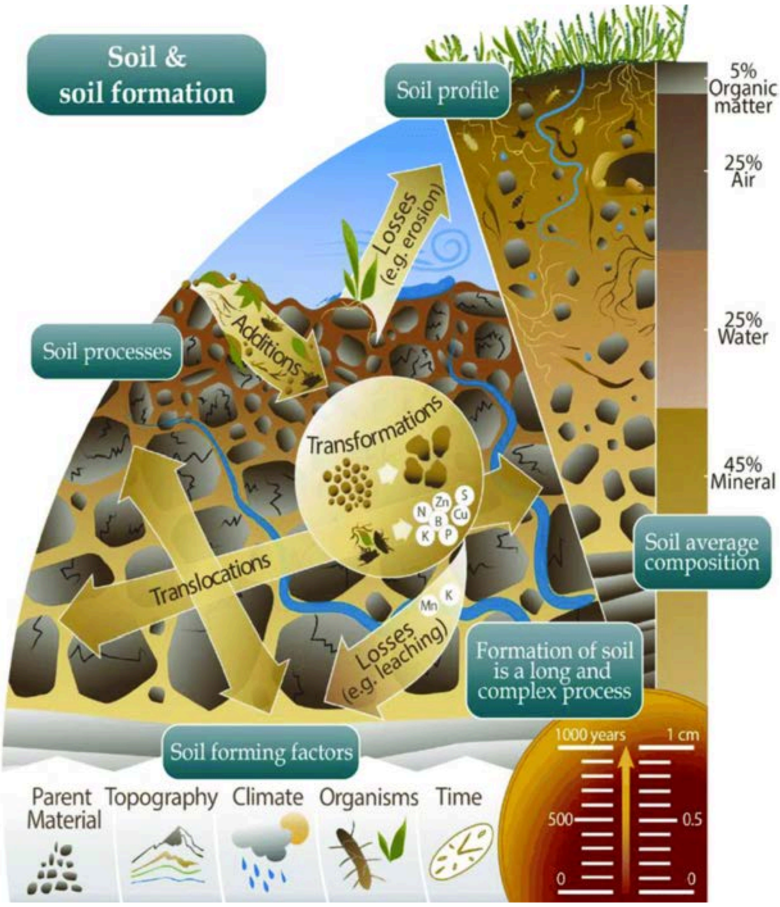


Fig. 3.3 Diagram showing the different forces that are involved in the formation of soil.

Physical weathering — a mechanical breakdown of the rocks, splitting through temperature changes, collision of rocks one on the other, frost when water seeps into cracks (but not common in the tropics!).

Chemical weathering — a breakdown of rocks through a change in their chemical makeup, as minerals within rocks react with water, air or other chemicals.

Biological weathering — a breakdown of rocks by living organisms. Burrowing worms and insects help water and air get into rocks, and plant roots split them by growing into cracks (also a factor in physical weathering).

Source: FAO How soil is formed.

5 Sometimes, people use the word 'dirt' to mean soil, but this is not correct. Strictly, dirt is the mineral component. The word also has negative associations such as dirty, not clean, etc., which is unfortunate.

6 How soil forms (2022) Environment, land and water, Queensland Government. https://www.qld.gov.au/environment/land/management/soil/soil-explained/forms

3.4 Components of soil

Soil is composed of a complex mixture of components that interact with each other and the plants that grow with them. Healthy soils have a balance of components that create a suitable environment for plant growth. Having a basic understanding of the components of soil and the processes involved, and their interactions, is essential for effective soil management, and for assisting farmers to create healthy soils.

The four main components of healthy soil are:

i. inorganic mineral particles — about 40-45% by volume
ii. organic matter — about 5%
iii. air and water — about 25% each
iv. living organisms.

Before covering this section, it is useful to find out what your trainees already know about the components of soil.

Fig. 3.4. Biological weathering. Lichen, a symbiosis between algae and fungi, growing on a rock. Minerals in the rocks are broken down by the fungus and then used by the alga, which in turn, shares the products made from photosynthesis. *Source: authors.*

Exercise 3.3: What is in soil?

What equipment do I need?

- ❑ brown or flip chart paper
- ❑ marker pens
- ❑ pins or blu-tack to fasten paper to the wall.

Trainee task

- ask your trainees to **brainstorm what they think is in soil**
- they should **write their answers** on a flip chart or brown paper
- put this on the wall with the **heading WHAT IS IN SOIL?**
- this can be **added to** as the workshop progresses.

3.4.1 Soil component 1: Minerals

Minerals are the inorganic particles in soils that come from the weathering of rocks in the earth's crust. The composition of any rock depends on what formed it in the first place, and the forces it has been subjected to. Natural forces — rain, heat, freezing, geological forces (earthquakes, volcanic activity) — erode rocks, and over millions of years, even wear down mountain ranges, releasing a continuous supply of mineral particles. The particles created are transported by wind and water, ending up at various distances from their source — the 'translocations' in Fig. 3.3.

Mineral particles make up about 45% of soil by volume. They give soils their main characteristics, determining their composition or texture (see Section 3.4.1.1), drainage capacity and, importantly, the nutrients that are held in them. Many hundreds of different kinds of mineral particles make up the solid inorganic component and help determine its physical and chemical properties including soil pH (see Section 3.7) Plant roots also play a part; they secrete a range of chemicals that bind minerals.

Minerals contain mainly eight elements: oxygen (47%), silicon (28%), aluminium (8%), iron (5%), magnesium (4%), calcium (2%), sodium (2%) and potassium (2%), and smaller amounts of several other elements, all important for plant health. It is the number and type of these elements that make a particular mineral.

The most common mineral particles are the silicates (SiO_4^{4-}). This group contains about 600 kinds of minerals that make up about 90% of the earth's crust. There are several basic mineral types, called feldspars, quartzes, pyroxenes, amphiboles, micas, hornblendes, olivines and clay minerals (aluminosilicates).

Plants need 17 elements to complete a healthy life cycle. With the exception of C, H, and O, which they obtain from air and water through photosynthesis, plants get the remaining 14 elements from minerals in the soil (or through fertilisers, composts or manures if these are added). If any elements are missing, plants may show nutrient deficiency symptoms, which we discuss later (see Section 3.9).

3.4.1.1 Texture/composition — sand, silt and clay

The three basic mineral components of soil are sand, silt and clay. The texture or feel of a soil (silky, smooth, coarse, etc., Exercise 3.4) depends on the size of the soil particles, which comes from how they have been ground down from their parent rock. From large to small, they are sand, silt and clay. Sand and silt particles are just like their parent rock, but ground into small pieces by the processes of weathering. By contrast, clay particles are the smallest and exhibit different characteristics from the parent rock because of their very small size.

As well, some soils contain gravel which is small, irregular pieces of rock and stone. Soils with gravel are rougher and rockier than sand, with particles from 2 mm to 80 mm in size. They are generally not very useful for cropping as stones can get in the way of root growth and also damage farm machinery and tools.

The relative size of sand, silt and clay particles is given in Fig. 3.5.

The percentage of sand, silt and clay determines the texture of a soil. Texture is very important because it affects:

- the overall structure of the soil
- its water holding capacity — the ability of soil to hold water
- infiltration and percolation (permeability) — how easily air and water can pass into and through a soil
- workability — how easy it is to till (cultivate) a soil
- soil fertility and nutrient availability
- crop productivity
- biological activity — the activity of soil organisms.

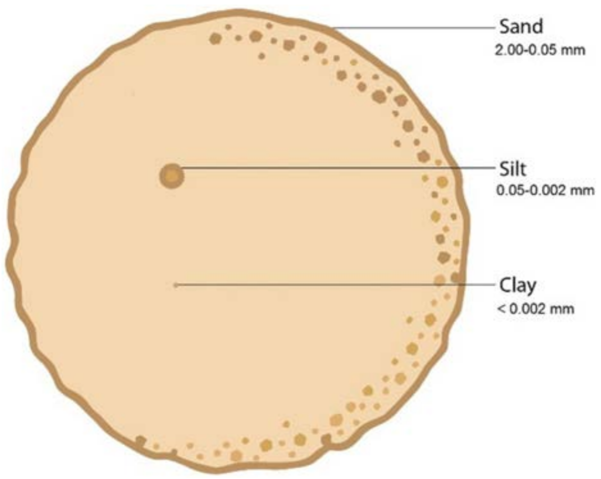


Fig. 3.5 The relative size of soil particles.
Source: The Nature Education What are soils?

The characteristics of sand, silt and clay are as follows:

- **Sand:** Very sandy soils are coarse in texture. They have little or no structure because the sand grains do not stick together, and any organic matter in the soil is easily lost. Compared with clay, they have a small surface area in relation to their volume. This means they cannot hold water for long. When soil is shaken up in water, any sand present settles to the bottom quickly (Exercise 3.5).
- **Silt:** Silt is made up of mineral particles that are larger than clay but smaller than sand. When soil is shaken up with water, any silt present settles to the bottom but more slowly than sand and forms a layer above it (Exercise 3.5).
- **Clay:** Clay particles are very small. Because of this, clay behaves differently from sand and silt. Clay-rich soils feel very fine and smooth in texture. Their very small particle size means they have a large surface area compared with their volume, and this allows electric charges to form on their surfaces; this gives them the ability to absorb and exchange ions[7] of elements such as calcium, potassium and magnesium in the soil. This makes them important as they can retain nutrients and water that plants need.

  Organic matter is also an important constituent of clay particles in soil. Clays also influence the pore spaces (see Section 3.5.1) in the soil because they can form clumps (aggregates or 'peds') as they link to each other and to organic matter. This is important in air and water movement through the soil.

  Clays can become waterlogged in high rainfall or flooding, where water pushes out air from the pores so that the roots are unable to respire (breathe). On the other hand, clay soils can dry out, shrink and become hard so that water cannot infiltrate or percolate through them. If you have a house built on clay you may find it moves according to the weather!

  Clay comes in many different types, common forms being kaolinite, smectite, illite, chlorite and vermiculite.

  When a soil containing clay is shaken up in water, the clay component tends to stay in suspension above any sand or silt or settle out very slowly over days (Exercise 3.5). Soils high in clay can be formed into ribbons which hold together (Exercise 3.4). This is why clay can be used to make pottery.

[7] An ion is a charged atom or group of atoms. If the charge is positive, the ion is called a cation, if negative, an anion.

Exercise 3.4: Practical activity — composition or texture of soil, the ribbon test

What do I need?

- ❑ soil samples
- ❑ water
- ❑ droppers
- ❑ paper.

1. **Trainees should take about 2 tablespoons** of one or more of the soil samples and add water drop by drop, working the soil with their fingers until it becomes sticky. Ensure all soil types are tested by the class.
2. **They squeeze the wetted soil between thumb and forefinger** to try to form a flat ribbon that does not break when they pick it up. They should use a ruler to measure how long their ribbon can hold together without breaking. Trainees should wash their hands afterwards!
3. **Classify the soil** according to the table below.
4. **Trainees should demonstrate their soil ribbon** to the class, and describe and name the type of soil with reasons for their answer.

Classification of soil according to sand, slit and clay components

Length of ribbon (mm)	This is my soil	Soil type
<15		Sand
15-25		Sandy loam
25	X Tasmanian	Loam
25-40		Silty loam
40-50		Clay loam
50-75		Clay
>75		Heavy clay

Exercise 3.5: Practical activity — sedimentation test

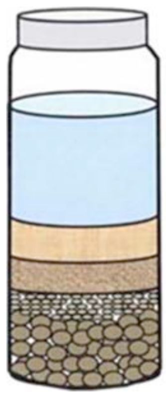
When a sample of soil is left to settle (sediment) in water, the larger particles (sand) settle out of suspension faster than smaller ones (silt and then clay). Sometimes clay particles are so small that they take a very long time to settle. Organic matter that has not broken down will float on the top.

What equipment do I need?

- ❑ about 2 teaspoons of soil
- ❑ glass jar
- ❑ stirrer
- ❑ water
- ❑ ruler
- ❑ magnifying glass.

Trainees should **mix about two teaspoons of a soil with about 150 ml water**, allow it to settle for several hours, or overnight (Fig. 3.6).

Fig. 3.6 Soil components settle out in water.
Source: ScienceDirect Soil Texture Settlement of soil materials



Your answers — sedimentation test

Soil sample	Depth of sand layer (mm)	% of total	Depth of silt layer (mm)	% of total	Depth of clay layer (mm)	% of total	* Soil type from soil triangle (ex. 3.6, p. 142)
1							
2							
3							
4							
Tasmanian	0	0	7	7/8=87.5	1	1/8=12.5	silt

* Once all the layers have settled, trainees can use a ruler to measure the depth of each separate layer in mm and draw an accurate diagram of the soil layers. The trainees may need a magnifying glass to see the layers properly. Complete the table below, except the last column.

Total depth of soil layers (mm) =

Trainees should present their results to the class and explain their answers.

3.4.1.2 Texture/composition — measuring with USDA texture triangle

Soils are often described according to their texture or composition. The USDA Soil composition/texture triangle diagram is used to work out the composition of a soil (Fig. 3.7). For example, a clay loam has 30-40% clay; 60-70% silt, and 40-60% sand.

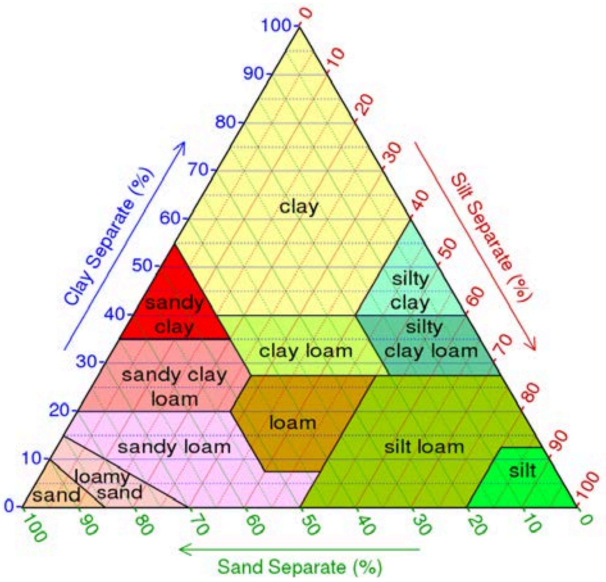


Fig. 3.7 The USDA soil composition triangle.

The diagram is used to work out the type of soil in an area. A sample of soil is left to settle in water. Larger particles settle out of suspension faster than smaller ones. Soil particles are placed in three categories depending on their size: sand (largest), silt and clay (smallest).

Once the layers have settled, the depth of the layer is used to work out its percentage as a component of the soil. The three percentages are then read off the axes of the triangle clay horizontally, silt towards bottom left and sand towards top left.

Source: Loam. Wikipedia. United States Department of Agriculture - Soil Texture USDA.

Exercise 3.6: Interpreting the soil composition triangle

Trainees should practice using the triangle diagram by working through this example:

A soil has a composition of 40% sand, 35% silt and 25% clay. Use the USDA composition triangle below to determine the soil (Fig. 3.8).

Do the following:

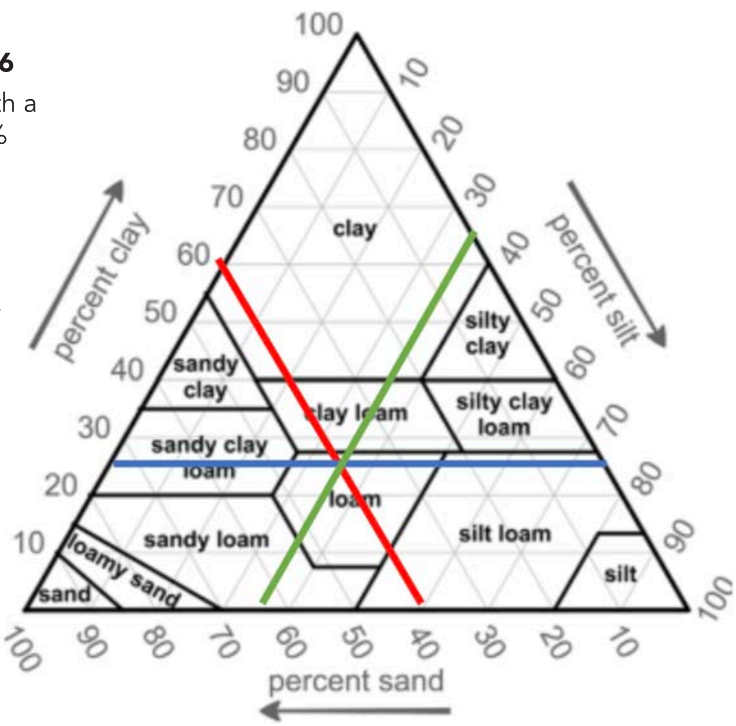
- ❑ **Step 1:** For SAND: draw a line from the 40% point on the sand axis UPWARDS TO THE LEFT (red line).
- ❑ **Step 2:** For SILT, draw a line from the 35% point on the clay axis DOWNWARDS (green line).
- ❑ **Step 3:** For CLAY, draw a line from the 25% point on the clay axis HORIZONTALLY (blue line).

Trainees task

- now, ask the trainees to use the **USDA soil composition triangle** diagram to work out their soil type using their results from Exercise 3.5
- use three percentages to read off the axes of the triangle – sand, silt and clay
- they should enter the results for their soil sample and complete the last column of the table in Exercise 3.5 — sedimentation test.

The Tasmanian soil from Exercise 3.5 is silt.

Fig. 3.8 Result of Exercise 3.6
The determination of a soil with a composition of 40% sand: 35% silt: 25% clay. Where the lines (red, blue and green) intersect will indicate the soil type.
In this case, it is a LOAM.
Source: Wikipedia. By cmglee, Mikenorton, United States Department of Agriculture - SoilTexture USDA.svg.



3.4.2 Soil component 2: Organic matter

3.4.2.1 Soil carbon

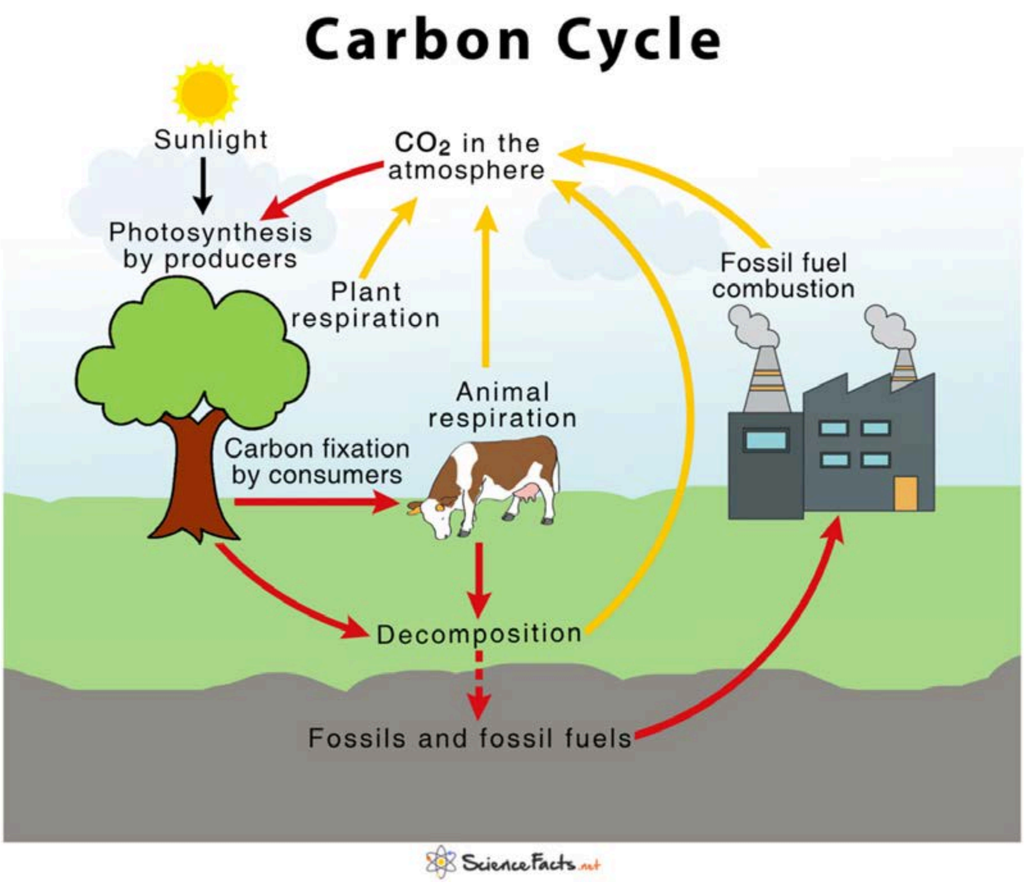
The organic matter in soil comes from the decaying remains of plants, animals and their wastes. Although oceans store most of the earth's carbon, soils contain approximately 75% of the carbon on land, three times more than the amount stored in living plants and animals. This means that soils play a major role in maintaining a balanced global carbon cycle (Fig. 3.9).

Organic matter makes up 1 to 5% of the soil volume and is where soil carbon is held. Earth's soils store about 1.5 trillion metric tons of carbon, but it can be lost when microbes digest organic matter and respire carbon dioxide (CO_2) back to the atmosphere. It is also lost as temperatures increase due to climate change.

Soils with high clay content retain more organic matter, and therefore retain more carbon than sandy soils.

Organic matter adds nutrients to the soil, improves its water holding capacity, especially in sandy soils, and reduces water-logging in clay soils. Organic matter also has a very important impact on soil structure (the clumping or aggregation of soil — see Section 3.5). It can change hard soils

Fig. 3.9 The carbon cycle. On land, carbon travels from the atmosphere to plants and then via photosynthesis to the soil. It travels back to the atmosphere, by processes of respiration, animal and plant decay or by burning fossil fuels.
Source: Science Facts: What is the carbon cycle?



into soils that are crumbly, i.e. composed of smaller aggregates or crumbs. This makes it easier for roots to penetrate and spread and for pore spaces to form containing air, water and nutrients.

Levels of soil organic carbon are generally lower in the tropics due to the hotter climate, especially in the lowland wet tropics where soils tend to be highly weathered. Even so, tropical soils contain one-third of the global carbon store, so any loss of soil organic matter caused by global warming could accelerate climate change by releasing additional carbon dioxide into the atmosphere. Over the years, clearing of tropical forests for agriculture in the wet tropics has led to a reduction in the amount of carbon stored in soil (see Section 3.8, Pacific soil)

3.4.2.2 Humus

Soil organic matter or humus, consists of molecules such as proteins, carbohydrates and other substances produced through microbial action, as well as the microbes themselves. It is described as a 'sticky mass of organic chemicals and microbes'[8]. Soils with a high humus content are generally dark brown or black in colour. Humus plays a very important role in the control of soil acidity, cycling of nutrients, and detoxification of hazardous compounds, so we can say that soil fertility, health, and functioning relate to the amount of soil organic matter a soil contains. Humus helps mineral particles stick together and also bond with clay to form complex crumbs; this is important for soil aeration, water infiltration and drainage. Since humus holds 80 to 90% of its weight as water, it plays a major role during drought conditions. Cultivated soils with 2% humus are considered high-quality farmland (it is much higher, perhaps as much as 20%, in ancient temperate forests)[9].

Some experts think that humus helps make the soil more fertile; others think that it prevents plant diseases, while a third view is that humus acts more as a plant hormone rather than a nutrient, controlling all aspects of growth and development. Possibly, it acts in all these roles.

Next, we are going to look at what happens to the organic carbon that enters the soil, i.e. its decomposition into humus. In the soil, it is the work of microorganisms (bacteria and fungi) and some macroorganisms, especially earthworms, that break down organic matter into humus. Firstly, the organic matter is decomposed releasing inorganic minerals, nitrogen mainly, but also, calcium, magnesium, and sulphur that plants can use – this is called 'mineralisation'. Most of the available nitrogen in the soil is bound up in humus within its organic compounds. As humus decays, it releases the nitrogen either as ammonium (NH_4^+) or as nitrate ions (NO_3^-), forms that are readily taken up by plants.

[8] What is soil? http://www.agroconection.com/soil/organic-matter-in-the-soil/

[9] Eco Farming Daily. https://www.ecofarmingdaily.com/build-soil/humus/humus-how-is-it-formed/

Secondly, there is the decomposition of the starches and sugars in the organic matter, as well as cellulose (from plant cell walls) and lignin (from wood), although this occurs more slowly as these are large molecules. This is called 'humification'.

Because of the importance of organic matter in plant health, the percentage of decomposed organic matter in soils is often used as an indicator of a productive and fertile soil.

Exercise 3.7: Practical activity — organic soil carbon content

The test uses potassium permanganate which is deep purple. It is an oxidising agent which reacts with the organic carbon in the soil and becomes lighter in colour.

What equipment do I need?

- ❑ 200 ml 0.02 M potassium permanganate solution ($KMnO_4$) (3.16 g / L)
- ❑ teaspoon
- ❑ glass container
- ❑ filter funnel
- ❑ filter or kitchen paper
- ❑ stirrer
- ❑ **use PPE — handle with care and do not allow permanganate to come in contact with eyes or skin — wear glasses (plastic goggles) and plastic gloves.**

Trainees should:

1. Place about **5 g (1 teaspoon) of soil in a small glass** or plastic container.
2. **Add 10 ml** (about 2 teaspoons) of a 0.02 M (3.16 g/L) potassium permanganate ($KMnO_4$) solution.
3. **Stir for 2-10 minutes** to oxidize the carbon in the sample.
4. **Filter the mixture** into the glass container through filter paper or kitchen paper.
5. **Check the colour** of the filtrate. The lighter the colour, the greater the amount of active carbon.
6. **Compare colour changes** between samples and with the original permanganate colour.
7. **Line their samples up in order** from darker and more purple to lighter and less purple.

Your answers — results of organic soil carbon test

Soil	Colour after mixing with permanganate	Contains active carbon — high, medium, low	Soil type (from Exercise 3.5)
1			
2			
3			
4			
5			
Tasmanian	Pale yellow	High	Silt

Disposal of the potassium permanganate.
This is a toxic substance so needs to be disposed of safely though dilution. Fill a large container — at least 10 L — with water and pour in the remaining permanganate. Dig a pit away from crops or animals and dispose of the solution into the pit. Cover with soil.

3.4.3 Soil component 3: Air and water

Air and water are essential to plant health as well as to the health of the majority of other organisms in soils (some bacteria can exist in soil without air, these are called anaerobic bacteria). Air and water occupy the pores in the soil between the soil particles (see Section 3.5). Larger pore spaces are called 'macropores' while small ones are 'micropores'. The pores take up between 20% and 30% of the soil volume. The amount of air and/or water in them depends on the size of the pores which in turn, depends on the size of the mineral particles, and how they aggregate or clump together. As water is drained from soil, air is drawn in from the surface. If the soil becomes waterlogged, air is pushed out.

Air consists mainly of 20% oxygen and 79% nitrogen, with small amounts of carbon dioxide and other gases. Oxygen is needed for all aspects of plant growth and the survival of most soil microorganisms. Nitrogen is taken up by plants through the activity of nitrogen-fixing bacteria (e.g. *Rhizobium* species) that live on roots of leguminous species (peas, beans, acacias, and many others). A second way for nitrogen to enter soil is by lightning which converts atmospheric nitrogen into ammonium (NH_4^+) and nitrate (NO_3-) ions. These enter the soil with rainfall. And a third way, which is generally slow, is the release of nitrogen as ammonia (NH_3) as soil minerals decompose, particularly clays.

Most of the carbon dioxide formed by plant and microbial respiration as well as decomposition activity, is released into the atmosphere.

It is important that air reaches deep enough into the soil for root growth. If it is restricted in any way, then roots will tend to be shallow, because the concentration of oxygen is greater near the surface, or they may die. Compaction of the soil by feet, animals or vehicles is the main cause of poor air circulation in soils.

Different types of soils respond differently to pressure and to compaction. Sandy soils are least affected as the sand particles are relatively large and do not stick together, whereas it is greatest in those with a high percentage of clay. It is also worse when soils are wet, as the water pushes out the air causing water-logging. Waterlogged soil is potentially damaging for plant growth as it may prevent roots from exchanging gases and leads to their death (apart from rice and taro that are able to pump air from their leaves to their roots).

The presence of water in soil is vital for plant growth. It moves nutrients to roots and to microorganisms. It also helps in the absorption of nutrients by soil particles and supports microbial activity. The amount of water held by soil is dependent on its texture - the relative amounts of sand, silt and clay - with clays having the ability to hold most. But the amount of organic material present also plays a part, as it can also form strong bonds with water to hold it in the soil. Section 3.5 discusses how the structure of soil affects it ability to hold and allow water to flow through it.

3.4.4 Soil component 3: Living organisms

Living organisms in soils are microorganisms — bacteria, fungi, oomycetes, viruses, protozoa, etc., and the larger macroorganisms — earthworms, insects, nematodes and spiders, that have evolved to live there. By their activity, nutrients are released that plants need for their growth, and tunnels are created for roots and water to find a passage. Further, the living organisms work on organic matter creating humus that binds the different components together, keeping soils stable.

Soil scientists talk about a Soil Food Web (Fig. 3.10)[10]. The idea is that there is a complex cycling of nutrients, starting with the formation of plant sugars and starches through photosynthesis in leaves, which eventually fall, decompose and sustain soil-living organisms, which then go on to sustain plant growth. The important point here is that the micro and macroorganisms in the soil release nutrients from the organic and inorganic matter in forms that roots can absorb.

3.4.4.1 Microorganisms

Microorganisms such as fungi, bacteria, algae, archaea[11], viruses[12] and single-celled animals (i.e. protozoa, that feed on bacteria and fungi) are present in large numbers in healthy soil.

A quarter of a teaspoon of soil can contain a billion bacteria or more, with thousands of different species, even though they might only make up 1% to 5% of the soil by volume. It is said that soils are the most species-rich ecosystem in the world, suggesting that two-thirds of all species live there[13]. Together, these microorganisms are known as the soil microbiome. They are the primary decomposers of organic materials making humus. Bacteria and fungi also produce sticky secretions (glomalin) that bind soil particles, giving the soil structure, which protects it from water and wind erosion.

As plants grow, fungi and bacteria colonise the surface and interior of roots producing chemicals that have nutritional and antibiotic properties. The result is that the plants are healthier because they have a supply of compounds from the 'friendly' microbes on or in their roots that they would otherwise find difficulty in obtaining. The fungi that colonise roots we call mycorrhizae, and most plants have them.

Mycorrhizal fungal threads colonise roots, either internally (arbuscular mycorrhizae) or externally (ectomycorrhizae). Here, they access organic chemicals such as sugars, in exchange for water and mineral nutrients such as phosphorus derived from the soil, to make them available to the plants

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10 USDA Soil Food web. Soil nutrients and your crops. https://www.nrcs.usda.gov/sites/default/files/2022-10/AK-Soil-Nutrients-brochure.pdf

11 Archaea are a group of microorganisms that are similar to, but evolutionarily distinct from bacteria. In soils they are vital to soil functions, e.g. nitrification, and methane production in rice paddies.

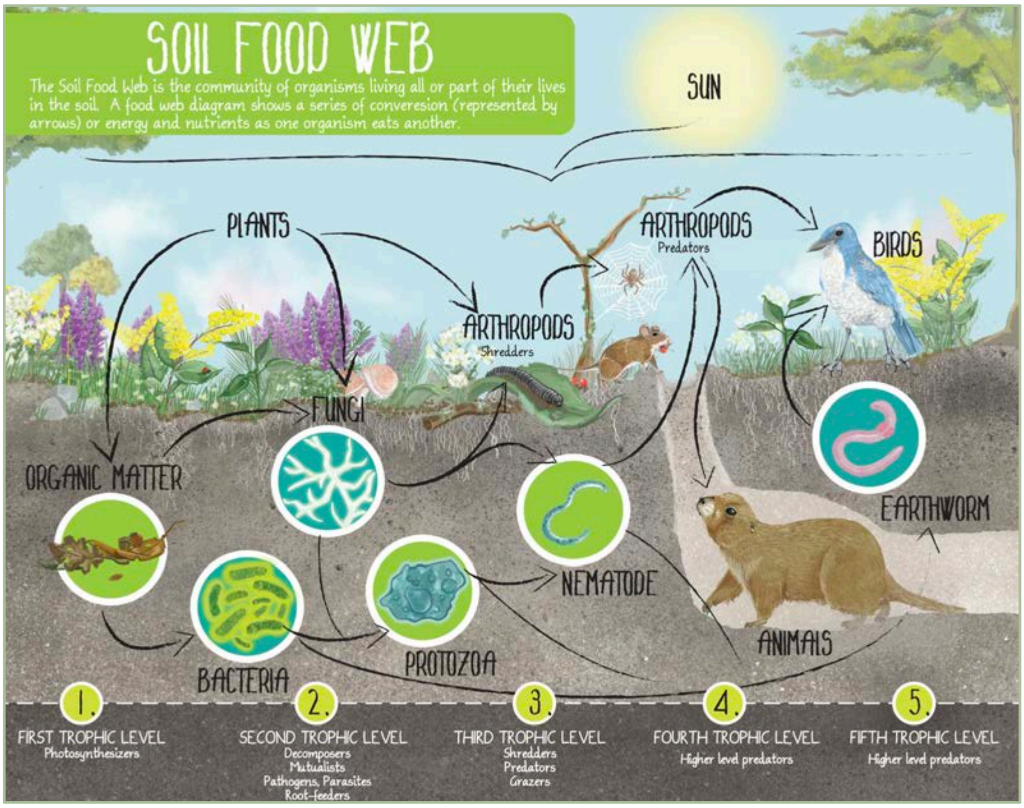
12 A new study found that soils can contain many kinds of RNA viruses. Most of these RNA viruses are likely to infect fungi, but they could also infect bacteria, plants, and animals. Viral populations in soil change quickly, meaning that viruses may be multiplying and responding to environmental changes. https://www.energy.gov/science/ber/articles/soil-viruses-rich-reservoir-diversity#

13 Anthony MA, *et al.* (2023) Enumerating soil biodiversity, Proceedings of the National Academy of Sciences. DOI: 10.1073/pnas.2304663120

Fig. 3.10 The Soil Food Web: the relationship between soil organisms living entirely or partly in the soil. The web begins with the sun's energy converting inorganic compounds (carbon dioxide and water) into energy-rich organic compounds (sugars) through the process of photosynthesis.

Sugars and other organic compounds — excreted into the rhizosphere from living plant roots — recently dead plant roots, crop residues, and soil organic matter, feed the many and varied members of the soil food web. Trophic levels refer to the relationships of the different organisms in the food chain or food web: one (trophic) level feeding on another.

Source: Soil Food Web. USDA



they inhabit. We say more about the mycorrhizae when we talk about the rhizosphere — the area just outside the root (Section 3.10.1). Also present are specialist microorganisms that ensure plant health, for example, nitrogen-fixing *Rhizobium* bacteria that form symbiotic relationships with plants (primarily in the legume family). They invade plant roots, developing nodules to manufacture nitrogen-containing chemicals that are exchanged for the carbohydrate foods they need from their hosts.

The interaction between roots of plants and the microorganisms can be seen in other ways. It is becoming clear that the genetics of the host plant influences the microbial composition associated with the roots. This was the case in a recent study on the grass (*Panicum* sp.) growing across a range of different natural sites in North America[14]. The study found that a large proportion of the root microbiome was influenced by the host, and they identified the genes of the grass that appeared to influence the microbes' abundance.

[14] Edwards JA, *et al.* (2023) Genetic determinants of switchgrass-root-associated microbiota in field sites spanning its natural range. Current Biology 33(10): 1926-1938. DOI: 10.1016/j.cub.2023.03.078.

It is not only microorganisms that are important in healthy soil, but also larger organisms (macroorganisms) such as earthworms, nematodes and insects, most of which we can see with the naked eye.

3.4.4.2 Macroorganisms

Earthworms, insects and other larger organisms are extremely important components of healthy soil. They burrow through the soil, creating pore spaces and tunnels through which air and water pass, and roots can grow to deeper levels. They are also active in breaking down organic matter by feeding near the surface and depositing nutrient-rich excrement (worm castings) in tunnels, so that it can reach the lower depths.

Earthworms can be divided into three groups:

- *Epigeic worms*, which include the common red wiggler, *Eisenia fetida,* used in composting. They live on the surface of the soil and eat rotting organic matter. They have a high rate of reproduction, so are very useful for starting a worm farm.
- *Endogeic worms*, which live within the soil and make burrows. They eat large quantities of soil, preferring those rich in organic matter. These worms are important in decomposition of dead plant roots and in soil aeration.
- *Anecic worms* (*nightcrawlers*), which come to the surface at night to drag organic matter into their burrows. These worms play an important role in the decomposition of leaf litter, and soil formation.

Earthworms such as, *Perionyx excavatus* and *Pontoscolex corethrurus*, have been identified as potential native earthworm species for vermicomposting in Pacific countries. The red wriggler (*Eisenia fetida*) is also adapted to the region and reported to be an efficient species for commercial worm farming (vermicomposting)[15]. It is not found naturally in Fiji, but worm farming using these worms has been started there recently[16].

Apart from earthworms, there are other large animals in soil. Nematodes are present, although they are mostly microscopic and not seen with the unaided human eye. They live in the water around soil particles, feeding on organic matter, bacteria, living roots, other nematodes, and fungi. Some cause plant diseases by feeding on or inside roots (e.g. species of *Hirschmanniella, Meloidogyne, Pratylenchus,* and *Radopholus*).

Ants and termites are also important in soil as they alter its chemical and physical characteristics. They can increase the carbon, nitrogen and phosphorus content, and mix soil from different soil layers as they make their nests.

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[15] Pierre-Louis, *et al.* (2021). Potentiality of vermicomposting in the South Pacific Island countries: AS Review. Agriculture 11(9): 876. https://doi.org/10.3390/agriculture11090876

[16] Fiji Sun (2015) Grave Road Food introduces earthworm farming here. 11 April. https://fijisun.com.fj/2015/04/11/grace-road-food-introduces-earthworm-farming-here/

Exercise 3.8: Practical activity — growing soil microorganisms

What equipment do I need?

- ❑ agar plates need to be prepared before the practical activity, unless you want the trainees to make them themselves
- ❑ glass or plastic Petri dishes or glass plates
    - the tops from coffee jars work well
    - Petri dishes or glass jars should be boiled in water for 5 minutes before using to sterilise them unless they are already sterilised
- ❑ cotton buds.

FOR FUNGI

1. V8 juice agar to make 100 ml:

- ❑ 80 ml boiling water
- ❑ 20 ml V8 juice (NOT the spicy one)
- ❑ 0.2 g calcium carbonate (chalk)
- ❑ 1.5 g agar powder
    - put the V8, agar and chalk into the boiling water
    - pour into glass dishes or jars
    - put the lids on and allow to cool till the agar is set.

2. Malt agar

- ❑ 2 g of malt extract
- ❑ 2 g of agar
- ❑ 10 ml water
- ❑ Additional 90 ml water
    - mix the first 3 ingredients into a paste
    - slowly add more water with stirring until the volume is 100 mls
    - boil for 5 minutes
    - allow to cool a little then pour into the Petri dishes or glass jars
    - put the lids on and allow to cool till the agar is set.

3. Alternative medium for fungi – potato dextrose agar:

- boil 200 g sliced, unpeeled potatoes in 1 L water for 30 minutes
- filter through kitchen cloth and collect the liquid
- mix with 20 g dextrose (glucose) and 20 g agar and boil for 5 minutes
- allow to cool then pour into the plates or jars
- put the lids on and allow to cool till the agar is set.

Exercise 3.8: Practical activity continued...

FOR BACTERIA

- ❑ 5 g of beef stock powder or cubes
- ❑ 2 g sugar
- ❑ 2 g agar powder
- ❑ 100 ml boiling water
- ❑ glass or plastic Petri dishes or glass jars
    - dissolve the beef stock, sugar and agar in the boiling water, boil for 5 minutes
    - allow to cool then pour into Petri glass dishes or glass jars
    - put the lids on and allow to cool till the agar is set.
- ❑ soil microorganisms can be grown on nutrient agar
- ❑ plating out the soil organisms:
    - take a teaspoon of the soil sample and mix it with water
    - stir for one minute
    - using a cotton bud, take out some of the water and spread in drops thinly over the surface of each type of agar
    - leave in a warm place (about 30 degrees) for 3 days.

Ask trainees to describe what they can see on the agar.

- Which soils have the most microorganisms?
- Which have the least?
- Why do they think that is?

Fig. 3.11 Agar dish growing soil fungi (dark green colonies) and bacteria (pink/orange colonies). *Source: Authors*

EXERCISE 3.8: continued...

Exercise 3.9: Practical activity — examining soil for earthworms

Earthworm populations are very patchily distributed and variable. Their location and abundance are heavily influenced by soil moisture, temperature, organic matter and time of the year.

What equipment do I need?

- ❑ 1 m² soil in several locations, preferably with different soil types, one could be a compost heap
- ❑ shovel
- ❑ jar for earthworms
- ❑ shallow dish
- ❑ water
- ❑ dissecting microscope or hand lens.

Also, see Exercise 3.21 — building a worm farm. This could also be done at the same time using the worms collected.

Divide the trainees into two groups. Each group should pick a location with different vegetation, and usage. Trainees should:

- measure out 1 m² and carefully clear all litter from the area.
- with a shovel, dig down about 20 cm
- carefully place any worms found in the jar and cover with a little soil
- in the classroom, carefully transfer a worm to a shallow dish with a little water to prevent it from drying out
- examine with a hand lens or dissecting microscope
- place earthworms back where they were found afterwards, and return the soil.

Trainees should answer these questions:

1. Look at Fig. 3.12. Can the structures be seen on the worms?
2. Is there any relationship between the type of soil and the number of worms?

Place your earthworms back where they were found afterwards.

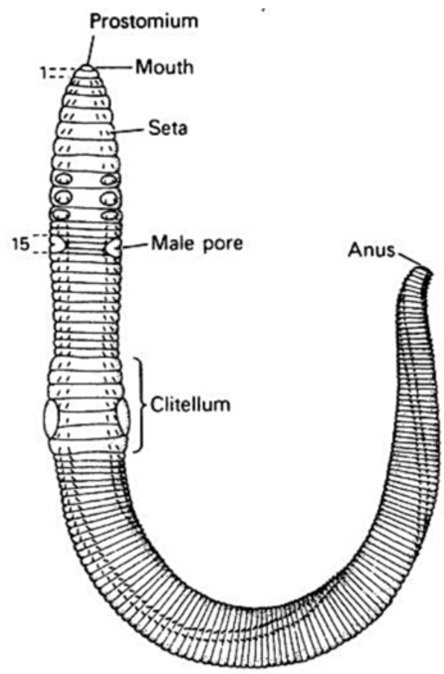


Fig. 3.12 Diagram of an earthworm.

Source: D Ventin, 1989 Earthworm Biology, CSIRO Division of Soils.

EXERCISE 3.8: examining soil for earthworms

Exercise 3.10: The carbon food web role play

This exercise helps trainees to understand the way carbon cycles in the soil food chain/web.

What equipment do I need?

- ❑ string cut into 2 m lengths, 3 per trainee

Cards containing the name of feature in a soil food web/chain:

- ❑ bacteria
- ❑ fungi
- ❑ humus
- ❑ carbon dioxide
- ❑ sunlight
- ❑ plants
- ❑ worms
- ❑ sugars
- ❑ animals
- ❑ photosynthesis
- ❑ respiration
- ❑ animal manure
- ❑ dead plants
- ❑ compost
- ❑ worm castings
- ❑ fossil fuel burning.

Trainees should:

- **collect several lengths of string and a card** with a feature of the food web (carbon cycle)
- **find the person who has the next element** in the web and ask them to hold the other end of the string
- **keep connecting** till you have used up to three pieces of string per person.

Once everyone is connected, draw the web as a diagram on the board.

Discussthe pathways that show how carbon cycles through the web, and energy flows through the web.

3.5 Structure of soils

3.5.1 Soil structure

So far, we have discussed the four most important components of soils – minerals, organic matter, air and water and microorganisms. We have mentioned texture or how soils vary from fine to course depending on the relative amounts of sand, silt and clay, and how to determine textural classes using the USDA triangle. The different amounts account for the names of soils with which we are familiar: loams, sandy loams, silty clay loams, etc. We have mentioned that texture affects several important characteristics of soil: water holding capacity, permeability, workability — how easily a soil can be tilled.

But these characteristics can also be affected by soil structure, and this is described in this section.

Soil structure is the 'architecture' of soil, the arrangement of soil particles (sand, silt and clay) and organic matter into naturally forming lumps or crumbs called 'aggregates' or 'peds' (Fig. 3.13). They are held together by roots, root exudates, soil microbes, inorganic iron oxides and electrical charges from clays.

Peds vary in size from small crumbs of less than 2 mm to greater than 10 mm in diameter. (In contrast, a 'clod' is a lump of soil that has been formed by an unnatural disturbance such as ploughing or compaction and has poor or no pore structure). In agriculture, a well-structured soil will have a continuous network of pore spaces to allow drainage of water, free movement of air and unrestricted growth of roots[17].

Soil structure is very important because it has a direct impact on many soil properties, but especially on aeration, water-holding and drainage capacity. In turn, this affects water availability for crops and how well roots can penetrate the soil. Compacted soil reduces the ability of water to vertically infiltrate the soil and thus increases surface runoff and the risk of flooding.

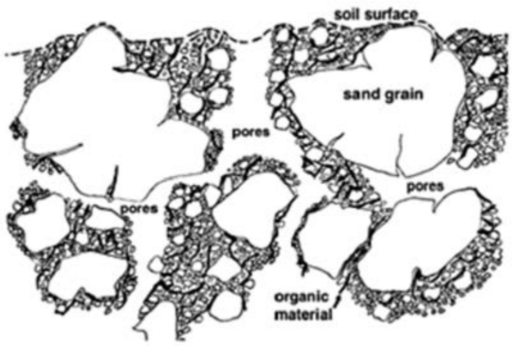


Fig. 3.13 Soil structure.
Structure is the arrangement of the solid parts of the soil and the pore spaces between. The solid parts (sand, silt, clay) and organic matter are bound together into what are called clumps, crumbs or aggregates. The way that this binds together determines, for instance, water storage capacity, drainage, and how a soil behaves when tilled or under the forces of compaction. *Source: Victorian Resources Online Statewide. Agriculture Victoria. Soil health. Soil structure.*

17 Soil structure. Victorian Resources Online Statewide. Agriculture Victoria. https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_soil_structure

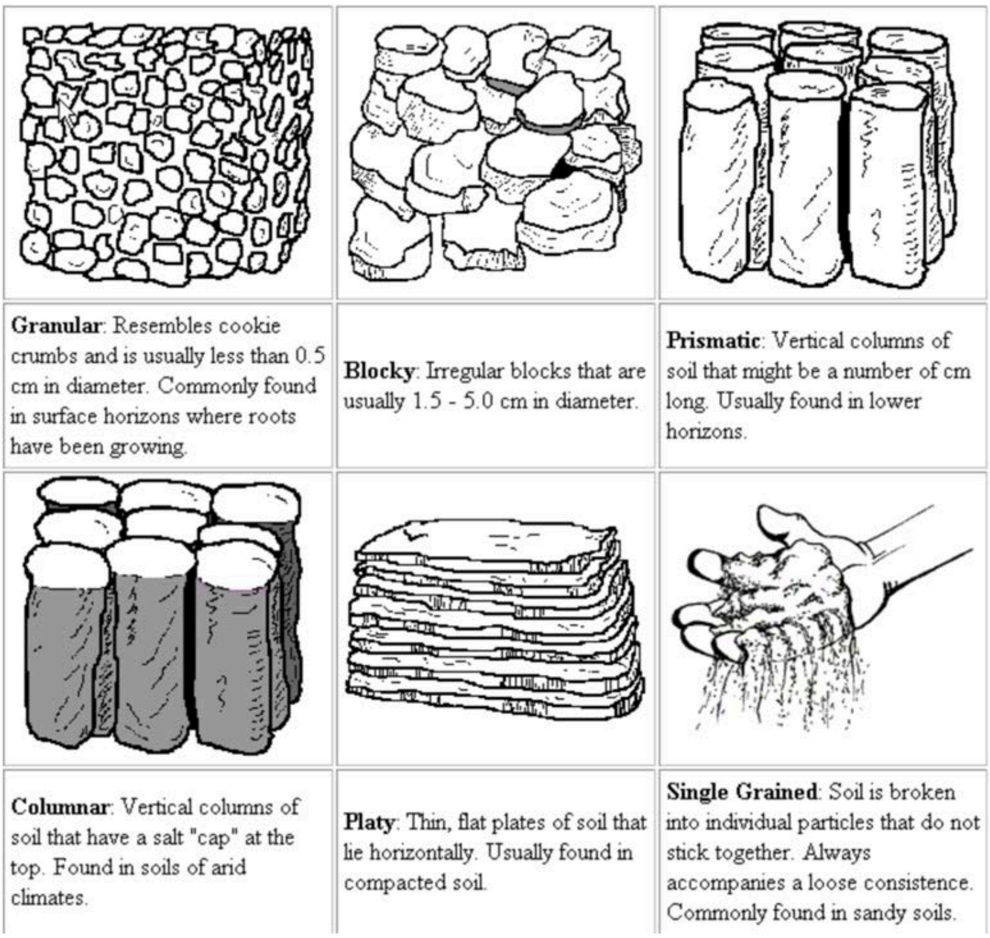
3.5.1.1 Types of soil structure

Peds are classified on both their size and shape. A well-structured soil will have a mix of small and large peds, allowing water to soak into the soil and excess water to drain away, and for air movement.

At least six types are recognised on the basis of their shapes (Fig. 3.14), including single grained — without structure — spheroidal, platy, blocky, columnar, and prism. The differences between them affect water and air movement in and through a soil, nutrient availability, root growth and microorganism activity. The presence of peds rather than individual (primary) particles of sand, silt or clay, means there is greater air and water movement and better root growth.

The factors that increase aggregation – how soil particles group together — are biological activity, organic content, and wetting/drying and freezing/thawing cycles. Conversely, tillage, and compaction, decreases aggregation.

Fig. 3.14. Types of structure in soils
Source: Soil nutrient management for Maui County. University of Hawai'i at Manoa



Source: http://www.cst.cmich.edu/users/Franc1M/esc334/lectures/physical.htm

3.5.2 Movement of water through soils

The ability of water to move into and through and also be held in soil, are important factors in soil and plant health. A soil needs to be able to allow water and air to pass through the pores i.e. not be waterlogged, but also to hold enough water and air so that plants and other soil organisms do not dry out (as happens in drought).

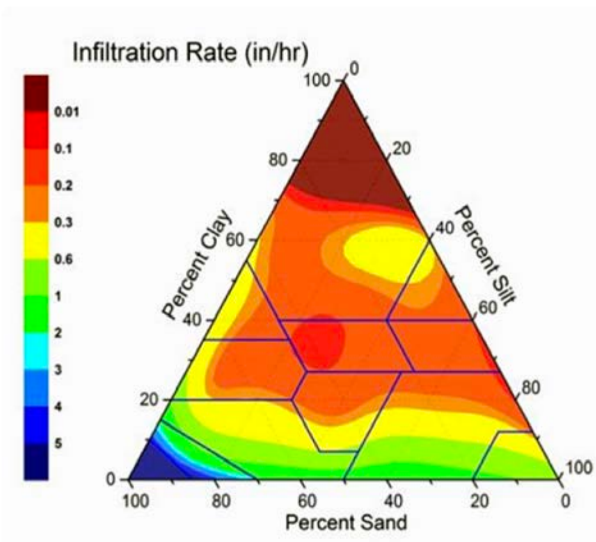
The infiltration rate is a measure of how fast water enters the soil (Exercise 3.11). Because infiltration is related to soil texture and structure, different soil types will have different infiltration capacities. Sandy soils are free draining compared with clays, so will have higher infiltration capacities. Also, soils with a lot of pores from earthworms or old root channels will have a high infiltration rate.

High infiltration capacities mean less surface run-off and risk of water-logging. However high infiltration can also lead to some nutrients being lost from the root zone through leaching into deeper parts of the soil profile.

Infiltration capacities can be altered by soil management practices. Practices that degrade the structure of the soil such as compaction, will have a negative effect on infiltration, so having an idea of the infiltration rate is a good indicator of how good a farmer's soil management is.

Fig. 3.15 uses the soil triangle to show the infiltration rates of different kinds of soil. The lower the rate, the longer it takes for water to infiltrate into the soil. (Here it is given in inches/hr — American — to get to cm/hr, multiply by 2.54).

Fig. 3.15 Soil triangle showing the infiltration rates of different kinds of soil.
Source: Healthy soils for a healthy California. University of California.



The water-holding capacity of soil is the ability of the soil to hold water against the pull of gravity. The higher the clay content, the higher the water holding capacity (and the lower the infiltration rate). Pure sand has a high infiltration rate and a low water holding capacity. Organic matter increases the water holding capacity. This is why it is important to add organic matter to sandy soils. The water holding capacity or field capacity of soil is a measure of the maximum amount of water retained by soil per gram of its dry weight, after no more water can flow through it. It is possible to test this at different levels in the soil to see how water holding changes with depth (Exercise 3.12).

Percolation (permeability) refers to the downward movement of water into the soil through the pore spaces. A soil with good percolation is much easier to till and work than one that is compacted.

The next two practical activities allow your trainees to observe the infiltration rate and measure the water holding capacity of soil, which is related to soil structure.

The presence of water in soil is also vital for plant growth. It moves soluble nutrients to roots and to microorganisms. It also helps in the absorption of nutrients by soil particles and supports microbial activity. The amount of water held by soil is again dependent on its texture — the relative amounts of sand, silt and clay, with clays having the ability to hold the most water. Organic material present also plays a part, as it can also form strong bonds with water to hold it in the soil.

The water holding capacity or field capacity of soil is the maximum amount of water retained by soil per gram of its dry weight, after no more water can flow through it. This can be tested at different levels in the soil to see how water holding capacity changes with depth.

Exercise 3.11: Practical activity — soil infiltration rate

What equipment do I need?

- ❑ access to 2 different types of outside soil (alternatively, use soil and sand)
- ❑ 2 empty coffee or other large tins (they should be the same diameter
- ❑ 200 ml water
- ❑ stopwatch

This exercise uses soil outside the venue. Trainees should observe the demonstration and discuss the results.

Trainees should:

- **push the empty coffee tins** with the bottom removed into two different types of soil so they are both at the same level above the soil
- **fill each tin** with 100 ml water
- **using the stopwatch** on a phone, time how long it takes for the water to be absorbed into the soil in each tin
- **discuss the results.**

The quicker the water infiltrates into the soil, the higher the infiltration rate. However, although very sandy soil has a high infiltration rate, it is not good for plant health because it does not have all the other factors that make soil healthy.

A long time (i.e. low infiltration rate) means the soil is probably very compacted and has poor water and air quality. Or it may mean that it has a very high clay content.

A good soil has a good structure as well as a good infiltration rate.

Source: AHDB water infiltration test

Exercise 3.12: Practical activity — measuring the water holding capacity of soil

What equipment do I need?

- ❑ 100 g of dried soil — each group should use a different type of soil and compare results
- ❑ funnel
- ❑ filter or kitchen paper
- ❑ measuring cylinder or jug with measurements marked.

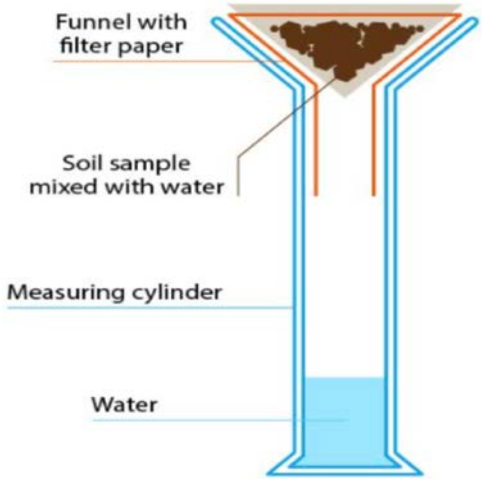


Fig. 3.16 Diagram of equipment for measuring the water holding capacity of soil. *Source: authors.*

Trainees should:

- line a funnel with filter or kitchen paper
- place it on a measuring cylinder
- put 100 g of the dried sample of soil in the filter paper
- pour 100 ml of water into the funnel
- record the volume of filtered water in the measuring cylinder when the water stops dripping from the funnel.

Record the whole class's results in table below.

Trainees should answer these questions:

- Which soil has the highest water holding capacity? Why?
- Which has the lowest? Why?
- What have you learned about the water holding capacity of different soil types?
- What is the consequence of a too-high water holding capacity?
- What is the consequence of a too-low water holding capacity?

Your answers — measure the water holding capacity of soil

Soil	Volume (weight in grams) of water flowing through the soil (ml)*	Volume (weight in grams) of water retained by 100 grams of soil (ml)	Water holding capacity of soil in grams of water per gram of dry weight of soil x 100=%	Soil type from soil triangle Exercise 3.12
1				
2				
3				
4				
Tasmania	18 ml	82 ml	82%	Silt
* The volume of water in mls is the same as its weight in grams				

3.6 Soil profile and horizons

Over time, and with organic matter accumulating on the surface, distinct layers develop in soil. A vertical section of the soil from the surface to where it meets the underlying rock defines the 'soil profile'. The layers in the profile are known as 'horizons'. Invariably, these show a dark layer of organic matter at the surface, with the parent rock at the bottom, and other layers in between.

In the scheme developed by soil scientists, there are six 'master horizons'. This is the maximum number of horizons that can develop, but not all will be present in all profiles as they differ with location. For instance, a profile under grass will not be the same as one in a forest. All six are shown in Fig. 3.17[18].

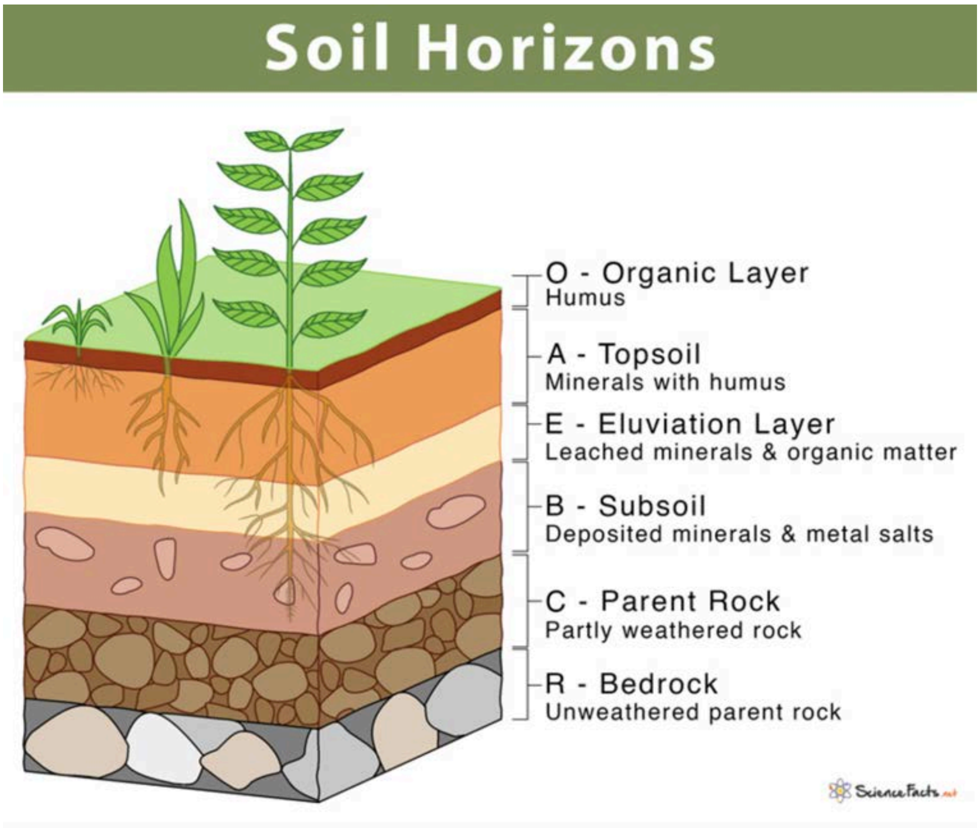
In general, it is estimated that it can take 1000 years to produce 2-3 cms of soil.

Details of the various layers are as follows:

- **O – surface**, mostly leaves and other organic materials in various stages of decomposition, often dark brown
- **A – topsoil**, consisting of minerals (sand, silt, clay), plant roots, crumbly with various amounts of organic matter, high biological activity, porous and can retain water; dark in colour
- **E – leached** (minerals lost) with low clay content — not always present; for example, present in forests but not grasslands; usually light in colour
- **B – subsoil**, harder and more compact than topsoil, high clay, iron and aluminium oxides, low in organic matter; less biological activity; lighter brown
- **C – parent material and mineral particles**, less weathered than other layers, low in organic matter, lacking plant roots; transition layer been soil and bedrock
- **R – bedrock**; made up of sedimentary (deposited by water or air) and metamorphic rock (this is sedimentary rocks transformed by heat and pressure).

18 Sciencefacts.net https://www.sciencefacts.net/soil-horizons.html

Fig. 3.17 Soil profile. The layers are called 'horizons'. The maximum is six, but not all may be present. It depends on the parent rock and the environment where the soils form. For instance, profiles in forests differ from those in grasslands.
Source: Soil Profile. ScienceFacts.



Exercise 3.13: Practical activity — soil horizons (layers), digging a soil pit

NOTE: This exercise could be carried out after Exercise 3.14 when trainees have covered all the other exercises needed. Or, the more extensive tests could be carried out as extension exercises if time permits.

What equipment do I need?

- ❑ access to an outside area about 1 m^2
- ❑ shovel
- ❑ plastic sheet or tarpaulin
- ❑ mobile phone or camera for photographs.

Trainees should:

1. **Choose a less compacted and disturbed area** of soil away from concrete, pavement or roads. The presence of vegetation is usually a good place to dig a pit.
2. **Using a shovel to dig a pit about 1 m deep**, and wide enough to easily observe the different layers (horizons) of soil all the way to the bottom.
3. **Remove soil layers from the pit one by one** with the shovel and place them on the plastic tarpaulin in piles that correspond to the soil layers. The soil should be replaced after the exercise.
4. **Identify the different soil horizons** (O, A, E, B, C, R) and measure their depth. Take a photo of the layers.
5. **Retain the soils for testing** — test each horizon layer for moisture, colour, smell, texture/structure, pH, active carbon (Exercise 3.7) and microorganisms (Exercise 3.8).

Your answers — soil horizons (layers)

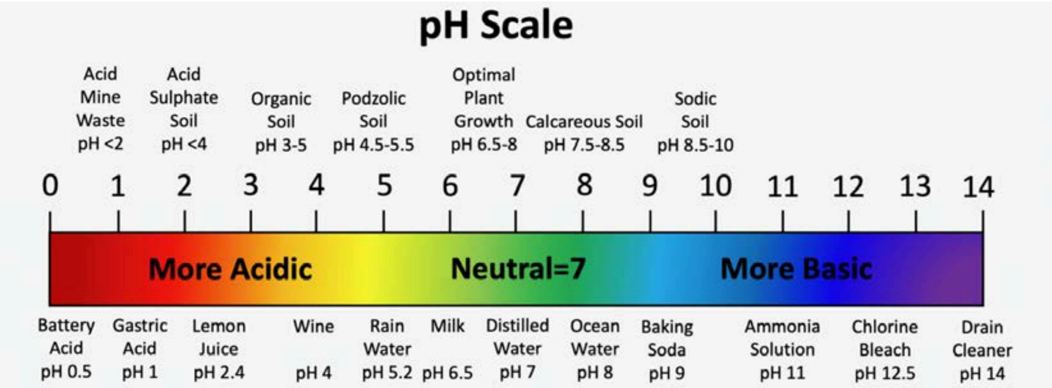
Soil horizon	Colour	Texture (sand/silt/clay)	pH	Active carbon (this can be done after Exercise 3.7) high, medium, low	Microorganisms (after Exercise 3.8)	No. of worms
O						
A						
E						
B						
C						
R						

3.7 Soil pH and nutrient availability

It is important to know the pH of soil, as it influences plant growth and how well plants can take up nutrients[19]. Soils can be acid, neutral or alkaline, depending on the rocks they come from, e.g. soils from limestone and coral are alkaline, and those from granite are acidic. Also note that carbon dioxide produced by decaying organic matter reacts with water in soil to form a weak acid (carbonic acid).

Fig. 3.18 The pH scale. It is a measure of the hydrogen ion concentrations of the soil, and varies with the type of rock, weathering, vegetation, and time.

Source: University of Saskatchewan. Soil Chemistry.



The acidity or alkalinity of soil is measured by its pH (Fig. 3.18)[20]. The pH scale runs from 0 to 14. An acid pH is less than pH 7, neutral pH is 7, alkaline pH is greater than 7.

The pH of most soils is between pH 3 and 10, but most plants require a pH of between 4.5 and 7.5 for healthy growth, although different plants have different pH requirements. Some berries prefer an acid soil, while brassicas prefer a soil nearer to neutral. For a majority of crops, best growth is between 6 and 7.

Soil pH regulates the availability of nutrients in solution in soil[21]. Fig. 3.19 shows how different minerals are affected by the pH of soils. Most plant nutrients are readily available to plants within the 6.5 to 7.5 pH range. Nitrogen (N), potassium (K), and sulphur (S) are less affected directly by soil pH. However, phosphorus uptake is particularly sensitive to soil pH. For example, at alkaline pH values greater than pH 7.5, phosphate (in the form of phosphate ions (PO_4^{3-}) tends to react quickly with calcium (Ca^{2+}) and magnesium ions (Mg^{2+}) to form less soluble compounds which plants cannot

19 pH stands for 'potential hydrogen ion (H^+)'. The concentration of the H^+ is usually given in moles/litre. The pH is the negative log to the base 10 of the H^+ concentration. For example, if a soil has a hydrogen ion (H^+) concentration of 0.001, i.e. 10^{-3}, then the pH is 3. A soil with a pH of 7 has a H^+ concentration of 10^{-7} or 0.0000001 moles H^+ per litre. With each unit the H^+ is 10 times more acid or alkaline.

20 Soil Chemistry. Digging in Canadian Soils. University of Saskatchewan. https://openpress.usask.ca/soilscience/chapter/soil-chemistry/

21 Deep Green Permaculture. https://deepgreenpermaculture.com/2020/05/26/soil-chemistry-fundamentals-part-1-understanding-soil-ph-and-how-it-affects-plant-nutrient-availability/

absorb. At acidic pH values, phosphate ions react with aluminium (Al^{3+}) and iron ions (Fe^{3+}), again to form less soluble compounds. Soils below pH 5.5 also impact calcium (Ca), magnesium (Mg) resulting in inadequate availability.

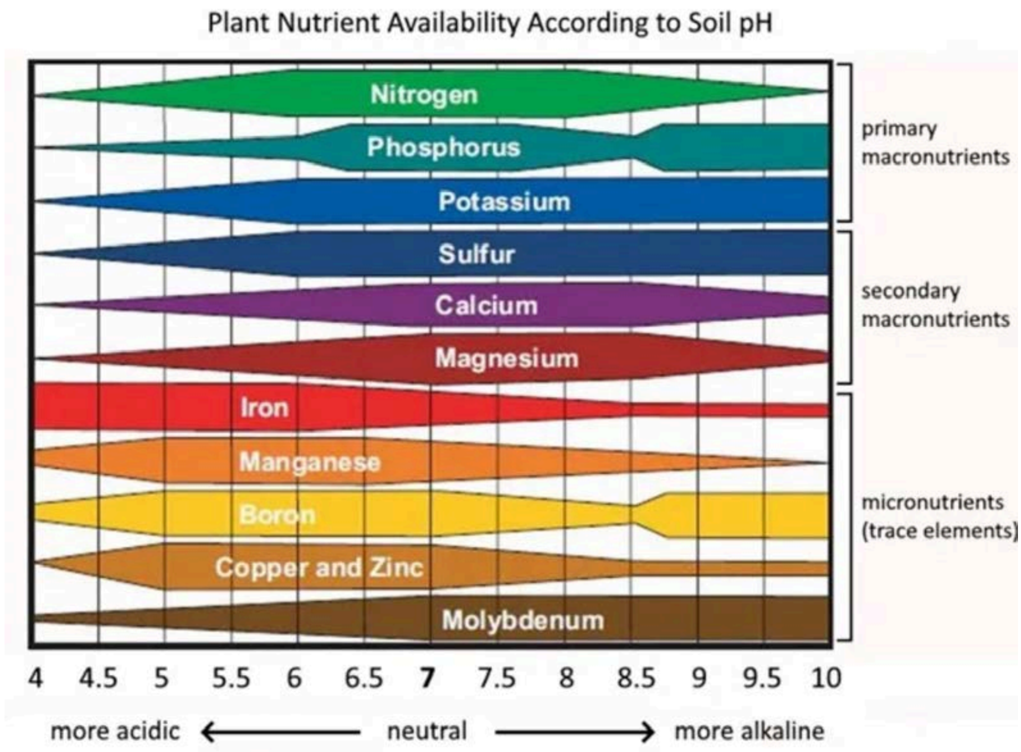
For most micronutrients, there is a tendency for them to be less available at high pH soils (>7.5); this is so for boron, copper, iron, manganese and zinc, which are most readily available at a slightly acidic pH around 6.5 to 6.8.

The exception is molybdenum in the form of molybdate ions (MoO_4^{2-}), which appears to be less available at acidic pH and more available at moderately alkaline pH values.

When nutrients are missing or there is too much of them in the soil, the plant will normally show symptoms in its leaves. These are discussed in the next section.

Fig. 3.19 Plant nutrients and pH. The thicker the bar, the more available the nutrient is to the plant. Look at how pH affects the availability of phosphorus and some of the micronutrients at the bottom of the figure.

Source: Deep green permaculture. Soil chemistry fundamentals.



Exercise 3.14: Practical activity — measuring soil pH

What equipment do I need?

- ❑ about a teaspoon of soil
- ❑ pH paper, preferably with a narrow range between 3.5 and 8.5, or Universal indicator liquid
- ❑ water
- ❑ glass jar.

Trainees should:

1. **Mix a teaspoon of soil** with about 25 ml of water. Allow the soil to settle.
2. **Dip a pH paper** or add a few drops of Universal Indicator into the liquid above the soil.
3. **Record the pH** of the soil.
4. **Compare the pH** of the different soils tested.
5. **Consider** — is there any relationship between **pH and soil texture**?

Exercise 3.15: pH and nutrient availability

Two soils, A and B, have different pH.

- **trainees should use the diagram in Fig. 3.19** to work out which elements might be available and unavailable to plants
- also, ask them to **compare with their own soil samples** they are using in class.

Your answers — pH and nutrient availability

Soil sample	pH	Nutrients readily available	Nutrients not readily as available
Soil A	8.5		
Soil B	5.0		
Class soil: 1			
2			
3			
4			
Tasmanian soil	5.5	Cu, B, Mg, Fe	Ca, Mg, K, P, Mo, N

3.8 Common types of soil & Pacific soils

3.8.1 Comparison of soil types

Some soils have a better natural structure than others because of the composition of their main components — sand, silt and clay; organic matter; air and water. The variation comes from differences in the parent rocks; differences in rainfall and temperature; shape of the land, whether hills or valleys; types of living organisms; and the length of time over which the processes of soil formation has occurred. Clay particles have a large surface area and that is one of the main reasons why clay soils have the greatest quantities of nutrients and are potentially very fertile. The properties of these different soils based on texture are given in Table 3.1 below.

Table 3.1: Properties of different soils based on texture

- **Sandy soils:** These are 'light' soils, gritty with large particle sizes (from the parent rocks), they are low in organic matter and nutrients, so are generally not very fertile. They have large pores and, consequently, good drainage but poor water-holding capacity, draining quickly after rain. They dry out very quickly.
- **Silty soils:** These have a silky feel, derived from sediment at the bottom of rivers. They are composed of medium size particles (silt) that pack together tightly, creating very small pore spaces. They may compact if there is heavy traffic on them (e.g. walking by humans or animals, or machinery). Generally, they are fertile.
- **Clay soils:** These are known as 'heavy' soils. They have the smallest particle size, hold the greatest amount of nutrients bound to the clay minerals, and high water-holding capacity, but drain slowly. Also, they can become hard and compacted (by humans, animals or machinery), which can limit root growth and reduce the entry of water. Potentially, they can be fertile, but need organic matter to break up the clods (clumps) to make the nutrients and water more available.
- **Loamy soils:** These soils are ideal for growing plants because they are fertile with a good balance of sand, silt, and clay particles. They are 'crumbly' with visible pore spaces for air and water movement, consequently, they are well drained.
- **Chalky soils:** These are made up of calcium carbonate and derive from coral or limestone and are alkaline. They are free draining. They have low organic matter content and lack or are low in several essential elements because they have a high pH. Iron is invariably low. Generally, they are of low fertility.
- **Peaty soils:** These are mainly composed of organic matter. They are acidic and very fertile, but moisture content can be high and drainage is necessary.
- **Alluvial soils:** These are composed of loose clay, silt, sand, or gravel that has been deposited by running water in a stream bed, on a floodplain, an estuary or a beach. These soils are geologically young and generally fertile. The 'fertile crescent' in the Middle East and the banks of the Nile are made of alluvial soils that line rivers and have supported food production for millennia.

3.8.2 Pacific soils

The following is the conclusion from the FAO Soil Status of the World's Soil Resources and summarises the threats to soils in the Pacific islands[22]. But if more detail is needed for Fiji, Tonga and Samoa, go to the Pacific Soils Portal[23]:

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22 FAO and ITPS (2015) Status of the World's Soil Resources (SWSR) – Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy. https://www.fao.org/3/i5199e/i5199e.pdf/

23 Pacific Soils Portal. Information and knowledge in Pacific soils, their health and uses. https://psp.landcareresearch.co.nz/

The status of soil resources in the Southwest Pacific region is mixed. The region is a globally significant exporter of agricultural products and nearly all of the 24 countries rely heavily on soils for wealth generation. The threats to soil function in some countries are serious and require immediate action to avoid large scale economic costs and environmental losses. These threats to soil function combined with other pressures caused by increasing population and climate change are especially challenging in southwest Western Australia and on the atoll islands of the Pacific. It is difficult to assess some threats because of the lack of surveys and monitoring networks. The example of soil monitoring from New Zealand demonstrates the practical value of having the capability to track and respond to soil change. The intensification of land use in New Zealand and to a lesser extent Australia provides an indication of the soil management challenges that will dominate in coming years as countries attempt to substantially increase food production within a resource constrained world. Poor land management practices, and especially uncontrolled logging in the low-income countries in the Southwest Pacific are a significant challenge to national prosperity.

3.8.3 Sampling soil

Sometimes soil samples need to be taken from a farm for analysis. The procedure for this is provided in the SPC publication: *Soil sampling guidelines: Strengthening regional collaboration on soil analysis*[24].

[24] Soil sampling guidelines: Strengthening regional collaboration on soil analysis (2022). SPC, Suva, Fiji. https://spccfpstore1.blob.core.windows.net/digitallibrary-docs/files/80/80fe46e74fe0ea2d62b1b38819d09c02.pdf?sv=2015-12-11&sr=b&sig=lPn9PT%2BOMirTlGoW01nBVMTLbQikyQl3UXxYW3XMvJM%3D&se=2024-02-19T04%3A14%3A08Z&sp=r&rscc=public%2C%20max-age%3D864000%2C%20max-stale%3D86400&rsct=application%2Fpdf&rscd=inline%3B%20filename%3D%2262413_Soil_sampling_guidelines_Strengthening_regional_collaboration_on_soil_analysis.pdf%22

3.9 Plant nutrient deficiencies and their symptoms

3.9.1 Nutrients: Role and sources

Earlier, we discussed the importance of soil nutrients and how the pH of soil affects their availability. Soil is the major source of nutrients needed for healthy plant growth. Other than the three elements supplied by photosynthesis (carbon, oxygen and hydrogen), the essential plant nutrients are obtained through the soil and enter through the roots.

They are divided into two groups:

- **major or macronutrients:** those needed in large amounts, nitrogen, phosphorus, potassium, calcium, magnesium and sulphur
- **minor or micronutrients:** those needed in smaller amounts, boron, iron, copper, manganese, molybdenum and zinc.

The role of each macro and micronutrient in plants is given in Table 3.2, together with common sources of the nutrients. Some examples of deficiency symptoms from Pacific islands are presented in Figs. 3.20 to 3.30.

3.9.2 Deficiency symptoms

When a nutrient is absent in the soil, plants may show deficiency symptoms. However, unless the deficiency is well known and the symptoms are clear, it can be difficult to diagnose nutrient deficiencies accurately. Sometimes, unfavourable growing conditions can prevent a plant from taking up a nutrient, even though it is present in the soil. This can happen if the soil is too acid (low pH) or alkaline (high pH) (Fig. 3.19). Also, it can happen if the soil is too wet, too dry, or compacted — preventing roots from accessing deeper layers, reducing the pore size and impacting flows of air and water.

Pests such as spider mites, and some pathogens (e.g. viruses), can also cause leaf symptoms similar to nutritional deficiencies. Roots can be damaged by pathogenic bacteria, fungi or nematodes, which can be seen as symptoms on the leaves, which confuse easy distinction between their cause and nutrient deficiencies.

Furthermore, as can be seen from the descriptions in Table 3.3 below, many of the symptoms of different nutrient deficiencies are similar, with yellowing of leaves being common. Where distinctions can be made due to the lack of nutrients, they are often related to the sensitivity of a particular crop, for instance, boron deficiency of papaya, calcium deficiency of tomato, and zinc deficiency of sweet potato. All these (and more) show symptoms which are unique to particular crop/nutrient deficiency combinations.

Finally, an imbalance of nutrients can occur where one nutrient prevents access to another, for example, too much potassium, sodium or magnesium may suppress the uptake of calcium. Also, excess magnesium can affect the availability of potassium and vice versa.

It is always a good idea to consider carefully whether any other possibilities might exist before concluding that a nutrient deficiency is the cause of the symptoms of concern. However, even when it is certain that a nutrient imbalance exists, there is always the possibility that it is caused by more than a single nutrient; this can make diagnosis a challenge. That is why tests for soil pH and nutritional analyses should be done if possible. If not possible, then application of a full complement of nutrients as a fertiliser or manure is the best way to proceed.

Fig. 3.20 Possible Nitrogen deficiency: chilli (Fiji, left) and watermelon (Vanuatu, right). Note the yellowing on the leaves of chilli starts at the bottom of the plant and, on watermelon, shows first on the older leaves.

Fig. 3.21 Possible Phosphorus deficiency: sweet potato (unknown country, left). Note, in some plants leaves become dark purple due to formation of anthocyanin.

Source: Anya Polytech & Fertilizers Pvt Ltd India.

Fig. 3.22 Possible Potassium deficiency: *Xanthosoma* (Tonga); this interveinal symptom is also seen on taro. It has been suggested that it is due to bacterial infection as well as associated with K deficiency[25]. *Source: authors.*

Fig. 3.23 Possible Potassium deficiency: pumpkin plants (Fiji) showing yellowing leaves turning necrotic at the edges, beginning with the eldest leaves.

Source: authors.

Fig. 3.24 Possible Calcium deficiency: tomato showing blossom-end rot. This is caused by a deficiency in calcium brought about by a lack of water in the plant, or too much water. The problem can also be caused, or made worse, by low pH, or the application of too much nitrogen fertiliser. *Source: authors.*

[25] Miyasaka SC, Hamasaki RT, de la Pena RS (2002) Nutrient deficiencies and excesses in taro. Honolulu (HI): University of Hawaii. 14 p. Soil and Crop Management; SCM-4. https://www.ctahr.hawaii.edu/oc/freepubs/pdf/SCM-4.pdf

Fig. 3.25 Possible Sulphur deficiency: long bean (Fiji, left) showing pale green leaves, and similar yellowing on maize (Fiji, right). The deficiency is similar to that of nitrogen except the young leaves are first to show symptoms. *Source: authors.*

Fig. 3.26 Possible Magnesium deficiency: sweet potato (Fiji) showing a pale-yellow leaf and veins that remain green. *Source: authors.*

Fig. 3.27 Possible Boron deficiencies: papaya with knobbly fruit (New Caledonia, left); and broccoli showing a hollow stem (Papua New Guinea, right). Broccoli may first show watery tissues in the stem before stem dry and cavities appear. *Source: authors.*

Fig. 3.28 Possible Iron deficiency: yam with pale green leaf and veins remaining green. Leaves may become very pale, even white. *Source: authors.*

Fig. 3.29 Possible Manganese deficiency: coconut leaf showing brown streaks forming patches (Kiribati). Younger leaves may at first show yellowing. *Source: authors.*

Fig. 3.30 Possible Zinc deficiency: maize (Fiji) showing interveinal chlorosis of leaves, later turning necrotic with purple pigmentation. *Source: authors.*

Table 3.2: Plant nutrients and their use in plants and where they can be sourced

Nutrient	Use in plants	Common sources &/or comments
Major or Macronutrients		
Nitrogen (N)	Major constituent of amino acids & manufacture of proteins. Essential too for nucleic acid & chlorophyl formation. Involved in activity of many enzymes.	From (i) the atmosphere – some plant (i.e. legumes) fix nitrogen in root nodules; or (ii) from organic matter. Easily leached from soil.
Phosphorus (P)	Involved in cell energy transfers (e.g. ATP is used when energy is required); a component of proteins, nucleic acids, DNA/RNA. Present in membranes as phospholipids. Concentrated in actively growing plant parts, and in seeds — essential for early growth.	From rocks high in P (ocean deposits or guano). Slowly lost from soils. Use chicken manure (about 0.5% by weight).
Potassium (K)	Involved in activity of many enzymes. Has a role in movement of water & regulation of leaf stomata that control water loss & exchange of gases. Aids photosynthesis. Promotes flowering, fruiting and disease resistance.	From parent rocks & bound to soil minerals. But easily lost in limestone (calcareous) soils. Also, from seaweed & chicken manure (about 1 to 1.5% by weight).
Calcium (Ca)	Major constituent of cell walls, cell division, cell growth. Involved in movement of carbohydrates within plants, and movement of other nutrients into the plant. Involved in activity of many enzymes.	From calcite (calcium carbonate) or dolomite (calcium magnesium carbonate), or in complexes with organic matter.
Sulphur (S)	Present in amino acids and enzymes. Essential for chloroplast growth. Essential in root nodule formation of legumes, and nitrogen fixation by *Rhizobium* bacteria, and conversion of nitrate into amino acids & protein.	Mostly mined as gypsum (calcium sulphate). Elemental sulphur is used but it cannot be taken up by plants directly (it is not soluble in water) but is slowly converted to soluble forms (sulphates) by soil bacteria.
Magnesium (Mg)	Essential constituent of chlorophyll & involved in transfer of energy. Involved in activity of enzymes producing carbohydrates, sugars and fats.	From geological deposits formed from evaporation of sea water. Also, from dolomite limestone (calcium magnesium carbonate).
Minor or Micronutrients		
Boron (B)	Essential for cell differentiation and found where cell division is most active, e.g., flowering, fruiting, pollen germination and cell division.	Borax or boric acid as a foliar spray.
Copper (Cu)	Important for photosynthesis, respiration, enzyme functions, and manufacture of cell walls.	Best to improve cultural conditions, especially add organic matter.
Iron (Fe)	Essential in the synthesis of chlorophyll.	Best to improve cultural conditions, especially add organic matter. Check pH is below 6.5. Spray with iron sulphate or chelated iron. On atolls, rusty tins into planting holes.
Manganese (Mn)	Chlorophyll formation, respiration & cell division.	Best to improve cultural conditions; or use manganese sulphate.
Molybdenum (Mo)	Essential part of enzymes involved in amino acid building, and in processes using nitrogen, e.g., uptake from soil. Helps legumes 'fix' nitrogen in root nodules.	Best to improve cultural conditions, especially farmyard manure.
Zinc (Zn)	Essential for production of chlorophyll, enzyme actions, sugars and in DNA copying to form proteins.	Best to improve cultural conditions; or use zinc sulphate.

Table 3.3: Deficiency symptoms of macronutrients and micronutrients necessary for healthy plant growth[26]

Nutrient	Deficiency symptoms	Reason for deficiency
Major or Macronutrients		
Nitrogen (N)	Uniform yellowing on older leaves & early death; younger leaves pale green. Leaves, shoots & fruit smaller than normal. Slow growth.	Causes: (i) pH too high or too low; (ii) nutrient imbalance or lack of N in soil; (iii) leaching; (iv) soil compaction; (v) too little or too much water; (vi) root damage by pests or pathogens.
Phosphorus (P)	Symptoms first on older leaves: purplish due to anthocyanin accumulation on leaves with tip dieback. Young leaves may be without symptoms, except smaller than normal, or remain dark green with purplish veins, especially on underside.	Causes: (i) pH too high or too low; (ii) nutrient imbalance making P unobtainable although present (e.g. excessive iron or aluminium in the soil); (iii) compacted soil.
Potassium (K)	Palms especially susceptible — symptoms first on older leaves: orange and brown spots on leaves. Scorching at leaf margins, dieback of tips, then yellowing, browning and death. Broadleaf plants — older leaves yellow then brown at tips and margins; yellow between veins. Possibly, curling and distortions.	Causes: (i) pH too high or too low (i.e. sandy soils or soils high in calcium); (ii) damaged roots (by nematodes or pathogens); (iii) soil compaction; (iv) water-logging. It is easily leached from soil.
Calcium (Ca)	Affects new growth causing withering, tip-burn, flower and fruit drop. Also, leaf distortions (leaves curl down with browning of edges and tips) & stunting. Roots short and stubby. In tomato (and others in the Solanaceae family), blossom-end rot is a common symptom.	Causes: (i) wrong pH for plant growth (too high or too low); (ii) too much or too little water; (iii) nutrient imbalance. Note, Ca is immobile in plants, i.e. does not move from older to younger leaves.
Magnesium (Mg)	More common in palm — leaf tips bright yellow, yellow margins with green midrib. Lower leaves may die early. Broadleaf plants — on older leaves, yellowing between veins that remain green; plants may become stunted, leaves fall early (tomatoes and potatoes are susceptible).	Causes: (i) sandy soils; (ii) overuse of potassium or calcium; (iii) pH too low.
Sulphur (S)	Newer leaves become deep yellow, and growth is stunted. Leaves are small and often narrow. Note, similar to N deficiency, but S deficiency starts in young leaves.	Causes: (i) incorrect pH & (ii) nutrient imbalance; (iii) sandy soil with low organic matter. Note, S is immobile in plants, i.e. does not move from older to younger leaves.
Minor or Micronutrients		
Boron (B)	Stunted, deformed growth, dark green leaves. Shoot tips die with proliferation of short-stemmed side shoots and green small leaves. Deformed fruit (e.g. papaya); hollow stems (e.g. cabbage, cauliflower); heart rot (e.g. celery)	Causes: (i) leaching of sandy soils with low organic matter; (ii) low or too high pH; (iii) under watering. More common in laterite (high iron) soils; (iv) low levels in soil.
Copper (Cu)	New leaves stunted, wilted, with necrotic (brown) spots. Leaves of some species show yellowing with green veins.	Causes: (i) low and high pH (i.e. common in both sandy and limestone soils); (ii) high P and Fe can affect uptake; (iii) low levels in soil.
Iron (Fe)	Similar to manganese deficiency. Interveinal chlorosis on the young emerging leaves, with veins remaining green. In severe cases, the leaves are undersize, white with dark spots, and drop early. Stems dieback.	Causes: (i) low organic matter; (ii) nutrient imbalance (excess of calcium, manganese, copper, zinc); (iii) over-watering; (iv) pH too high; (v) root decay; (vi) low levels in soil.
Manganese (Mn)	On palms. Yellowing and brownish streaks. Younger leaves remain smaller than older leaves. Leaves become ragged, shrivelled with scorched appearance. On broadleaf plants — young leaves, yellowing and spotting with green veins. Similar to iron deficiency with both showing on younger leaves first. But in some plants, there is less contrast between veins and interveinal areas and symptoms appear similar to S deficiency.	Causes: (i) high pH; (ii) compacted poorly drained & aerated soils; (iii) low levels in soil.
Molybdenum (Mo)	Older leaves — leaves with yellow mottled margins. Leading to browning of the edges.	Causes: (i) low pH; (ii) low levels in soil.
Zinc (Zn)	Similar to Fe and Mn. Can affect young and old leaves (but rare in palms). Broadleaf plants — young leaves yellowing between veins that remain green (common in citrus). Leaves small, with short distances between leaves (e.g. little-leaf symptom on sweet potato). Cocoa leaves show wavy margins, sickle shaped.	Causes: (i) low and high pH (e.g. sandy and limestone soils; (ii) excess amounts of P; (iii) leaching; (iv) poor water retention and aeration; (v) excessive amount of organic matter; (vi) root damage (pests or diseases); (vii) low levels in soil.

26 Plant Nutrition. Wikipedia. https://en.wikipedia.org/wiki/Plant_nutrition

3.9.3 Deficiency remedies: macronutrients

What to do if the following macronutrient deficiency symptoms are diagnosed:

- **Nitrogen:** Add a mulch or dig in organic matter — compost or well-rotted manure. Grow legume crops, turn in before flowering. If adding an inorganic form, apply ammonium nitrate or ammonium sulphate but check pH as these are acidic. Slow-release products are a good solution but expensive. Organic forms: blood meal, fish meal or well-rotted poultry (chicken, duck, geese) manure[27].
- **Phosphorus:** Add superphosphate, rock phosphate or ammonium phosphate. For organic solutions the addition of well-decomposed poultry manure can be beneficial. Bone meal can also be used, it contains phosphorus and calcium. Till or plough soil.
- **Potassium:** Add potassium chloride, potassium nitrate or potassium sulphate, or slow-release fertilisers; for organic sources use mulches of seaweed or well-decomposed poultry manure.
- **Calcium:** Add fertilisers with good sources of calcium, e.g. bone meal, lime (calcium carbonate) or gypsum (calcium sulphate). Bonemeal is used as a slow-release organic fertiliser, supplying calcium and phosphorus to plants.
- **Magnesium:** Add magnesium sulphate (Epsom salts). This is mined from dry lake deposits and it also occurs in limestones, in dolomite (calcium magnesium carbonate) especially, although this common natural source is not as soluble as magnesium sulphate. A foliar spray with Epsom salts is a possibility (approximately one tablespoon per 4 L water). Adjust if low pH.
- **Sulphur:** Add calcium sulphate, commonly found as gypsum, ammonium sulphate, calcium sulphate, or elemental sulphur.

3.9.4 Deficiency remedies: micronutrients

What to do if the following micronutrient deficiency symptoms are diagnosed:

- **Boron:** Add organic matter. Foliar sprays with borax or boric acid are commonly used. Adjust pH. See Nitrogen correction.
- **Copper:** Spray foliage with copper sulphate.
- **Iron:** Improve drainage (use raised beds), lower pH if soil is alkaline, increase well-decomposed organic matter and mix into the soil – soil becomes more acidic as the organic matter decays. For a foliar spray, use ferrous sulphate.
- **Manganese:** Similar cultural practices as for iron deficiency. Foliar sprays of manganese sulphate.
- **Molybdenum:** Fertilise using sodium molybdate.
- **Zinc:** Improve cultural practices and condition of soil, in similar way to iron deficiency (above). Zinc sulphate foliar spray.

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27 Fresh poultry manure can burn crops and also contain Salmonella. It must be well composted (preferably hot) before use.

Exercise 3.16: Deciding on nutrient deficiencies

Trainers should collect samples of known deficiencies as far as possible as well as using Figs. 3.20-3.30 for the trainees to examine.

Also ask the local agriculture department if there are any known nutrient deficiencies they are aware of, and can give you some examples.

- trainees should carefully **describe the symptoms**
- then use the description in Table 3.3 above to try to decide on the **possible nutrient deficiencies** that might be present.

Your answers — nutrient deficiencies

Plant	Symptom (veins, leaves, fruit, other parts)	Possible deficiencies

Exercise 3.17: Data from soils from three Pacific countries — Fiji, Samoa and Tonga

These data comes from the Pacific Soil Portal[28].

- trainees should analyse the data in Tables 3.4-3.6 and complete the table below to compare the three soils, adding in their ideas about the soil quality.

Your answers — comparing three Pacific soils

Soil location	Source of soil (parent material)	Texture	Soil pH	Fertility	Minerals present	Minerals lacking	Drainage/ flooding	Soil quality - good for growing crops?	Soil amend -ments necessary
Fiji									
Samoa									
Tonga									

Table 3.4: Fiji — Sigatoka

Soil parent material	River alluvium from basic and intermediate rocks
Soil profile(horizon) texture	0-25 cm clay loam 25-35 cm silt loam 35-100 cm clay loam >100 cm fine sandy clay loam
Minimum effective rooting depth	>150 cm
Soil pH (acidity)	0-150 cm — slightly acid
Salinity	Non-saline
Soil fertility under natural conditions	Low organic carbon (C) values Low potassium (K) values in subsoils
Soil moisture regime	Moisture can sometimes be limiting, but is present at a time when conditions are suitable for plant growth (known as 'ustic')
Soil drainage	Well drained
Susceptibility to water-logging	Subject to short duration water-logging during periods of low frequency major flood events. Water table >125cm from surface at all times
Susceptibility to flooding	1 in 10-year return period for major floods contributing minor amounts of sediment. Days under water: 4 to 7

[28] Pacific Soils Portal https://psp.landcareresearch.co.nz/

Exercise 3.17: continued...

Table 3.5: Samoa — Lata Hill

Soil parent material	Basalt from volcanic lava
Soil profile texture	10 cm stony clay loam 20 cm very stony clay Base very rocky clay
Minimum effective rooting depth	<50 cm
Soil pH (acidity)	Strongly acid (pH = 5.1)
Salinity	Non-saline
Soil fertility under natural conditions	Moderate fertility. Base saturation 65% topsoil, 35% subsoil. Potassium (K) very high but very low in subsoil
Soil moisture regime	Without a dry season — precipitation exceeds evapo-transpiration in all months, but soil is not saturated for long periods (known as 'perudic')
Susceptibility to drought	Very weak to no dry season (seldom 1 month <100 m rainfall) Rainfall 3250-5000 mm
Soil drainage	Well drained
Susceptibility to water-logging	Never water-logs
Susceptibility to flooding	Never floods

Table 3.6: Tonga — Na Nuku'alofa

Soil parent material	Not given
Brief soil profile description	0-17 cm black coarse sand; 17-50 cm yellowish brown coarse sand; on coral limestone
Soil profile texture	Not given
Minimum effective rooting depth	50 cm
Soil pH (acidity)	Moderately alkaline
Salinity	Not given
Soil fertility under natural conditions	High in organic carbon (C) and nitrogen (N) in A horizons; phosphorus (P) high to very high
Soil moisture regime	Not given
Susceptibility to drought	Dries out in dry periods
Soil drainage	Excessively drained
Susceptibility to water-logging	Not given
Susceptibility to flooding	Not given

Exercise 3.18: Review — what have trainees learned so far about their soils?

Now your trainees have covered a lot of information, it is a good time for them to bring together all they have learned so far about their own soil samples, and soil in general.

- ask them to **complete the table below**, adding in the results for the whole class
- it is also a good time to **add any new information** to the charts on the wall.

Your answers — comparing class's soils

Soil	Colour Ex. 3.1	Smell Ex. 3.1	Texture/ Com-position from triangle Ex. 3.6	Water holding capacity Ex. 3.7	Comp-action High, medium, low Ex. 3.8	Organic matter High, medium, low Ex. 3.11	Micro-organisms present (fungi, bacteria) Ex. 3.12	Soil pH Ex. 3.15	Overall health rating 1=poor 5=good	Re-mediation needed
1										
2										
3										
4										
5										
Tas-manian	dark brown	earthy	silt 100%	82%	low	high	fungi, bacteria	5.5	4	Raise pH with dolomite or lime

3.10 The plant microbiome

The term 'plant microbiome' describes the whole diversity of microorganisms both within and on the outside of plants and their interactions. It plays key roles in determining plant health and, through its influence on agricultural production and other life processes, human health.

The plant microbiome can be divided into three regions according to location:

- rhizosphere (1-10 mm of soil immediately surrounding roots)
- endosphere (within the plant), and
- phyllosphere (on and within the aerial parts — leaves, stems, flowers and fruits).

Here, we concentrate on the first two regions, and the microorganisms that are associated with soil.

3.10.1 The rhizosphere

The rhizosphere is colonised by bacteria (and the bacteria-like archaea), fungi, oomycetes (p. 75), viruses, algae, protozoa and nematodes. Within this thin layer of soil around roots, complex interactions between microbes and plant take place for the benefit of both. Mycorrhizal fungi are of great importance here and are estimated to be associated with 80% of the world's plants. They are indispensable for the cycling of nitrogen and phosphorus from the soil to plants and, consequently, indispensable for plant growth and health. They are attracted to root exudates — mucilage, sloughed off cells, gases from other organisms, and the sugars, amino acids and organic acids released.

The number of species of mycorrhizae present in any one place, and the quality of the plant microbiome, depend on many biotic and abiotic factors, such as the composition of the plant exudates, soil moisture, organic matter, soil structure, soil type, pH, soil salinity, pollutants, and agricultural practices. It is becoming clear that the chemicals produced by the rhizosphere — nutrients, hormones, enzymes, auxins, flavonoids, antibiotics, volatiles — affect important biochemical functions of plants and hence plant health. In a changing climate this is important because of the stresses that it will place on plant growth caused, for instance, by drought, flooding, attacks by insect pests and pathogens, or by inappropriate cropping systems. Ultimately, what happens in the rhizosphere, but also in the endosphere and phyllosphere, will affect the health of plants and hence humans and other animals. In the next two sections we describe the endosphere and activities of mycorrhizae.

3.10.2 The endosphere and mycorrhizae

The endosphere is colonised by microorganisms that enter and live within roots. They are called 'endophytes'. Bacteria, fungi and archaea are active here, with the first two groups predominating. They live in stems, leaves and roots. The majority are beneficial, entering cells to obtain essential nutrients and gain safety within their hosts. In return, they provide chemicals which plants cannot otherwise obtain.

Fungi known collectively as 'mycorrhizae' are of two kinds: ectomycorrhizae, which do not penetrate plant cells, and arbuscular mycorrhizae which have sac-like structures (called arbuscules) that grow from their mycelium and enter plant cells[29]. Both types of mycorrhizae exchange nitrogen, phosphorus, and other chemicals from the soil with products of photosynthesis manufactured by the plant.

However, the role of mycorrhizae in storing the products of photosynthesis in the soil and mitigating the impact of the climate crisis are sometimes overlooked. We have already said that 75% of the carbon on land is stored in soils. Key to this are the two types of mycorrhizal fungi, with arbuscular mycorrhizae playing the dominant role[30]. It is conservatively estimated that 13.2 gigatonnes of CO_2 fixed by plants is stored by these two kinds of mycorrhizae each year, though there will be losses due to respiration and decomposition. That is more than 35% of the current annual CO_2 emissions from fossil fuels, an extraordinary amount[31].

Further, mycorrhizal fungi release carbon and nitrogen-containing exudates as they grow through the soil, and these become an important store of stable carbon within the soil aggregates. When mycelium of fungi die, the network remaining becomes a scaffold for the formation and stabilisation of soil aggregates. Soil particles become attached to these scaffolds, aggregate (crumb) size increases and organic matter is protected from decomposition.

3.10.2.1 Ectomycorrhiza

About 2% of plants form an ectomycorrhizal relationships, usually woody types (trees and shrubs). The fungi do not penetrate the cells, instead, they form an external sheath of hyphae (the filaments that make the mycelium) around the root — known as the 'mantle' (Fig. 3.31). Hyphae from the sheath extend several centimetres into the soil, which significantly increases the volume of soil from which nutrients and water are extracted.

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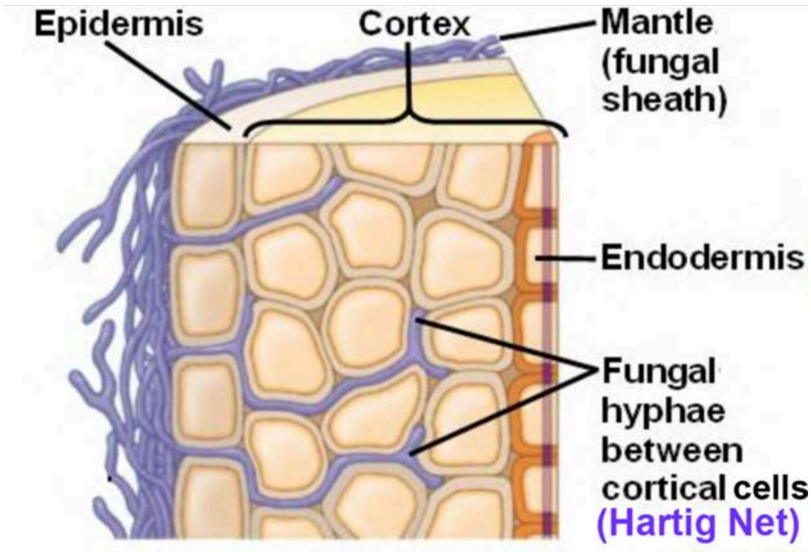
29 Wikimedia. Arbuscular mycorrhiza seen under microscope. Flax root cortical cells containing paired arbuscules. https://commons.wikimedia.org/wiki/File:Arbuscular_mycorrhiza_microscope.jpg

30 Hawkins Heidi-Jayne, *et al.* (2023) Mycorrhizal mycelium as a global carbon. Current Biology 33. http://creativecommons.org/licenses/by-nc-nd/4.0/

31 Nine A (2023) Fungi store a third of the world's fossil fuel emissions underground. ExtremeTECH. https://www.extremetech.com/science/fungi-store-a-third-of-the-worlds-fossil-fuel-emissions-underground

Fig. 3.31 Ectomycorrhiza. Schematic representation of an ectomycorrhiza colonisation of a root. Hyphae of the fungus are present over the root (blue) forming the mantle and penetrating the root to form the Hartig net where exchange of nutrients occurs. *Source: Wikimedia Commons. Atrebe10. Basic morphology of a common ectomycorrhizal association (modified).*



The hyphae enter through the outer layer of cells — the epidermis — and form a network of hyphae between it and the cortex, called the Hartig net[32].

This is the area where the exchange of nutrients from the plant and soil occurs. It is estimated that ectomycorrhizal fungi receive approximately 15% of the products of photosynthesis from the host plant and the host plant receives more than 80% of its nitrogen needs via the fungal net.

3.10.2.2 Arbuscular mycorrhiza

About 80% of plant families have arbuscular mycorrhizal associations (AM)[33]. The fungi penetrate the cortical cells and form 'arbuscules' — highly branched fungal structures (Fig. 3.32). They are especially important in transfers of phosphorus, sulphur, nitrogen, micronutrients and water from the soil into plants. AM fungi have other important roles: they are involved in reducing the impact of plant stresses, such as those caused by salinity[34] and attacks by soil-borne insects and pathogens. They are also suppliers of the soil protein, 'glomalin', the glue-like substance which is important in soil structure.

Interestingly, colonisation of roots by AM is helped by the plant[35]. It is not a chance occurrence. Roots produce hormones which stimulate AM spore

32 Ectomycorrhiza. Wikipedia. https://commons.wikimedia.org/wiki/File:Ectomycorrhiza_illustration.jpg.

33 Wikipedia. Arbuscular mycorrhiza. https://en.wikipedia.org/wiki/Arbuscular_mycorrhiza

34 *Rhizophagus iranicus* var. *tenuihypharum*. Wikipedia. https://en.wikipedia.org/wiki/Rhizophagus_iranicus_var._tenuihypharum

35 Jacott J, Murray JD, Ridout CJ (2017) Trade-offs in arbuscular mycorrhizal symbiosis: disease resistance growth responses and perspectives for crop breeding. Agronomy 7(4): 75). https://doi.org/10.3390/agronomy7040075

germination, mycelial growth, branching and root recognition. Further, the external cells of the root guide the fungus to where entry into the root should take place. Once inside the root, the hyphae travel through the epidermal cells to the cortex and enter the cortical cells where they form the branched arbuscles.

Note that overcultivation (ploughing or tillage) reduces the surface area spanned by the fungal hyphae and exposes them to air which dries them out. This lowers the amount of phosphorus delivered to plants through the fungal network.

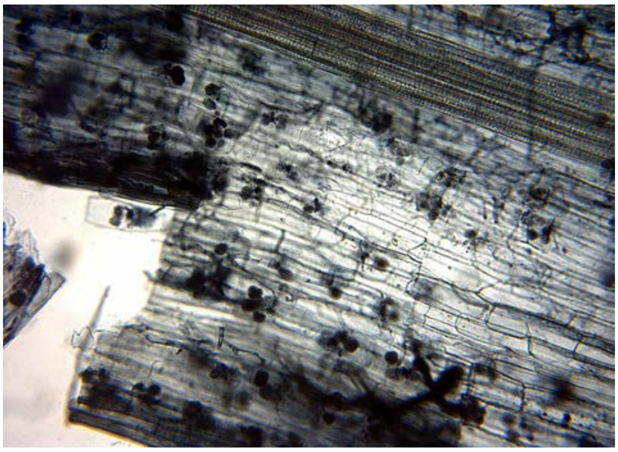


Fig. 3.32 Arbuscular mycorrhiza (AM). Flax root cortical cells containing paired arbuscules. Most plants have evolved this symbiotic relationship with AM. Where the fungus hypha touches the root a flat 'appressorium' forms and from that an infection peg grows into the cell.

Source: Wikimedia Commons. MS Turmel University of Manitoba, Plant Science Department.

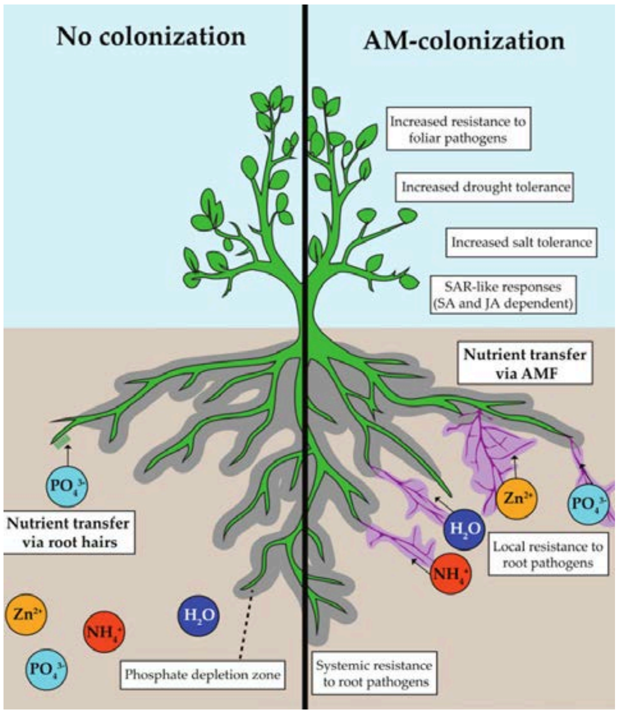


Fig. 3.33 Benefits of arbuscular mycorrhiza (AM). The network of hyphae of AM extends beyond the immediate vicinity of the root, accessing a larger area of soil for phosphate uptake. Nitrogen (ammonium) and zinc are also sourced in the same way. The benefit of AM colonisation includes improved tolerances to abiotic (mainly salinity and drought) and biotic stresses (mainly soil-borne pathogens). Research shows plants have developed immune systems somewhat similar to animals. Plant hormones (e.g. salicylic acid and jasmonic acid) are produced in response to infection and other stresses, and systemic resistance responses occur throughout the plant.

Source: Wikimedia Commons. Catherine N. Jacott. Positive effects of arbuscular mycorrhizal (AM) colonization.

3.10.2.3 Soil microorganisms, carbon dioxide and soil health

As we have seen, microbial activity is essential for soil health. Because they produce carbon dioxide during respiration, the quantity of microorganisms in soil can be measured by the amount of CO_2 they produce. The amount of CO_2 is also directly linked to nitrogen mineralisation. The test to measure the CO_2 level used is called the 'CO_2 burst'. Dried, weighed samples of soil are wetted with a specific amount of water, which triggers a burst of carbon dioxide which is measured over a 24-hour period. The amount of CO_2 burst is proportional to the mass of microorganisms. It is also related to the potential release of nutrients such as nitrogen and phosphorus that are components of plant residues, microbes and humus. Unfortunately, this test cannot be carried out without specialised equipment (Fig. 3.34)[36].

CO_2 respiration is an indicator of soil health. The quantity of CO_2 released over a specific period is generally regarded as an accurate indicator of healthy soil functioning. Depleted soils tend to have very low CO_2 emissions. The 'turnover rate' of CO_2 increases with improved management practices, including the use of legume cover crops and the addition of organic matter (e.g. compost and animal manures).

Exercise 3.19: Analysing CO_2 burst test results

These are some results from an actual CO_2 burst test.

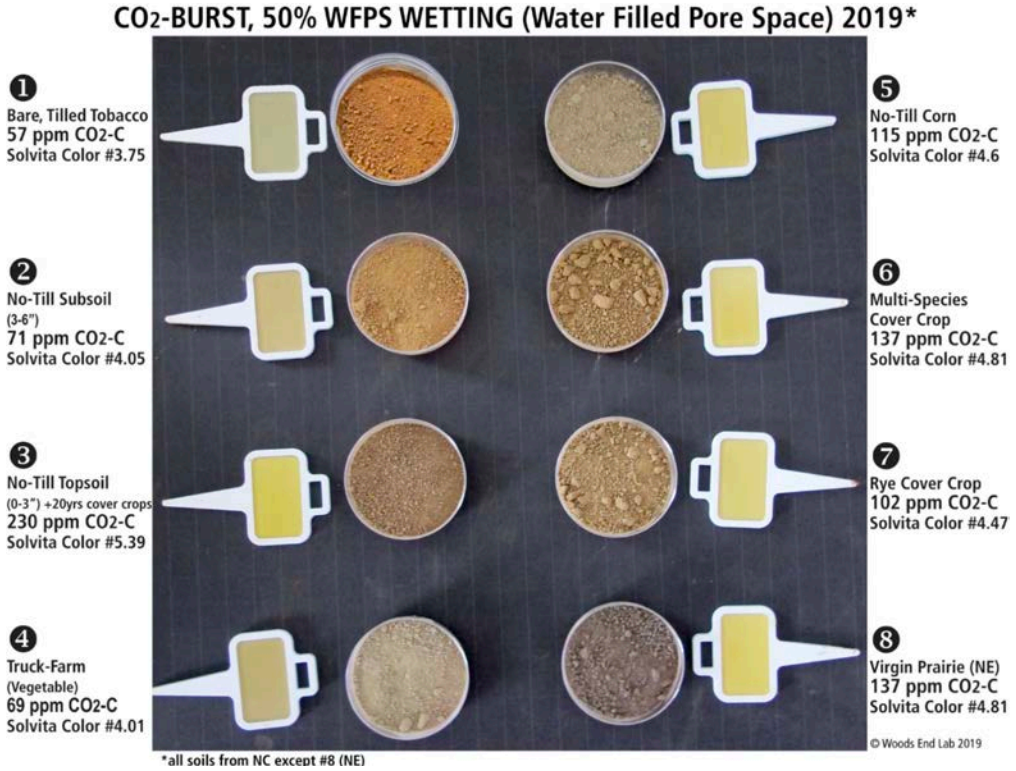
- what can your trainees conclude about the soil health and treatment of soil from these results?
- discuss with the class.

CO_2 burst test

Crop / treatment	CO_2 burst (ppm)
Maize, no till	115
Vegetables, truck soil	69
Topsoil, cover crops for 20 years	230
Multi-species cover crop	137
Subsoil (below topsoil) no till	71
Virgin grassland	137
Rye cover crop	107
Tobacco, tilled	57

36 Solvita CO_2-Burst. Measure CO_2 Respiration. https://solvita.com/co2-burst/

Fig. 3.34 Solvita CO_2 burst test colours provides the means for commercial laboratories to easily and efficiently measure CO_2 respiration from dried, sieved soil once rewetted. *Source: CO_2-Burst Measure CO_2 respiration. Solvita.*



3.10.3 The plant microbiome and soil-borne plant pathogens

In describing the rhizosphere, we noted its complexity, the vast numbers of microbes present, its diversity and the interactions which occur[37]. Other parts of plants are colonised by microorganisms, but not to the same extent as the rhizosphere. We also noted the close relationship between the microbes present, and the important roles of specialist fungi, mycorrhizae, that have a symbiotic relationship with plants, where the partners exchanged substances that they are unable to manufacture themselves. We also mentioned the other kinds of organisms present, and that plants produce root exudates that result in the selective colonisation of certain kinds of microbes. Mycorrhizae are important here, too. In general, the plant species and the exudates they produce determine the composition and structure of the rhizosphere microbiome.

However, plant exudates also contain compounds that both attract bacteria to the plant rhizosphere and nourish them once they are there (e.g. species of *Acidobacteriota, Bacteroidota, Planctomycetota, Pseudomonadota, Actinomycetota*).

Similarly, fungal species known to be plant-growth supporting, occur in the rhizosphere (e.g. *Penicillium, Phoma, Trichoderma, Fusarium, Aspergillus*).

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[37] Plant microbiome. Wikipedia. https://en.wikipedia.org/wiki/Plant_microbiome

Some fungi are also involved in defensive roles, for example, an isolate of *Fusarium oxysporum* (the non-pathogenic kind) was found to be attracted to root exudates of tomato, and antagonistic to the root knot nematode, *Meloidogyne incognita*[38].

Interestingly, particular soil types have been noted for providing crops with resistance to plant pathogens. They are called disease-suppressive soils. In Cameroon, for example, 'young' volcanic soils (andosols) are suspected to be suppressive to cocoyam *(Xanthosoma sagittifolium)* root rot disease caused by the oomycete pathogen, *Pythium myriotylum*[39]. By contrast, plants grown in a different soil type (iron-rich ferralsols) were susceptible to the disease. Andosols partly lost their suppressiveness when autoclaved and could recover suppressiveness following recolonisation by their original microorganisms.

The role of a healthy microbiome in reducing attack by plant pathogens is relatively well known, but the importance of protozoa and viruses, perhaps, has not been so well studied until recently. Studies on tomatoes have shown that protozoa can have an important role either directly by feeding on pathogens, or indirectly by altering the composition of bacterial communities by their predation. Viruses can also be manipulated to play a role in disease prevention. Work also on tomato infected by bacterial wilt, *Ralstonia solanacearum,* found a decrease in disease of up to 80% was possible by manipulating bacteriophage populations, i.e. viruses that infect bacteria[40].

In summary, we can list a number of ways that microbes can be used by plants in their defence against pathogens: antagonism, competition for nutrients or sites (such as the rhizosphere), or defence responses (Fig. 3.35)[41]. Antagonistic microbes do not allow other kinds to grow in their vicinity: they may be fast growing, utilising nutrients and limiting their use by competitors, or they may regulate hormonal levels of their host so that the plant develops a resistance to the potential pathogen. This is biocontrol of the utmost value, so we need to ask how sensitive it is to changes in the environment.

38 Sikora R, Dababat AEF (2007) Influence of the mutualistic endophyte Fusarium oxysporum 162 on Meloidogyne incognita attraction and invasion. Nematology 9: 771–776. doi: 10.1163/156854107782331225

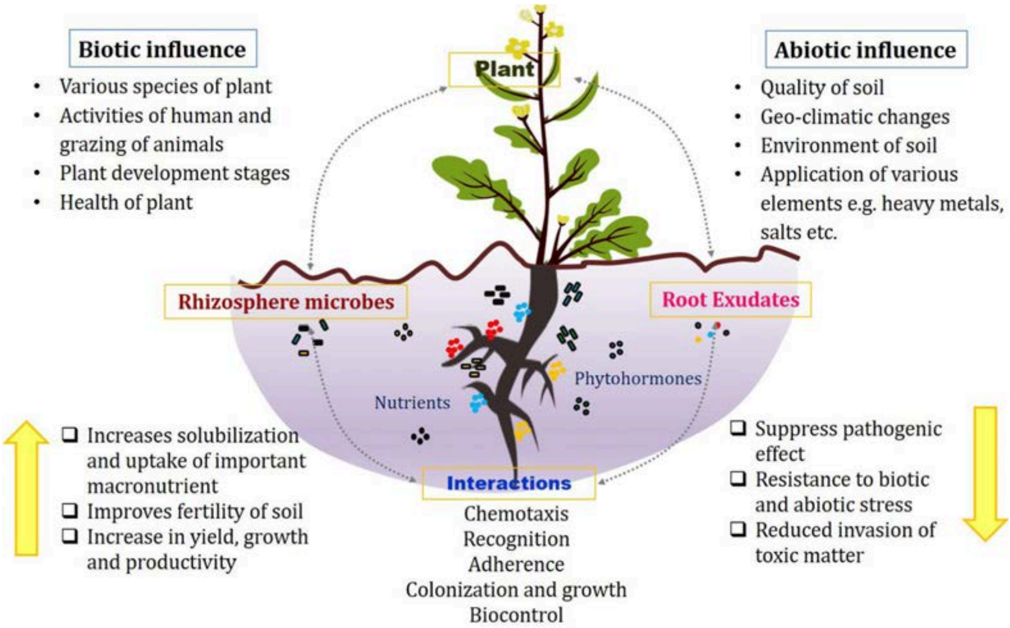
39 Adiobo A, *et al.* (2007) Variation of Pythium-induced cocoyam rot severity in response to soil type. Soil Biology and Biochemistry 39(11): 2915-2925.

40 Song C, Zhu F, Carrion V, Cordovez V (2020) Beyond Plant Microbiome Composition: Exploiting Microbial Functions and Plant Traits via Integrated Approaches. Bioeng. Biotech3l. 8. https://doi.org/10.3389/fbioe.2020.00896

41 Vishwakarma K, Kumar, N, Shandilya C, Mohapatra S, Bhayana S, Varma A (2020) Revisiting Plant— Microbe Interactions and Microbial Consortia Application for Enhancing Sustainable Agriculture: A Review. *Frontiers in Microbiology.* 11. (doi:10.3389fmicb.2020.560406. PMC 7779480. PMID 33408698).

Fig. 3.35 Rhizosphere. Associations of the rhizosphere — plant roots, root exudates and microbes, under biotic and abiotic influences. This whole system is the plant–root microbiome. The conclusion is that plants have evolved to control the microbiome in a way that is beneficial to their reproductive success.

Source: Kanchan Vishwakarma et al. Associations in the rhizosphere between plant roots, microbes, and root exudates under biotic and abiotic influences.



3.10.4 Climate change and the plant microbiome

Of immediate concern is how the climate crisis might affect plant-soil microbiome interactions. There is evidence that it could be very serious[42]. Microorganisms in the soil and rhizosphere will be affected directly by rises in temperatures[43] and by droughts, and indirectly by changing host responses if the relationships between microorganisms and plants come under stress. There will be changes to host physiology, morphology, exudation patterns and immune responses, that will result in threats to plant health[44]. However, the specific ways that the climate crisis is working its way through the complex ecological interactions between plants and pathogens, between plant microbiomes and pathogens, and between plants and their microbiomes, are not yet clear.

42 Trivedi P, Batista B, Bazany K, Singh B (2022) Plant–microbiome interactions under a changing world: responses, consequences and perspectives. New Phytologist. https://doi.org/10.1111/nph.18016

43 IPPC report predicts rise in temperature between 2.6 to 4.8°C by 2100. Intergovernmental Panel on Climate Change. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014). https://epic.awi.de/id/eprint/37530/

44 Singh BK, Delgado-Baquerizo M, Eleonora Egidi, Emilio Guirado, Leach JE, Liu H, Trivedi P (2023) Climate change impacts on plant pathogens, food security and paths forward. Nature Reviews Microbiology 21: 640–656.

Ultimately, it will be investigations into the changes that occur in gene expression between hosts and pathogens that will determine the impact of a changing climate, an area of research likely to take advantage of rapidly evolving molecular sequencing techniques. The aim will be to understand the interactions between plant-associated microbes, as well as the composition of important microbial populations that impact plant health in different types of soils and under different environmental conditions[45].

However, the threat of climate change to plant-soil microbiome interactions is not the only concern. Far from it. The Alliance of World Scientists and the Scientists' Warning movement was established to alert humanity to the impacts of human activities on global climate and the environment, specifically its impact on microorganisms which "support the existence of all higher trophic life forms"[46]. In 1992, 1,700 scientists signed the first warning; in 2017 a second warning was published signed by 15,000 scientists and today 21,000 have endorsed the warning. The Consensus Statement of September 2019 "documents the central role and global importance of microorganisms in climate change biology. It also puts humanity on notice that the impact of climate change will depend heavily on responses of microorganisms, which are essential for achieving an environmentally sustainable future".

Under a section entitled 'Terrestrial biome', the Statement lists many of its characteristics as a way of reminding us of its importance, and ways a warming climate will affect it:

- soils store ~2,000 billion tonnes of organic carbon, more than the combined amount of carbon in the atmosphere and vegetation
- the total number of microorganisms in terrestrial environments is $\sim 10^{29}$
- soil microorganisms regulate the amount of organic carbon stored in soil, the amounts released back to the atmosphere, and they indirectly influence carbon storage in plants and soils through provision of macronutrients
- plants provide a substantial amount of carbon to symbiotic mycorrhizal fungi and in many ecosystems, mycorrhizal fungi are responsible for substantial amounts of nitrogen and phosphorus uptake by plants
- plants remove CO_2 from the atmosphere through photosynthesis, creating organic matter that fuels terrestrial ecosystems. Conversely, respiration by plants and microorganisms releases CO_2 back into the atmosphere.

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45 Babalola O, Fadiji A, Enagbonma B, Alori E, Ayilara M, Ayangbenro A (2020) The Nexus Between Plant and Plant Microbiome: Revelation of the Networking Strategies. Frontier. Microbiol 11. https://doi.org/10.3389/fmicb.2020.548037

46 Cavicchioli R, *et al.* (2019) Scientists' warning to humanity: microorganisms and climate change. Nature Review Microbiology 17: 569–586. https://doi.org/10.1038/s41579-019-0222-5

The overall conclusion of the Consensus Statement is that temperature influences the balance between two opposing plant processes:

i. removing CO_2 from the atmosphere through photosynthesis and creating organic matter to fuel terrestrial ecosystems, and
ii. respiration by plants and microorganisms to release it back into the atmosphere — temperature alters this balance to capture and store anthropogenic (human-derived) carbon emissions — currently, storing approximately one quarter of it — the climate crisis is expected to accelerate carbon release into the atmosphere, bring about changes to microbial diversity and put at risk a system that supports global ecosystems. The hope for a sustainable future is not assured.

We have looked at the functions of soil, its structure, texture, and some of the interactions that occur between plants and microbes. We have some idea of what is needed to produce healthy plant growth, i.e. to produce nutritious and safe food for people and animals. Unfortunately, many soils cannot do this: they are not healthy, so they are unable to support healthy plant growth. They have become degraded. This might mean the soils have lost organic matter, structure, texture, or changes in salinity and pH have occurred, or there has been a build-up of toxic chemicals, such as pesticides and pollutants. How soils become unhealthy is the topic of the next section.

3.11 Degraded or unhealthy soils

Soil degradation is defined in the 2015 Status of the World's Soil Resources Report as the "accelerated removal of topsoil from the land surface through water, wind and tillage"[47]. Each year, ten million hectares of cropland are lost to soil erosion[48], and the UN has estimated that about one-third of the world's farmland has been lost in the last four decades both to soil degradation and the expansion of human settlements.

Erosion by wind and water has the greatest impact on soil degradation. They remove the fertile topsoil, exposing the lower levels and reducing crop yields through nutrient loss. Soil degradation occurs naturally in all continents, but it is accelerated (up to 1000 times) by human activity. Crop yields may be 10% lower by 2050 compared to the present day, and climate change will only make the situation worse.

3.11.1 Causes of soil degradation

According to a 2019 FAO report on soil erosion, the major causes of soil degradation are unsustainable agricultural practices, such as over-cultivation, i.e. tilling or ploughing, overgrazing, deforestation and improper

[47] AO and ITPS (2015) Status of the World's Soil Resources (SWSR) – Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

[48] Pimentel D, Burgess M (2013) Soil erosion threatens food production. Agriculture 3(3): 443-463.

land use[49]. Because it takes millions of years to form, soil is essentially a finite resource that is being lost faster than it is being replenished. Years of degrading agricultural practices, often promoted by agrochemical companies and the so-called Green Revolution, have led to soils becoming little more than inert support material for plants. Soils have been over-tilled, and large amounts of inorganic fertilisers and pesticides have killed the soil microbiome. Too many soils now lack the organic matter, nutrients, living organisms and good structure to support healthy plant growth.

3.11.1.1 Cultivation or tilling

If land is cultivated too often, especially in times of low rainfall, it causes a loss of the microbial 'glues' that hold the aggregates together. The topsoil becomes more like dust and is stripped away by wind and water, leading to erosion and, in extreme cases, to dust bowls or desertification. Alternatively, if cultivation is done when the soil is very wet, depending on the soil type, there is also the possibility of compaction. Here, the compression of soil particles leads to reduction in the size of pores, resulting in less air, lower water movement through the soil, and poor root penetration.

3.11.1.2 Burning crop residue

Traditionally, many cultures have burned crop residues after harvest in the belief that it is the most cost-effective way to stimulate growth and clear land for the next crop. However, these blazes and the wildfires that can spread from them, are the world's largest source of black carbon — carbon particles in the atmosphere that are a threat both to human and environmental health. Agricultural burning also reduces water retention and soil fertility by 25 to 30%, meaning that farmers have to invest in expensive fertilisers and irrigation systems to make up for nutrient and water loss[50].

3.11.1.3 pH and salinity

Other causes of soil degradation result from build-up of acidity or from salinity — the build-up of salt levels.

Acid soils have low phosphorus and high aluminium availability. They occur in subtropical and tropical regions with high rainfall in old soils where intensive agriculture is practised. Common causes are the addition of acidic ammonium-based nitrogen fertilisers and leaching (loss) of nitrate (NO_3^-) nitrogen.

Salinity occurs where irrigation practices are poor, especially in arid regions. High rates of evaporation occur in soils with high water tables caused by over-irrigation. The water table rises, bringing dissolved salts that accumulate at the soil surface as a salt-laden impervious 'hardpan'. This can also occur in drylands where shallow-rooted crops replace natural vegetation and cause a rise in the water table with dissolved salts.

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49 FAO (2019) Proceedings of the Global Symposium on Soil Erosion 2019. Rome.

50 https://www.unep.org/news-and-stories/story/toxic-blaze-true-cost-crop-burning

Indicators of soil salinity that can be observed include[51]:

- patchy crop growth
- bare soil
- salt crystals on the soil surface
- puffy, dry soils
- presence of salt tolerant species and weeds
- light grey or white colours on the soil surface
- crops in some areas within a field take longer to grow.

3.11.1.4 Pesticides

Many pesticides, whether herbicides, insecticides or fungicides, are broad-spectrum, meaning they do not discriminate, but act against a range of plants, insects and fungi, both beneficial and pest. Insecticides, for instance, are mostly nerve agents, stomach poisons, or act on cell membranes, and do not destroy only the targeted pest. They also kill organisms which are part of the soil food web (micro and macroorganisms) essential in making nutrients and other chemicals available to plants.

As well, synergistic effects are known, where one pesticide, for example a herbicide, is used with or close to the time when an insecticide is used. In this case, 'synergistic' means that the combined effects are greater than if the chemicals were used individually.

In general, pesticides should be used as little as possible and only as a last resort, and then the least toxic products to the chosen environment. This is discussed further in Chapters 5 and 6.

[51] FAO (2020) Soil testing methods — Global Soil Doctors Programme - A farmer-to-farmer training programme. Rome. https://doi.org/10.4060/ca2796en

3.12 Soil health management — improving and maintaining soil health

> "Agriculture is one sector that has the ability to transform from being a huge emitter of carbon to actually being 'climate-positive' by drawing down more carbon than it emits; effectively, playing a hugely important role in re-balancing the carbon cycle"[52].

In recent decades, the world has seen a rise in understanding how damaged soils impact plant health and, therefore, human and animal health. Healthy soil must be able to:

- grow healthy crops, without being attacked by pests and diseases
- produce nutritious food crops
- hold together to prevent erosion
- hold water, but drain any excess quickly
- store carbon.

The USDA tells us that "managing for soil health (improved soil function) is mostly a matter of maintaining a suitable habitat for the myriad of creatures that comprise the soil food web". This can be accomplished by disturbing the soil as little as possible, growing as many different species of plants as practical, keeping living plants in the soil as often as possible, and leaving the soil covered all the time[53].

If, according to the USDA, maintaining the organisms of the soil food web is most important in the management of soil health, then organic matter deserves special attention[54]. Quoting the USDA again: "because organic matter enhances water and nutrient holding capacity and improves soil structure, managing for soil carbon can enhance productivity and environmental quality". It goes on to say: that "managing for soil carbon" can reduce the severity and costs of natural phenomena — drought, flood, and pests and diseases and, in addition, increasing soil organic matter levels can reduce atmospheric CO_2 that would otherwise contribute to climate change.

Many farmers now recognise the impact and indicators of soil degradation. They understand that by changing agricultural practices soil health will be restored ensuring future food and nutritional security. However, this is not always easy due to economic circumstances. It can be costly and requires long-term changes such as tolerating lower crop yields for a time. For many farmers it is easier and cheaper to implement short-term solutions, such as continuing to till the soil, use pesticides and inorganic fertilisers containing mainly NPK (nitrogen, phosphorus and potassium), causing a further reduction in soil carbon.

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52 https://theregenerators.org/rachels-farm/what-is-regen-ag/#regenag

53 USDA Natural Resource Conservation Service. Soil health Management. https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/soils/soil-health/soil-health-management

54 USDA Natural Resource Conservation Service. Manage for soil carbon. https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/soils/soil-health/manage-for-soil-carbon

There is also a difficulty in accessing information about the problem for some farmers. This is why it is important for extension officers to have a good understanding about soil. Today, a number of practices are being widely used that restore soil health and maintain fertility, called ‘nature-based solutions’. These try to copy the way natural systems work. They are being promoted in many parts of the world to regenerate degraded soils and then to look after them. Nature-based solutions are variously known as ‘conservation tillage’, ‘regenerative agriculture’, or ‘agroecology’. They all have in common an ecosystem-based approach, in other words, they focus on the diversity of the living organisms in soils and their physical environments.

There are several important practices that aim to maintain healthy soil; these are discussed below.

3.12.1 Low or no cultivation or tilling

If soil is tilled (i.e. dug over or ploughed) too frequently, its delicate structure is destroyed, especially if it is turned over with a mouldboard plough (Fig. 3.36)[55]. Many beneficial organisms are killed and the soil becomes susceptible to compaction and erosion. Ploughing should be avoided when the soil is very wet when compaction or formation of soil clods (large, hard to break pieces of earth) is likely.

Conservation tillage promotes little or no disturbance to the soil (Fig. 3.37)[56]. Instead, crop residues are often left to rot down after harvest, rather than being ploughed in. This helps maintain the soil microbiome and prevents loss of topsoil.

Fig. 3.36 Ploughing.

The purpose of ploughing is to turn over the uppermost soil, bringing fresh nutrients to the surface while burying weeds and crop remains so they decay. This can be very destructive to soil organisms.

Source: Wikipedia. Amanda Slater. Ploughed field. The Forest of Arden Agricultural Society 62nd Hedging and Ploughing Match.

55 Plough. Wikiwand. https://www.wikiwand.com/en/Plough

56 EOS Data Analytics. No-till farming: Methods & how they affect agriculture. https://eos.com/blog/no-till-farming/

Fig. 3.37 No-till. Crop grown in soil that has not been tilled.
Source: EOS Data Analytics. N-till farming.

Minimising the amount of disturbance to soils is beneficial to re-forming their health, while providing energy sources for microbes to develop soil aggregates. But it is not enough on its own. As we have said at the beginning of this section, building organic carbon through increasing organic matter is key, and we repeat it here:

- increase in soil organic matter provides a food source for microbes, which can aid in the regeneration of soil structure — increasing organic matter can also help increase nutrient retention, infiltration (of water) rates, and water storage in loosely packed soils — if possible, keep a living crop in the ground for as long as possible or plant a cover crop after harvest in order to provide food for soil microorganisms — feed the soil food web (see Fig. 3.10) at all times
- choose crops with different root depths and rooting types as they can aid in breaking up compacted soil — diversity is key to creating and maintaining healthy soils: different crops create a diversity of plant carbohydrates which supports a diversity of soil microorganisms — alternatively, add composts, a key way of putting organic matter back into the soil.

3.12.2 Composts

Composts are made of organic materials that have been decomposed by microorganisms such as bacteria and fungi. These require oxygen to work properly. Plant material, animal manure and household food waste, can be turned into compost. Compost is added to the soil where it continues to decompose, to improve its structure and to add carbon and nutrients.

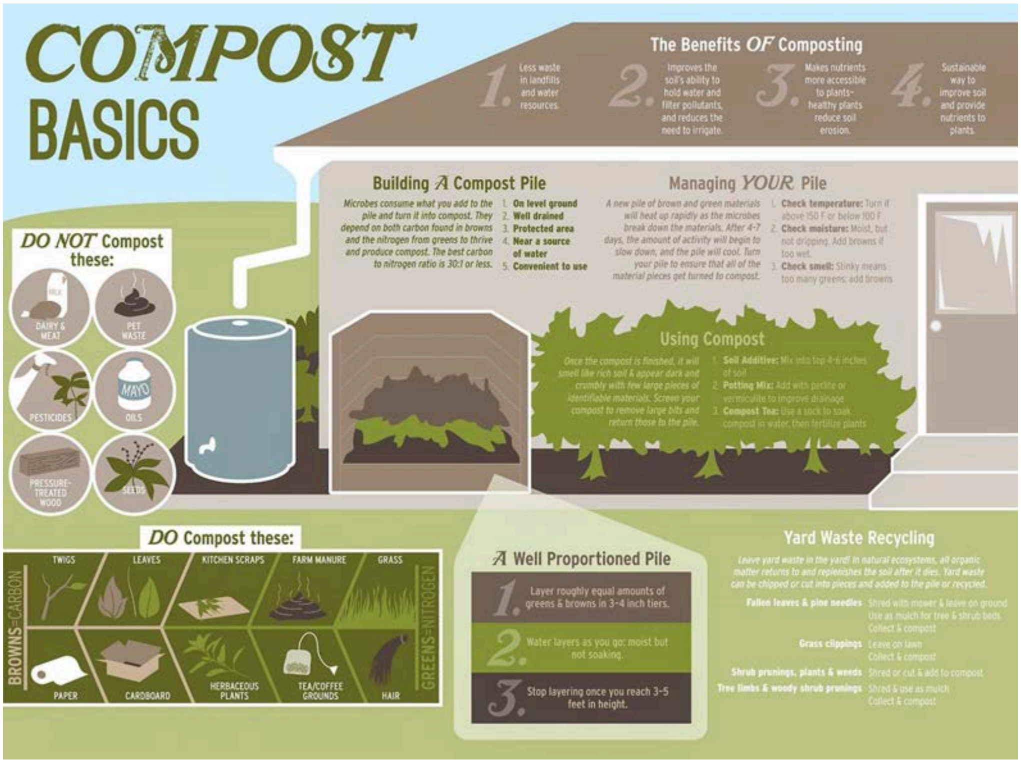
Composting organic materials such as farm and food waste, instead of allowing them to degrade and produce carbon dioxide, is an important way of keeping carbon in the soil and helps towards climate change mitigation. In the Pacific, there is much green and brown waste that could be used for compost instead of being left to rot down or burned.

3.12.2.1 How to make a hot compost

Hot composting is a quick way to make compost. It is also good for killing weed seeds, pathogens, and breaking down pesticides. Composting requires gathering a mixture of green and brown waste materials (Fig. 3.38). Green waste materials are rich in nitrogen, such as leaves, grass, food scraps and animal manure. Brown waste is woody materials rich in carbon, such as stalks, paper, straw, dried leaves and grasses, twigs and wood chips[57]. The ratio of green to brown should be about 1:25 by weight, and water should be added as the materials are mixed. The various components should be shredded to allow maximum access of microorganisms and air.

The green and brown materials break down into humus very quickly. The compost gets hot over a few days due to the action of aerobic (oxygen-requiring) microorganisms (Fig. 3.39). The heap should be a minimum of 1 m³ in size to ensure it retains the heat that builds up. It needs to be turned after a few days to make sure the microorganisms have enough oxygen. Also, it may get too hot. Both high temperatures (above 70°C) and lack of oxygen allow growth of anaerobic organisms. If these take over, the heap will begin to smell bad, and nitrogen will be lost.

Fig. 3.38 Hot compost in the tropics. Use both green and brown organic materials in alternate layers as well as thin layers of animal manure if available for the most efficient composting. Keep the heap damp but not wet and sprinkle each layer with dolomite lime. *Sources: Waldo Greiner. Compost basics.*



[57] Dennis Hearne. Best ways to make compost in the tropics. Tropical House & Garden. https://tropicalhousegarden.com/best-ways-to-make-compost-in-tropics/

Exercise 3.20: Practical activity — making hot compost

You need to time the building of the compost carefully. It takes about 3-4 days to heat up, so decide when it should be started.

What equipment do I need?

- ❑ site for building the heap — under cover if possible, and out of the sun
- ❑ **carbon-rich material:** usually brown in colour — dried leaves, straw, other dried materials. Shredded or small pieces of material work best. Dead stalks need to be pounded or shredded to break them up.
- ❑ **nitrogen-rich material:** food scraps, animal manure, green plant materials: grass clipping, leaves
- ❑ garden fork
- ❑ bucket or hose to provide water
- ❑ broom handle or wooden pole.

Building the compost

- build the compost heap by **adding alternative layers** of carbon and nitrogen materials
- **water each layer** before adding the next
- build to at least **1 m^3 in volume**
- **push a pole** into the centre of the heap.

Maintaining the compost

A. **After 1-2 days**, pull out the pole and feel it to see if the heap is heating up. If not, it probably needs more water. A good heap should operate between about 55-70°C to destroy pathogens and weed seeds.

B. The heap needs to be **turned after a few days** to make sure the microorganisms have enough oxygen.

C. **If it is too hot** and begins to smell bad, it means anaerobic organisms have taken over and nitrogen is being lost. If this happens, turn the heap using a fork to allow oxygen to enter.

D. **If the heap starts to dry out**, add some water but do not soak it.

E. **Check after a few days.** The material should be breaking down into black humus.

Fig. 3.39 Hot compost. A steaming compost heap after a few days due to the action of microorganisms. The heat will destroy most pathogens, weeds, weed seeds and roots. It produces a fine compost product.

Source: Deep Green Permaculture. Hot composting.

Fig. 3.40 A hot compost heap in the making.
Source: authors.

Fig. 3.41 Earthworms in a cold compost. Remember to keep it aerated by forking every few weeks. Large pieces of the original plant material will not be broken down. It produces a coarse compost. *Source: The unconventional gardener. Eco Garden. Worm composting.*

Fig. 3.42 Large scale composting. An example from South Africa. Farm livestock manure mixed with vermicompost in rows, covered with netting to prevent birds and other animals from feeding on the earthworms. It is mixed regularly using machinery.

Source: farmer's weekly. Large scale composting turns waste into healthy soils.

3.12.2.2 Cold compost

A cold compost can be thought of as a worm farm as worms are important in the decomposition process (Fig. 3.41). They eat the organic matter leaving their faeces ('worm castings' or 'vermicompost') which are rich sources of nutrients. Cold compost takes many months to form, and also includes the action of both macro and microorganisms, such as earthworms. To make a cold compost, you need a frame or container to build it in, and the container must have plenty of aeration.

To build the heap, layers of household scraps and other green material are alternated with layers of brown waste. The layers are built up till the heap is at least 1 m^3 in volume. Weeds that have seeds should not be used as these may not be killed in a cold compost. The compost must be kept aerated by turning it over with a fork every few weeks. It may take up to six months before it is ready, depending on the ambient (outside) temperature.

3.10.2.3 Large scale composting

Making a compost is easy on a small scale but it is more difficult on a large scale as either much labour or machinery is needed (Fig. 3.42). It is possible, however. A farmer in South Africa has shown that by composting manure, it releases nutrients — particularly potassium — in a form that plants can use, rather than applying it in the raw state where nutrients are less available[58]. Additionally, it was found that composting kills off pathogens present in the raw manure. The farm reported that levels of humus increased from 0.3 to 1%; this in turn increased the water-holding capacity of the soil and decreased the potential for wind and water erosion. More recently, the farmer has raised earthworms and now adds vermicompost to the (manure) compost. Finally, to keep the microbes alive the main crops are rotated with mixtures of cover crops, and cattle are allowed to graze the paddocks adding urine and dung to feed the microbial organisms. Synthetic fertilisers are no longer used!

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[58] Lloyd Phillips. Large-scale composition turns waste into healthy soil. Farmer's weekly. (was important to prevent wind and water erosion. https://www.farmersweekly.co.za/crops/field-crops/large-scale-composting-turns-waste-into-healthy-soil/

Exercise 3.21: Practical activity — building a mini worm farm in a bottle

What equipment do I need?

- ❑ 2 L clear plastic bottles, labels removed
- ❑ soil
- ❑ compost
- ❑ sand
- ❑ paper
- ❑ scissors
- ❑ tape
- ❑ worms
- ❑ water (in a spray bottle)
- ❑ worm food: vegetable peelings, shredded newspaper, dead leaves or flowers.

Fig. 3.43 worm farm in a bottle. *Source: Spell OUTLOUD. Observing worms with preschoolers.*

Making the worm farm

- **remove any labels** from the 2 L plastic bottle
- **cut the top** 10 cm off and keep both parts
- **fill the bottle** with alternating layers of sand, soil, sand and compost (or just soil)
- **spray or flick water** on each layer to dampen it (it should not be too wet)
- **wrap paper around the bottle** to make it dark inside for the worms (worms do not like the light) — use a piece of sticky tape to hold the paper in place
- **put the worms** in the bottle and add some worm food
- **put back the top** of the bottle — **wash hands afterwards.**

Maintaining the worm farm

A. **Check the worms daily** by carefully removing the paper. Have they moved or eaten the food? Have the layers mixed?

B. Check that the worms still **have some food** and that the soil is still damp. Add more to the top if necessary.

C. After a few days, empty out the bottle and **examine the worm castings**. **Place the worms back on some soil.**

3.12.3 Animal manures

Well-rotted animal manures (from cows, horses, sheep, pigs, chickens, ducks etc.) can be used as a compost and added into the soil to increase levels of nitrogen and other nutrients. Animal waste needs time to decompose before it is added to the soil, otherwise it may attract anaerobic biodegradation. It usually takes several months to release nutrients that plants can utilise. Chicken manure should always be well composted before use, as it may contain harmful *Salmonella* bacteria. Also, it generates heat as it decomposes, which may damage plant roots.

3.12.4 Mulch

Mulch is made from organic materials such as shredded bark, stalks, leaves, straw, broken up coconut or oil palm husks that are added to the soil as a top dressing. Compost can be a mulch if used in this way. Mulches control the temperature of the soil to protect it from extremes of heat and cold, control weeds, prevent water loss through evaporation, and reduce erosion.

A further advantage of using a mulch is that it prevents heavy rain from splashing pathogenic bacteria or fungi from the soil to the leaves or stems of plants. Rain-splash can move soil particles as much as a metre above the ground.

3.12.5 Cover crops and green manures

Cover crops and green manures are grown specifically to add nutrients to soils that have been planted with crops that require a large amount of nutrients to grow well, for example, brassicas and corn (maize). Cover crops add fertility to soil and are often used as part of a crop rotation.

There are many cover crop mixes and often include legumes (like peas, lentils, and beans such as *Mucuna, Pueraria* and *Glycine)* that will fix nitrogen back into soil (Figs. 3.44, 3.45 & 3.46).

Green manures are crops that are incorporated into the soil, either ploughed in, cropped and put between the next crop as a mulch, or made into manure, compost or silage and used as mulch. This is done before they flower to retain the maximum amount of nutrients in the green part of the crop. Cover crops can also be used as green manures if they are incorporated into the soil directly or after composting.

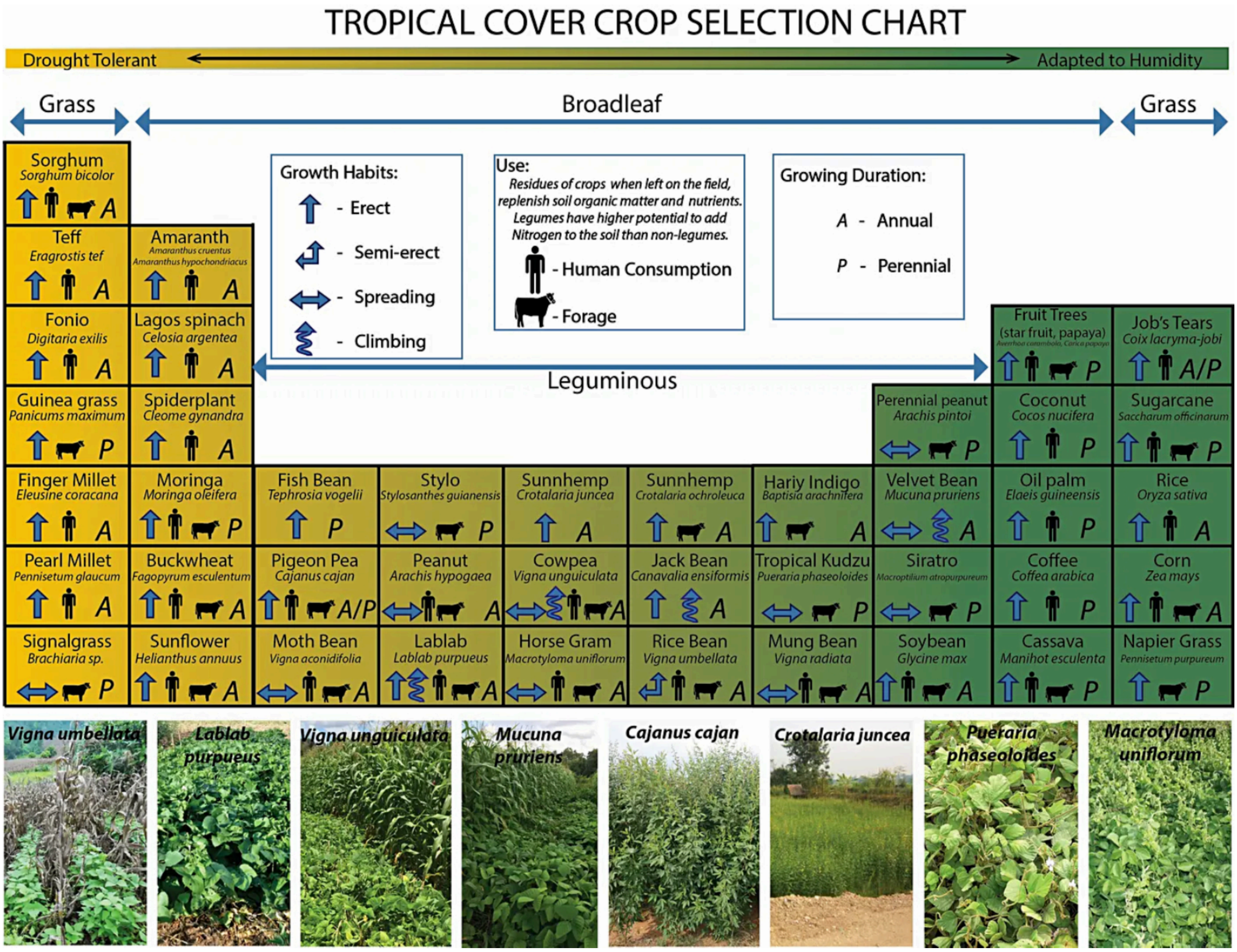
Figs. 3.44, 3.45 & 3.46 Cover crop rotation.
The legume, *Pueraria phaseoloides* (top), is used as a fallow, cleared and planted (middle) to grow intercrops of taro and yam (bottom). Osanti Luda (decd.), North Malaita, Solomon Islands. *Source: authors.*

Fig. 3.47 Alley cropping. Rows (hedgerows) of *Gliricidia* (*Leucaena* is also used) with crops between; here, in Vanuatu, taro is grown. The crops within the alley benefit in a variety of ways: abundant foliage production of the hedgerows provides additional organic matter to the soil as it decomposes; reduced water loss from the soil surface; and nutrient recycling — the hedgerows have deep root systems and being legumes carry out biological fixation of atmospheric nitrogen.

Source: Vincent Lebot, CIRAD, Vanuatu.

Fig. 3.48 *Mucuna pruriens.* An annual vine use as a leguminous cover crop in fallows between crops. Known both for its rapid vigorous growth, use of a forage for livestock, fallow, and a green manure crop to add nitrogen to the soil. It is also known to cause itchiness on contact! *Source: Vincent Lebot, CIRAD, Vanuatu.*

Fig. 3.49 Tropical cover crop selection chart. A range of grasses and legumes that can be grown in Pacific island countries. The chart shows the characteristics of each species and their uses for humans and animals.
Source: echo community. Tropical cover crop selection chart.



3.12.6 Fertilisers

Because minerals are constantly being removed from soils through cropping, they need to be replenished. Mineral fertilisers are synthetic and contain inorganic materials and are often described in terms of the amounts of N, P and K they contain. Some contain micronutrients as well. There are differences between organic and synthetic forms. Organic fertilisers are made from composts and green manures and contain large amounts of carbon as well and other nutrients. The differences between organic and synthetic fertilisers are listed below:

Organically derived fertilisers:

- benefit both plants and soil
- keep carbon in the soil
- generally, they will not burn or damage plants
- stimulate beneficial soil microorganisms and improve soil structure
- provide micronutrients that plants need
- have a lower NPK content; the impact may be slower, but it lasts longer than synthetic forms
- nevertheless, livestock manure contains bacteria, nitrogen and phosphates, that can be carried by rain to waterways.

Synthetically derived fertilisers:

- fast acting and come in a variety of forms, such as liquid, pellet, granule
- water-soluble, and can be taken up rapidly by plants
- may need to be applied repeatedly
- effective on plants, but do little for microbes, to improve soil texture, or to improve long-term fertility
- can make soils too acidic, particularly ammonium-based fertilisers
- can leach into waterways causing algal blooms that de-oxygenate them, killing fish and other wildlife
- usually more expensive than organic forms
- increase the chance that excessive amounts burn plants
- rely on petroleum for their manufacture, a non-renewable fossil fuel resource that generates carbon dioxide when used.

Exercise 3.22: Practical activity — what is in a fertiliser?

If farmers are using bags of fertiliser, trainees need to be able to see what they are adding by reading and understanding the contents of fertiliser bags.

Trainees should then be able to make a decision as to whether the particular fertiliser is good for the soil or not.

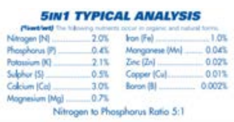
What equipment do I need?

❑ a range of fertiliser bags that are used locally.

Trainees task:

- for each example, trainees should **examine the information** on different bags of organic and inorganic fertilisers — three examples are given
- **discuss the results** with the class in terms of their usefulness in plant nutrition.

Your answers — fertilisers and their components

Fertiliser type for example	Trade name if available	Components	Nutrients contained	Photo if available
Super phosphate	Richgro Super-phosphate	Calcium phosphate	Calcium and Phosphorus	
Urea	Richgro Urea	Urea	Nitrogen	
All purpose plant food — organic fertiliser	Searles 5 in 1 organic fertiliser	 5IN1 TYPICAL ANALYSIS Nitrogen (N) 2.0%; Iron (Fe) 1.0% Phosphorus (P) 0.4%; Manganese (Mn) 0.04% Potassium (K) 2.1%; Zinc (Zn) 0.02% Sulphur (S) 0.5%; Copper (Cu) 0.01% Calcium (Ca) 3.0%; Boron (B) 0.002% Magnesium (Mg) 0.7% Nitrogen to Phosphorus Ratio 5:1	Seems to cover all nutrients	

EXERCISE 3.22: what is in a fertiliser?

3.12.7 Biochar

Biochar is the light black residue, made of carbon and ash remaining after the slow burning of organic matter without oxygen (pyrolysis). It is a stable solid that is rich in carbon and can remain in soil for thousands of years. Biochar is mainly used for soil application and can improve soil nutrient availability, soil aeration, and soil water filtration. It is also very useful for keeping carbon in the soil rather than returning it to the atmosphere as CO_2. Biochar contains a large number of pores in its structure which provides a large surface area for microorganisms to inhabit.

When using biochar, it is important to consider any potential negative effects, such as changing soil pH levels, or introducing harmful chemicals that might cause problems for microorganisms, i.e. if pesticides have been used on the crop from which the biochar is made.

The pH of biochar can range from 4.6 to 9.3, depending on the plant species it comes from and the temperature used to form it. In general, as the biochar production temperature increases, the resulting biochar pH also increases because CO_2 is given off, making it very alkaline. Biochar is useful for raising the pH of acid soils, but for those that are naturally alkaline it may increase the alkalinity too far for many plants. This means it is important to know the pH of a soil and of the biochar before using it.

There is enormous potential for biochar production in the Pacific, as large amounts of carbon-containing waste material is generated, such as coconut husks, oil palm shells and dead tree trunks. Often, this is burned or sent to landfill where it generates the greenhouse gases CO_2 and methane, adding them to the atmosphere.

'Terra preta' is Portuguese for 'black earth' and refers to areas of dark, fertile soil discovered in the Amazon basin (Fig. 3.50). It is thought that the fertility of the area (where soils are not usually very fertile) is due to the use of biochar by the civilisation that lived there some 2,500 years ago. It is not quite the same as biochar, as it is much older and complex[59].

[59] Glaser B, Birk JJ (2012) State of the scientific knowledge on properties and genesis of Anthropogenic Dark earths in Central Amazonia (terra preta de Iindio). Geochinica et Cosmochimica Acta 82:39-51. https://www.sciencedirect.com/science/article/pii/S001670371100144X

Fig. 3.50 Black Terra preta topsoil in the Amazon basin. Within some of the ecosystems of tropical countries there are small patches of highly fertile soils known as Anthropogenic Dark Earths or *terra preta de Índio* (*terra preta*). These soils exhibit high nutrient and soil organic matter.

Source: Glaser B. & Birk J.J. (2012). Geochica et Cosmochimica Acta 82: 39-51.

3.12.8 Crop rotation

Planting the same crop in the same soil for two or more years running is not recommended as it can increase pathogen populations. Planting different crops each time depletes a pathogen's food source. Not only is it important to plant a different crop each time, but also it is important not to plant another crop in the same family as the one grown previously. For instance, do not plant eggplant after tomatoes (both are in the *Solanaceae* family), or cucumber after watermelon (both are in the *Cucurbitaceae* family). It is also good practice to choose crops in the rotation that have root systems that grow to different depths, enabling plants to tap nutrients from different layers. See Chapter 5 for more information on crop rotation.

It is also important to ensure that crops with symbiotic relationships with *Rhizobium* (nodule-forming nitrogen-fixing bacteria) are planted before crops demanding high levels of nitrogen. For instance, planting a leguminous crop, e.g. a bean, before maize. Adding a cover crop in the rotation is also a good idea, although it need not necessarily be one that is grown for pods or seed, but rather grown for incorporating into the soil when it has reached peak growth.

Exercise 3.23: Crop rotation

Direct trainees to read Chapter 5, Section 5.4 Cultural control options for IPDM.

Trainees should carry out Exercise 5.3 from Chapter 5 and discuss their answers with the class.

3.12.9 Soil fumigants

Soil fumigants (biofumigation) kill soil pathogens, and soil with fewer pathogens is healthier for plant growth. Biofumigation has been tried as an agricultural technique: brassica plant tissues (often canola and Indian mustard) are chopped finely and added to soils to release antimicrobial plant chemicals, generally known as 'allelochemicals'. In this case, the chemicals are 'isothiocyanates'. Experimentally, the technique has been used against the bacterial wilt pathogen, *Ralstonia solanacearum,* and also the take-all fungus of wheat, *Gaeumannomyces graminis* var. *tritici*. One difficulty in their use has been to macerate (break up) the brassica leaves enough to break the cells to release the isothiocyanates that act against the pathogens of concern.

Exercise: 3.24: Thinking about all the componenets of healthy soil

This exercise helps your trainees recall all the components of soil that they have learned about in this chapter. The idea that healthy soil is complex cannot be stressed enough. Once the trainees have filled in as much as they can, compare answers and pin the sheets to the wall. Use them to draw attention to the importance and complexity of soil.

- **at the top of a piece of paper**, trainees should write one component that is important to healthy soil (e.g. microorganisms, nitrogen, water, etc.)
- then they **pass the paper to the next person** who writes down one more component underneath the first one and so on, till everyone thinks everything has been included
- now, ask trainees to work through the list and **categorise the components** into:
  - mineral
  - organic components
  - microoganisms
  - macroorganisms
  - nutrients
  - structure
  - others.

Exercise 3.25: Comparing landscapes

Trainees should compare the three pictures in Figs. 3.51-54.

- **ask: what can they see?** which do they think is the healthiest one with the healthiest soil, and why?
- **discuss their answers** with the class.

Your answers — comparing landscapes

Figure no.	Main things you notice	What do you think the soil is like?	Is this farm healthy?	Your reason
3.51				
3.52				
3.53				
3.54				

Fig. 3.51 Small organic farm, Australia.

Source: authors.

Fig. 3.52 Cattle grazed land, Australia.

Source: authors.

Fig. 3.53 Food garden, Kastom Gaden Association, Solomon Islands.

Source: authors.

Fig. 3.54 Sheep grazed land, Australia.

Source: authors.

3.13 The soil microbiome and the 'One Health' concept

'One Health' is a new idea that has come into prominence in recent years with the realisation that humans, plants and animals are all part of the same biological communities (ecosystems) and their lives are closely linked and interdependent. If ecosystems are degraded and unhealthy, they cannot produce healthy food, which affects animals and humans alike. There is no one definition of One Health, as people see the relative importance of the components in different ways. However, a useful definition put forward by the Food and Agriculture Organization of the United Nations (FAO), the World Organisation for Animal Health (WOAH, formerly OIE), the United Nations Environment Programme (UNDP) and the World Health Organization (WHO) by the One Health High Level Expert Panel (OHHLEP) convened under the auspices of the United Nations, is as follows[60]:

> **One Health** is an integrated, unifying approach that aims to sustainably balance and optimise the health of people, animals and ecosystems.
>
> It recognises the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and inter-dependent.
>
> The approach mobilises multiple sectors, disciplines and communities at varying levels of society to work together to foster well-being and tackle threats to health and ecosystems, while addressing the collective need for clean water, energy and air, safe and nutritious food, taking action on climate change, and contributing to sustainable development (Fig. 3.55).

Soil is now seen as a cornerstone of **One Health**. Its microorganisms connect the components, and are essential to terrestrial ecosystem health (Fig. 3.56)[61]. The old saying: "healthy soil means healthy plants means healthy animals and people" is a shortened version of this[62].

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60 Tripartite and UNEP support OHHLEP's definition of 'One Health'. https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health

61 Banerjee S, van der Heijden M (2023) Soil microbiomes and one health. Nature Reviews Microbiology 21 (6-20). https://www.nature.com/articles/s41579-022-00779-w

62 As a generalisation this is true, but there is another side to this, and it involves the production of chemicals by plants in response to stress and the benefit of those chemicals both to the health of plants and to humans and animals. Examples of stressed plants producing higher levels of potentially active compounds are given in the following paper. Hooper PL, *et al.* (2010) Xenohormesis: health benefits from an eon of plant stress response evolution. Cell Stress Chaperones 15: 761-770. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3024065/

Fig. 3.55 Definition of One Health. The diagram shows the relationship between the components of One Health, and that the approach can be applied at different levels in society, relying on shared and effective governance, communication, collaboration and coordination.

Source: WHO. Tripartite and UNEP support OHHLEP'S definition of "One Health". December 2021.

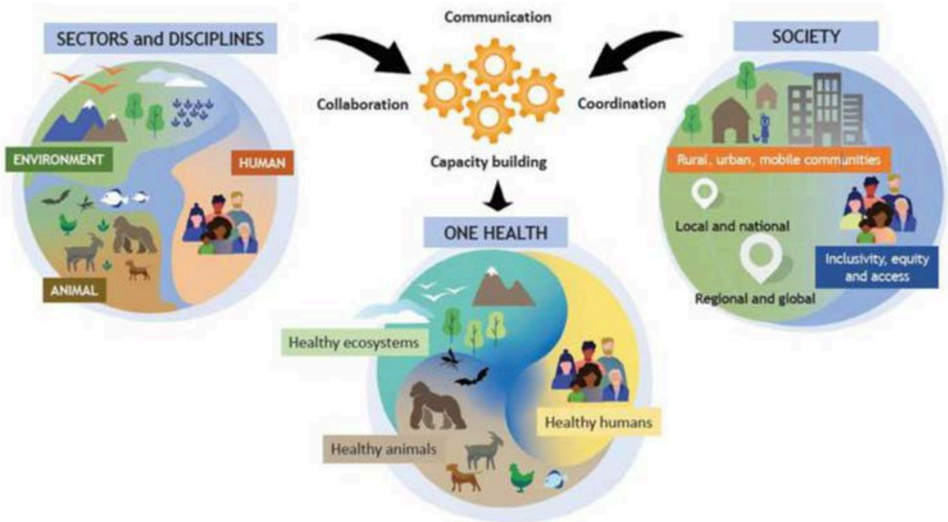
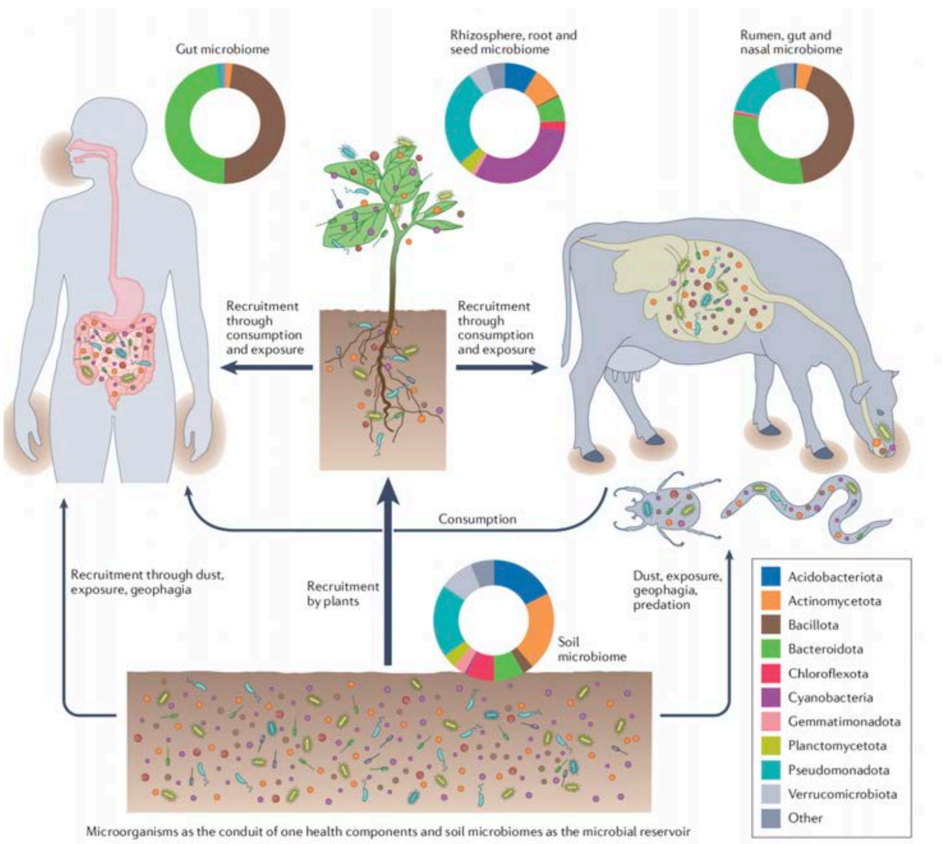


Fig. 3.56 Link between soil, plant, animal and human microbiomes. The diagram shows the way that soil microorganisms are 'recruited' by plants and then pass to humans and animals. The different types (phyla) of bacteria are shown in the coloured rings with a key lower right. The strength of the association is indicated in the width of the arrows. *Source: Nature. Soil microbiomes and one health. Source: Banerjee S. & van der Heijden M.G.A. (2023). Nature Reviews Microbiology 21(6): 6-20.*

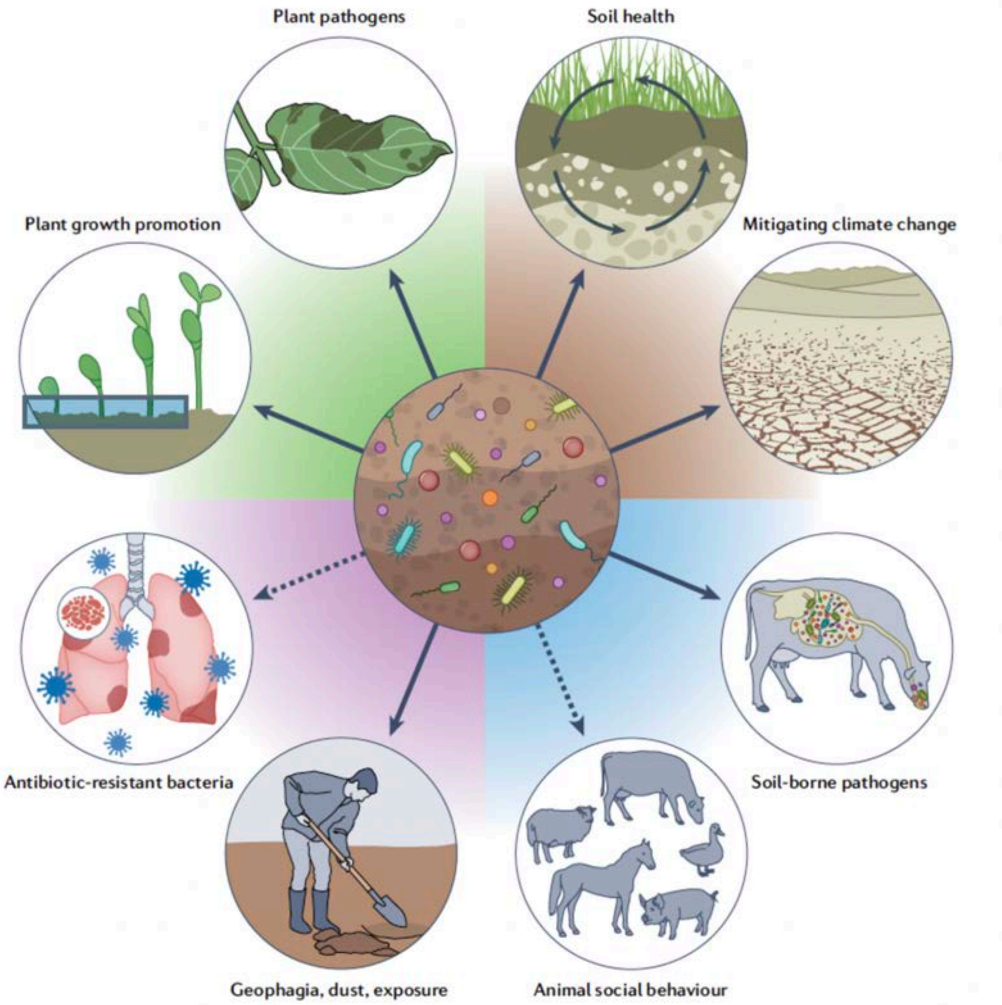


As we have already learned, the soil microbiome is critical to soil health and must be carefully preserved and regenerated where possible. Here, we list some of the interactions that show how interdependent soils, plants, animals and humans are, and how they contribute to the One Health concept.

In terms of soil health, the microbiome is instrumental in several major services: nutrient uptake and cycling (especially N, up to 80%, and P, up to 90%), preventing loss of soil structure, in water purification and carbon sequestration — all functions that are key to food and nutritional sustainability. The concern in recent years is that although more is known about the important role of the soil microbiome in soil health, challenges remain to preserve it. As we discussed earlier, modern agriculture with its strategy of land-use intensification to increase yield is causing loss of organic matter, loss of microbial diversity, loss of structure, and increasing compaction and erosion. These negative impacts undermine One Health and

Fig. 3.57 Summary how the soil microbiome influences One Health. Direct influences are given in solid lines (and mentioned in this chapter), indirect influences are in dotted lines. Effects on i) animal social behaviour draw evidence from gut bacteria influencing behaviour in humans, and ii) knowledge that genes from soil bacteria with antibiotic resistance are being passed to human (and animal) pathogens through e.g. mechanisms of horizontal transfer.

Source: Banerjee S. & van der Heijden M.G.A. (2023). Nature Reviews Microbiology 21(6): 6-20.



look likely to continue, with climate change only making the situation worse. However, some solutions are recognised as discussed earlier, based on a move to nature based approaches, including using fewer synthetic pesticides and mineral fertilisers, reducing intensive tillage, improving microbial biodiversity, and increasing crop diversity rather than repetitive monocultures. These solutions work with nature rather than against it, but putting them into practice in the time scale required is another matter.

The soil microbiome influences One Health in many ways (Fig. 3.57). However, not all components of the microbiome are beneficial. Plant pathogens exist there, too, such as important disease-causing fungi *(Fusarium, Rhizoctonia, Verticillium),* oomycetes *(Phytophthora, Pythium),* bacteria *(Erwinia, Pseudomonas, Ralstonia),* viruses *(tobamoviruses)* and nematodes *(Hirshmanniella, Pratylenchus, Radopholus).*

There are also many examples to show that the soil microbiome is important for animal health (not covered in this manual). For example, sheep are known to consume some 400 g of soil per kg body weight per year, and for dairy cows it is 350 kg of soil per cow per year. Further, 3% of the composition of the rumen microbiome of sheep and cows comes from soil. Eating soil is known among many other animals, including birds.

Insects, too, benefit from the soil microbiome, directly from soil or by eating plants, although the former is the more important pathway. In these ways, insects have obtained chemicals that give them the ability to detoxify insecticides. The soil microbiome also impacts animal health by way of its reservoir of animal diseases, just as occurs in plants. Several soil-borne pathogens, including anthrax, are transmitted as animals graze.

In terms of human health, the contribution of the soil microbiome can be just as extensive[63]. For example, among peoples of Asia, Sub-Saharan Africa, Europe, Central and South America and the Pacific islands there are those who eat soil. It is especially common in children and some think it may be important for the development of the gut microbiome[64]. So, perhaps, the English saying "that you have to eat a peck of dirt before you die" may not be a myth after all (or that some pregnant women crave clay or coal!) More substantive is the fact that farmers and farm animals inhale soil particles and soil microorganisms through dust, and observations that the mouth, nose and skin microbiomes of farmworkers are "associated with the soil microbiome composition of their farms".[65] There is growing evidence that exposure to soils is likely to result in people suffering less from allergic reactions, asthma, dermatitis and hay fever, whereas the immune systems of those living in urban areas may not have received sufficient exposure to be primed to resist these medical conditions.

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63 Banerjee and van der Heijden. MGA (2023) Soil microbiomes and one health. Nature Review, Microbiology, 13-14.

64 Krisch JA (2018) Parents should let kids eat dirt. It's good for the biome. https://www.fatherly.com/health/let-kids-eat-dirt-gut-health

65 Banerjee and van der Heijden, op.cit., p.8.

Humans also receive trace elements originating in the soil via plants and animals, such as zinc and selenium, as well as the nine amino acids and essential vitamins that we cannot produce ourselves. But just as pathogens exist in soils that infect plants and animals, there are also fungi that cause diseases in humans, as well as diseases caused by protozoa (e.g. amoebic dysentery), nematodes (e.g. hookworm), and bacteria (e.g. anthrax and tetanus).

However, it is the comparison between the plant rhizosphere and the human gut that connections are, perhaps, of most interest. Although the overlap between the species of bacteria in the two locations is not extensive, the links in terms of their similar functions are more obvious:

- both are systems with relatively vast surface areas (root hairs in plants and intestinal microvilli in humans)
- they are both open to the environment with large populations of microbes and micro-environments
- both respond to levels of oxygen, water and pH
- both are influenced by the genotype and age of the host
- both impact the immune system, providing protection against pathogens
- their health is related to the diversity of their microbiome
- both are provided continually with high energy nutrients by their hosts[66].

In summary, the plant rhizosphere and human gut are undeniably extremely important to health, producing essential amino acids and vitamins, B12 and K from the gut, and hormones that promote resistance to stress (drought, pathogens) in plants.

Finally, we leave this chapter with a quote from a recent issue in the New Scientist magazine which we thought was rather appropriate to end on, even if a little dismal[67]:

> "SCOOP up a handful of soil and you hold an entire ecosystem in the palm of your hand. That precious clod might not be much to look at with the naked eye, but it is teeming with life. A gram of soil contains around a billion single-celled organisms, including tens of thousands of different species, and if you could tease out the fungal strands, they would stretch for hundreds of kilometres. These are indispensable to life on Earth, including you and me. If they all died, we would soon follow."

But they ARE dying. Therefore, it is up to us all in the agriculture community to care for and regenerate our precious soils wherever we can. Remember what Franklin D Roosevelt said!

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66 Blum WFH, *et al.* (2019). Does soil contribute to the human gut microbiome? Microorganisms. 7: 287. (doi:10.3390/microorganisms7090287).

67 Lawton G. (2003). The hidden extinction. New Scientist No. 3434: 15 April.

The following exercises 3.26, 3.27, 3.28 and 3.29 are to check for understanding at the end of this chapter. Choose as many as necessary. These types of exercises can be as easy or as difficult as you decide to make them and can be carried out at any point during the training to strengthen learning.

Exercise 3.26: Creating a concept map

See Chapter 8, Section 8.5.3 for details on concept mapping.

- in pairs or in a group, trainees should **create a concept map** with lines linking at least 8 of the following terms
- trainees should **write how they are related** on the linking lines.

Soil	Carbon	Bacteria	Earthworms	pH
Texture	Mycorrhiza	Molybdenum	Fertility	One Health

Exercise 3.27: What am I?

What equipment do I need?

- ❑ sticky tape
- ❑ cards with words that you would like your trainees to understand, for example:
    - Mycorrhiza
    - Endophyte
    - Agro-ecology
    - Cover crop
    - Manganese
    - One Health
    - Water holding capacity
    - Weathering
    - Soil horizon
    - Vermicompost
    - Crop rotation
    - Microbiome
    - Carbon sequestration
    - Loam
    - pH
    - Aggregate
    - Archaea
    - Biochar
    - Hartig net

- using sticky tape, **stick a card with a word** on the back of each trainee
- instruct them **not to look at it**
- they should move around the room to **try to find out what their word** is, by asking questions, to which the answer is ONLY 'yes', 'no' or 'sometimes/ maybe'.
- trainees should **sit down when they have worked out** their word.

Exercise 3.28: Match the term to the definition

This can be done in pairs or individually, then trainees should compare answers.

Term	Definition
1. Mycorrhiza	A. Fungus that lives inside a plant cell
2. Endophyte	B. Amount of water that a soil can hold measured in grams of water/ gram of soil
3. Agro-ecology	C. Fertiliser produced by worms
4. Cover crop	D. Network of fungal hyphae
5. Manganese	E. Carbon formed by the anaerobic combustion of plant material
6. One Health	F. Decomposed organic matter in soil
7. Water holding capacity	G. Small clumps of soil
8. Weathering	H. Breaking down of rocks into small particles
9. Soil horizon	I. The application of ecological principles to make agricultural systems more sustainable
10. Humus	J. All the microorganisms present in soil
11. Vermicompost	K. A soil that is a good mixture of sand, silt and clay
12. Crop rotation	L. Idea that all life forms are interconnected and affect each other
13. Microbiome	M. A necessary micronutrient for plant health
14. Carbon sequestration	N. A type of microorganism, part of the soil microbiome
15. Loam	O. The level of acidity
16. pH	P. Carbon held in soil
17. Aggregate	Q. Crop planted to be ploughed into soil as a fertiliser
18. Archaea	R. Network of hyphae between epidermis and the cortex in a plant root
19. Biochar	S. Layers of soil from surface downwards
20. Hartig net	T. Sequence of crops grown that keep soil healthy, prevent pests and diseases and provide nutrients

Exercise 3.29: Applying learning about soils — giving a farmer advice

This exercise challenges your trainees to bring together their learning about soil to give advice to a farmer, something they may need to do at a PHC.

They should choose one of the three scenarios below and list everything they could do to create the healthiest soil possible for that farmer. Make sure all three scenarios are covered by the class. Trainees should discuss their ideas with the class. This exercise also relates to Exercise 7.9 in Chapter 7.

SCENARIO 1: Watermelon on the Guadalcanal plains, Solomon Is

The farmer reports:

- the field used to be grassland, it was burned before the first crop was planted
- since then, three crops of yam were grown in the field, one crop of sweet potato, and now watermelon, one crop after the other
- the watermelon plants are yellow
- on examination, the older leaves are first to become yellow.

Possible diagnosis with reasons

- what can the farmer do now?
- what can the farmer do in the longer term?
- reasons?

SCENARIO 2: Tomatoes in Fiji

The farmer reports:

- there was an unusually long dry season
- then we had a long spell of rain
- many fruit began to rot at the flower end
- what's the cause of this? what's happening to my fruit?

Possible diagnosis with reasons

- what can the farmer do now?
- what can the farmer do in the longer term?
- reasons?

Exercise 3.29: continued...

SCENARIO 3: Banana in Kiribati

The farmer reports:

- my banana, the mother plant, has a yellow leaf, it started yellowing from the base towards the tip
- in some parts its light green and yellow, like stripes
- even the midrib of the mother leaf has turned yellow; that was the last to go
- the young plant, the sucker, is now almost all yellow on all leaves; before it was yellowish green and yellow in stripes like its mother, only the midribs are green
- it's a worry because I might not get any fruits!

Possible diagnosis with reasons

- what can the farmer do now?
- what can the farmer do in the longer term?
- reasons?

CHAPTER 3 QUIZ: Test your knowledge

Multiple choice. Pick one answer only…

1. Sand particles are:

A. the largest particles in soil and float on the top of water
B. the smallest particles in soil and float on top of water
C. the largest particles in soil and sink in water
D. the smallest particles in soil and sink in water

2. Organic matter in soil is found in:

A. the bedrock
B. humus
C. clay
D. water

3. Which of these are NOT normally found in the soil microbiome:

A. archaea
B. bacteria
C. worms
D. fungi

4. Fungi that live inside the cells of plants are called:

A. endophytes
B. mycorrhizae
C. spores
D. microbiome

5. Soils with plenty of organic matter are likely to be rich in:

A. carbon
B. magnesium
C. potassium
D. iron

6. Which of these are NOT ways in which nitrogen can be made available to plants:

A. nitrogen fixing bacteria
B. using leguminous cover crops
C. drawing in nitrogen from the atmosphere
D. applying fertiliser

7. 'One Health' refers to:

A. the health of people in the Pacific
B. the idea that the health of all life forms is interconnected
C. how bacteria affect plant roots
D. the health of soil

8. The term 'aggregate' refers to:

A. soil particles bound together in clumps by organic matter and microbes.
B. all the layers in a soil horizon
C. compost
D. the total of minerals in a particular soil

9. A soil has a pH of 8. Which three minerals are likely to be less available to plants?

A. K, S, Fe
B. Mn, Cu, Zn
C. Ca, Mg, Mo
D. N, Ca, Mn

10. A soil contains 30% clay, 30% silt and 40% sand. It is best described as:

A. silty loam

B. compost

C. clay loam

D. sandy clay

11. The symptoms on this yam leaf (right) suggest:

A. nitrogen deficiency

B. boron deficiency

C. it is the normal colour of the leaf

D. sulphur deficiency

12. Practices that contribute to soil health are:

A. cover crops

B. flooding

C. use of pesticides

D. raising soil pH to above 8

13. Physical weathering of soil refers to:

A. minerals within rocks reacting with water, air or other chemicals.

B. splitting of rocks through temperature changes and collisions of rocks with each other

C. breakdown of rocks by living organisms

D. ploughing the soil

14. Which of these is not true:

A. *Mucuna pruriens* can be used as a cover crop

B. a plant under stress is less resistant to disease

C. a soil with a pH of 7.5 is slightly alkaline

D. compost requires a carbon to nitrogen ratio of about 1:25

15. The plant's rhizosphere includes:

A. roots, root exudates and microbes

B. rhizomes

C. flowers and leaves

D. compost.

Chapter 4

Diagnosing Unknowns Using Digital Platforms

This chapter covers a range of digital platforms available for plant health doctors to use for identification and diagnosis of plants pests and diseases.

What equipment do I need?

- ❑ smart phone or tablet
- ❑ membership of Plant Health Doctor social media group — WhatsApp, Messenger or Viber
- ❑ access to PestNet via
  - ◦ the website — https://www.pestnet.org
  - ◦ a mobile device
- ❑ Pacific Pests, Pathogens & Weeds app
- ❑ hand lens.

In Chapter 2, your trainees worked through the 'possible and probable' process for the diagnosis of pests and diseases. However, trainees and even experts, will come across symptoms that they cannot diagnose. These are the 'confused and/or unknowns' (the 'C' in A, B and C).

Confused and unknowns come about for a number of reasons:

- lack of experience with pests and diseases of the different crops
- too many symptoms are present and there may be more than one pest or pathogen present (i.e. the sample is confused)
- a problem has occurred that has not been seen in the area for some time (the sample is unknown)
- a problem has never been seen before, as it is newly arrived in the area or the country (the sample is unknown).

Chapter 4 introduces your trainees to digital resources to help them diagnose symptoms of pests and diseases that are confused or unknown. These resources are:

- WhatsApp (Messenger or Viber) groups
- PestNet
- The Pacific Pests, Pathogens & Weeds app.
- KoboToolbox and KoboCollect for PHC prescription data collection.

4.1 Country plant doctor networks

WhatsApp and other social media groups have been set up in Fiji, Samoa, Solomon Islands, Tonga and Vanuatu. These groups include extension, research and biosecurity staff as well as national and overseas experts, to assist in diagnosing unknown or confused pests and diseases. Images of problems encountered at a PHC or in the field, are posted via a smartphone or tablet for identification. The plant doctor can also ask the network questions about all aspects of plant protection. This means that information on diagnosis and management of problems can be easily and cheaply shared. As well, many of the problems in the Pacific islands are now known and captured in the Pacific Pests, Pathogens & Weeds app with sufficient information for digital diagnosis. Hence, focus can be directed to confused or unknown cases to save cost, time and effort.

WhatsApp and similar networks are ideal for extension staff and others to deal with unknowns for the following reasons:

- exchanges between members are rapid
- they can be used in the field or at PHCs to contact experts when extension staff need help in making diagnoses or management decisions
- they provide a list of the pests and diseases of a particular crop in a locality, and alert plant health doctors to be prepared for problems farmers are likely to bring to a PHC
- the information collected can be databased and used to build a knowledge bank of crop pests and diseases, location, frequency and relative importance, for research and training purposes. In time, this database will become an essential tool for plant health doctors and the plant health system in general.

Other benefits of these networks include:

- promotion of the use of digital tools to complement plant protection research in filtering or prioritisation of field sampling and laboratory diagnoses
- improving communication and networking of members
- serving as a platform for continuous refreshing and updating of knowledge/information related to pest ID and management
- providing aid to early warning and pest alert systems to support Biosecurity authorities
- supporting further development of the Pacific Pests, Pathogens & Weeds app by supplying quality pictures and/or potential subjects for factsheets, and to update information on existing factsheets, wherever applicable.

4.1.1 How to send a photograph and information for diagnosis

Good quality pictures are essential for accurate diagnoses. Doctors need to practice their camera skills and always choose the best, clear and in-focus picture(s) from the gallery to post to WhatsApp

Plant doctors should take a picture using the WhatsApp app and send it directly to the group.

Either a picture, record audio, or a video of the problem can be taken, but pictures are probably the best especially where internet costs are high.

The images need to be of sufficient quality to show fine detail. Taking images through a x10 pocket lens can add important details, and is useful for tiny insects, mites and sporulating fungi.

A number of pictures may be necessary for accurate diagnosis, so doctors should take a picture of the whole plant as well as the parts affected wherever possible. Also, where possible, images of the plants in the field are helpful in making a diagnosis, especially if they show the pattern of infestation.

The sender should also add details about the image(s) that include:

- date picture was taken
- location
- weather conditions – hot/cold; wet/dry
- information on the host plant — parts infected, the extent of the infection
- estimate of how many or what percentage of plants are infected
- whether it is a new problem
- a possible diagnosis.

You DO need a Wi-fi connection to upload a photo to a social media group. If you do not have one, you can still take a photo and then send it later when you have internet access

Fig 4.1, Fig 4.2, Fig 4.3 and Fig. 4.4 show images sent to a country WhatsApp , Viber and Messenger group for diagnosis. Not all of great quality, but good enough for comment and possible diagnosis.

Fig. 4.1 A post on WhatsApp Fiji from a plant health doctor: is it anthracnose? And a response: it is more likely sunscald? *Source: authors.*

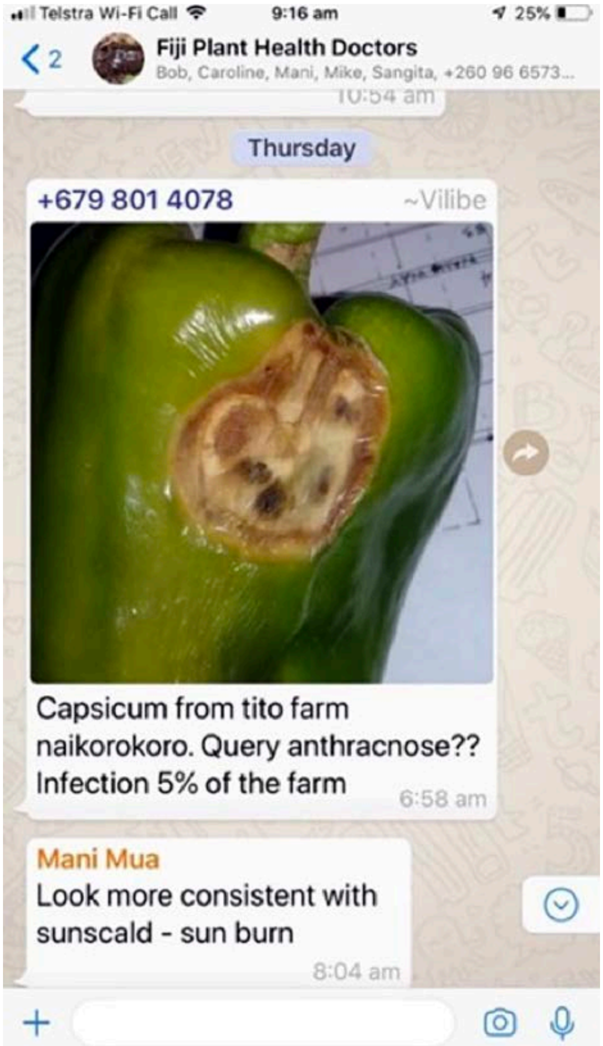


Fig. 4.2 Images from WhatsApp showing a cushion scale and nymphs from eggplant (top), and busy plant health doctors making a diagnosis (below). *Source: authors.*

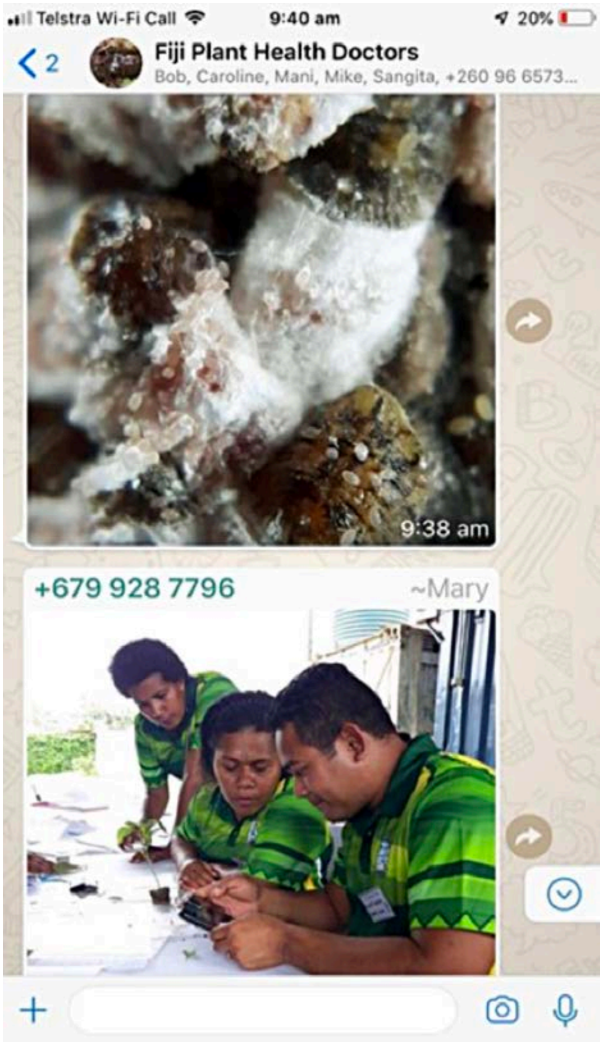


Fig. 4.3 What is the cause of marginal necrosis on pearl guava, Nabitu. Can it be K deficiency? Taken on Viber (Fiji). *Source: Ministry of Agriculture and Waterways. Fiji.*

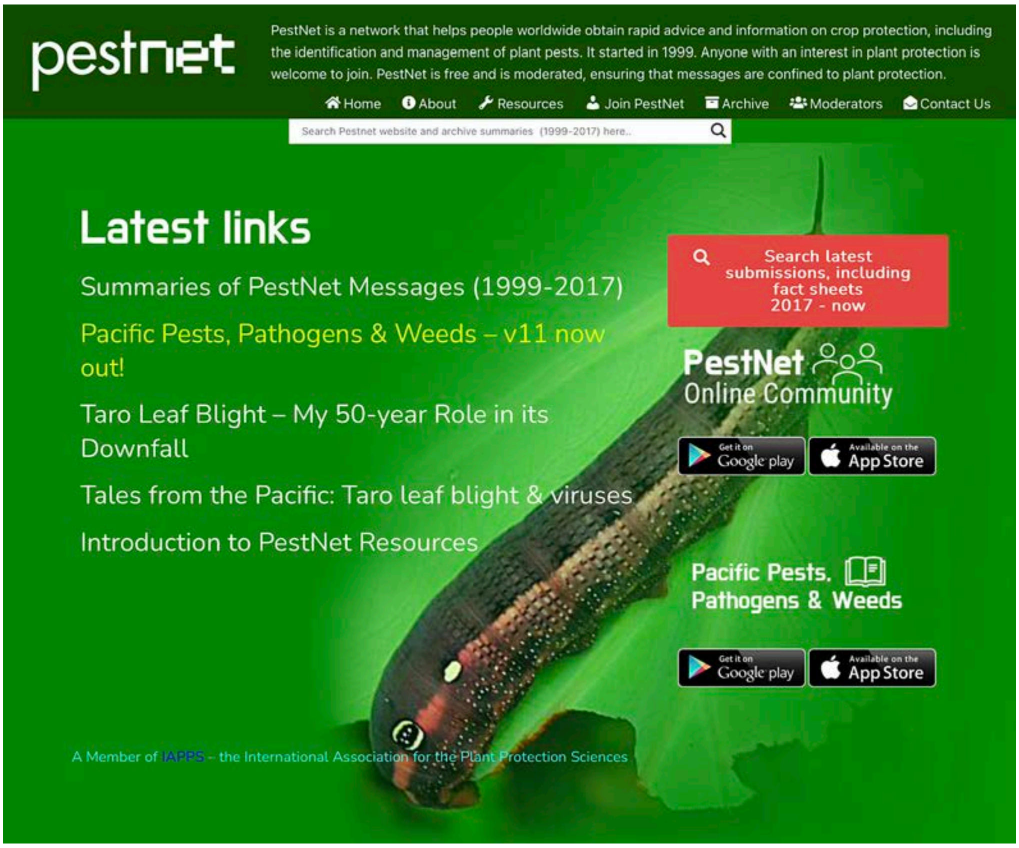
Fig. 4.4 Plantlets with *Banana bunchy top virus* sent on Messenger (Samoa). *Source: Ministry of Agriculture and Fisheries. Samoa.*

4.2 PestNet

PestNet is an online service providing crop protection information of all kinds, in particular pest and disease identification and management. It was started in December 1999 and has about 1300 members. It is open to research and extension staff, farmers, and students. Daily, it gives out information on plant protection from the Internet. To access PestNet Online Community go to www.pestnet.org.

PestNet is now amalgamated with the Pacific Pests, Pathogens & Weeds (fact sheet) app. So from the PestNet website (www.pestnet.org) you can access PestNet's Online Community and more than 500 fact sheets, and from each of the fact sheets you can access PestNet.

The next section shows you how to join PestNet, send a submission (e.g. request for an identification or for other information), and how to respond to someone else's submission.

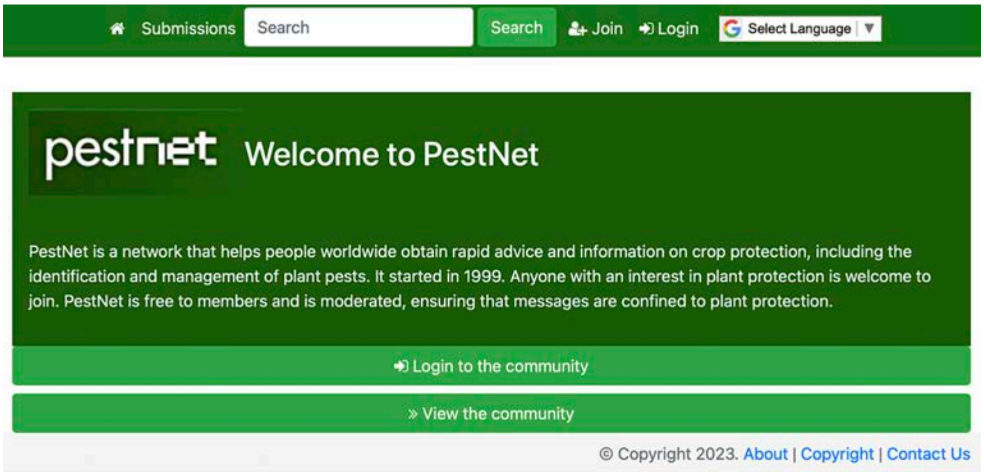


4.2.1 Accessing PestNet from a computer

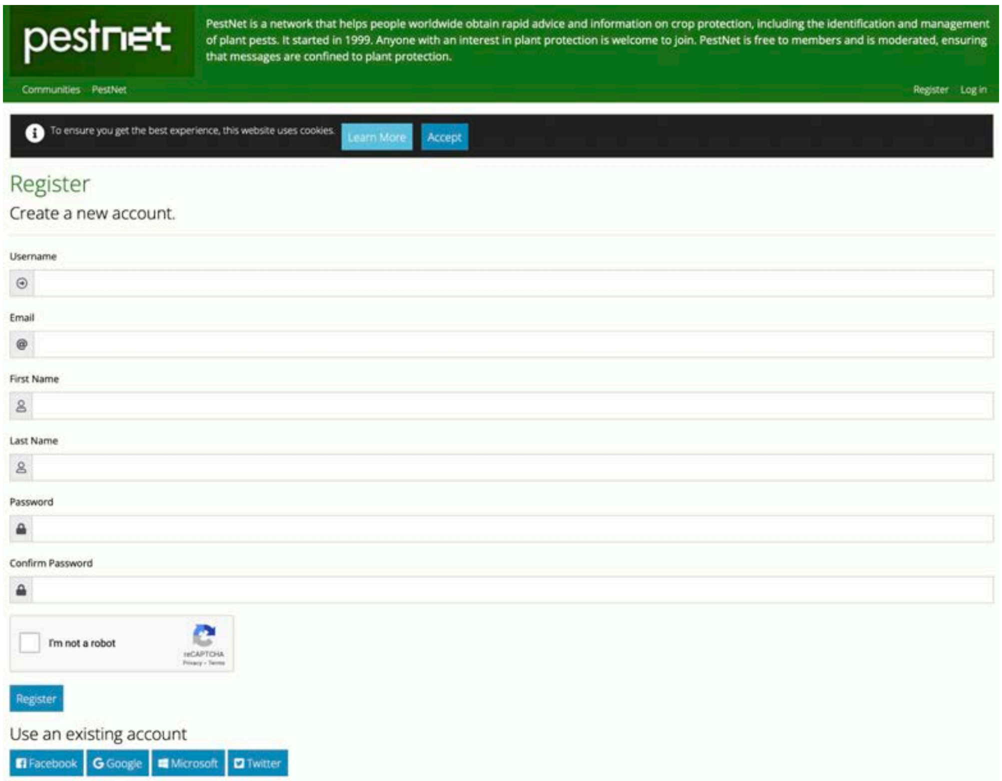
Trainees should work through the following process to become familiar with accessing and using PestNet on a computer. From the PestNet website (above) they should go directly to the 'Welcome to PestNet' page to **join**, **login** or **view** submissions via the 'PestNet Online Community' link.

STEP 1. Welcome Page: Click on one of three choices:

1. Click on 'Join' if you want to become a member
2. Login if you are a member, or
3. View the Community, just to see the submissions.

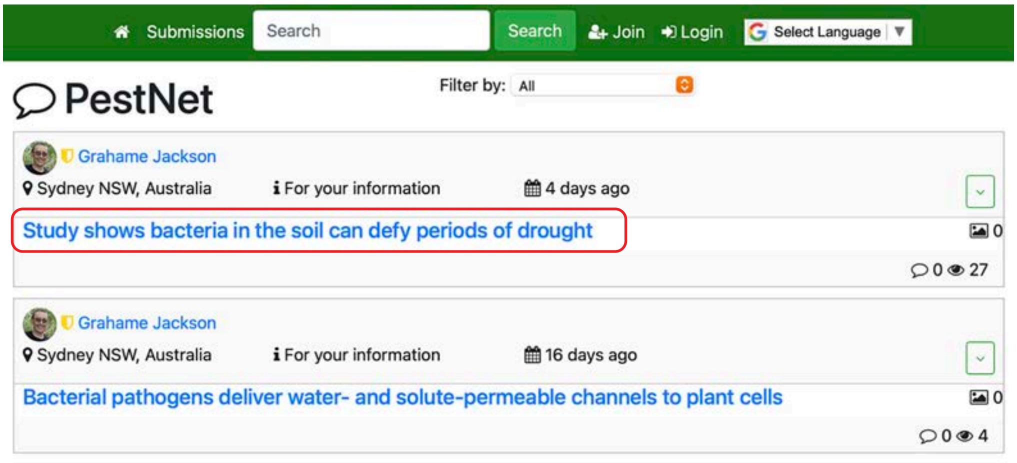


STEP 2. To join PestNet: After click on the link Join then complete the registration form with an email and password or use a social media account.

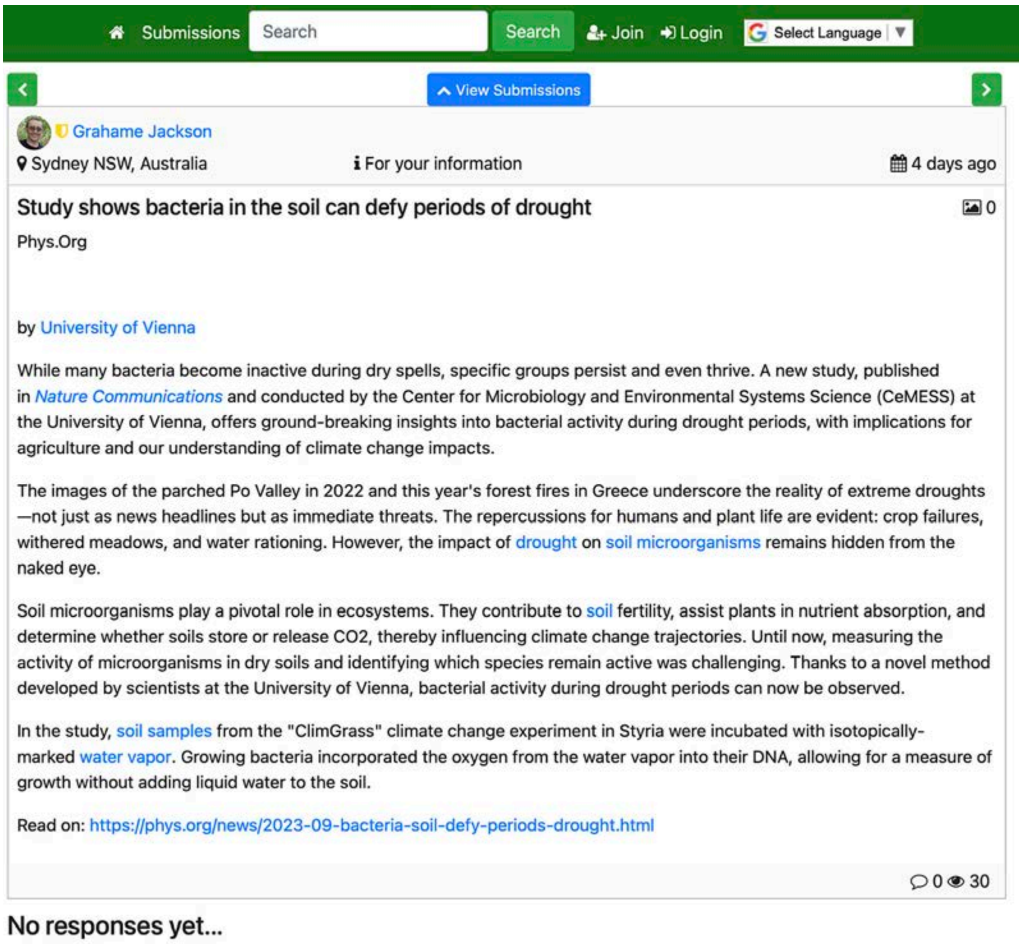


STEP 3a. To 'View the Community': To look at submissions without registering or logging in, on the PestNet Welcome page, click on the 'View the community'.

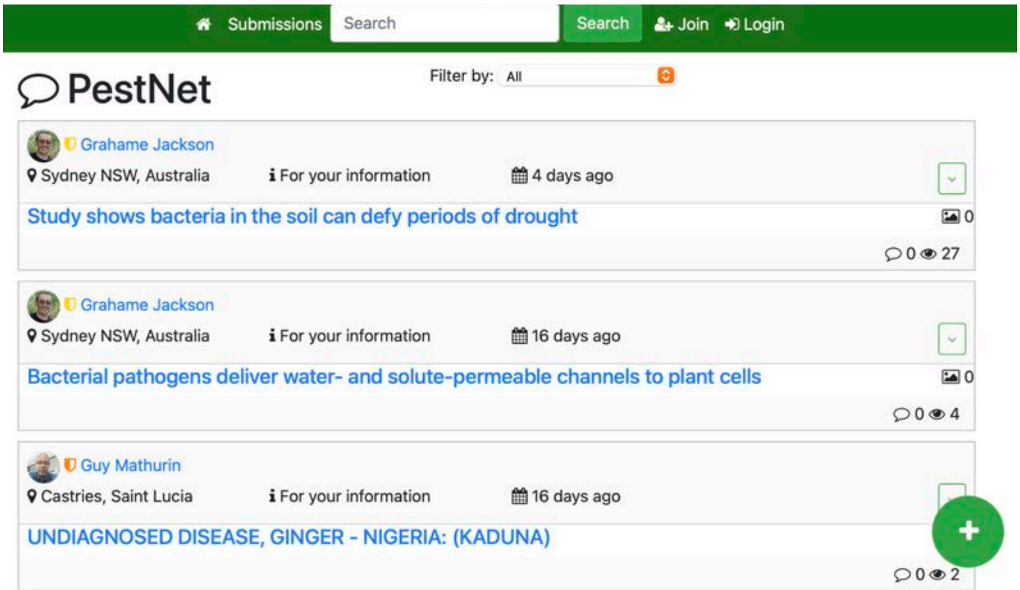
In this view you will not be able to make a submission or respond to one. If you are already a member, go to 'Login' to the community.



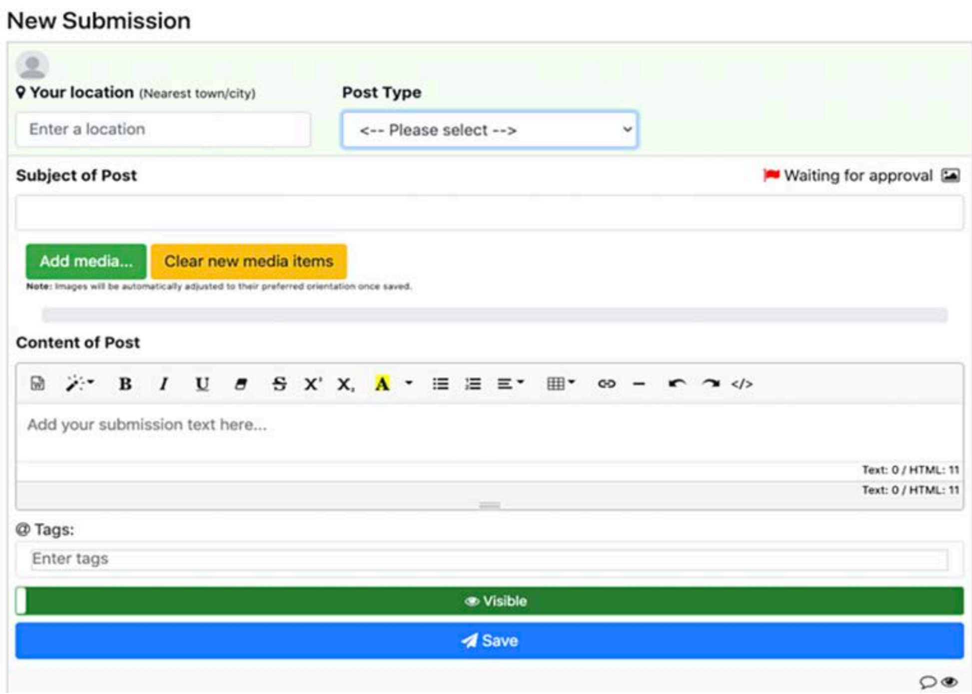
STEP 3b. An expanded submission: To view the details of a submission, click on the link indicated above in red to reveal the details. Note that images can also be expanded.



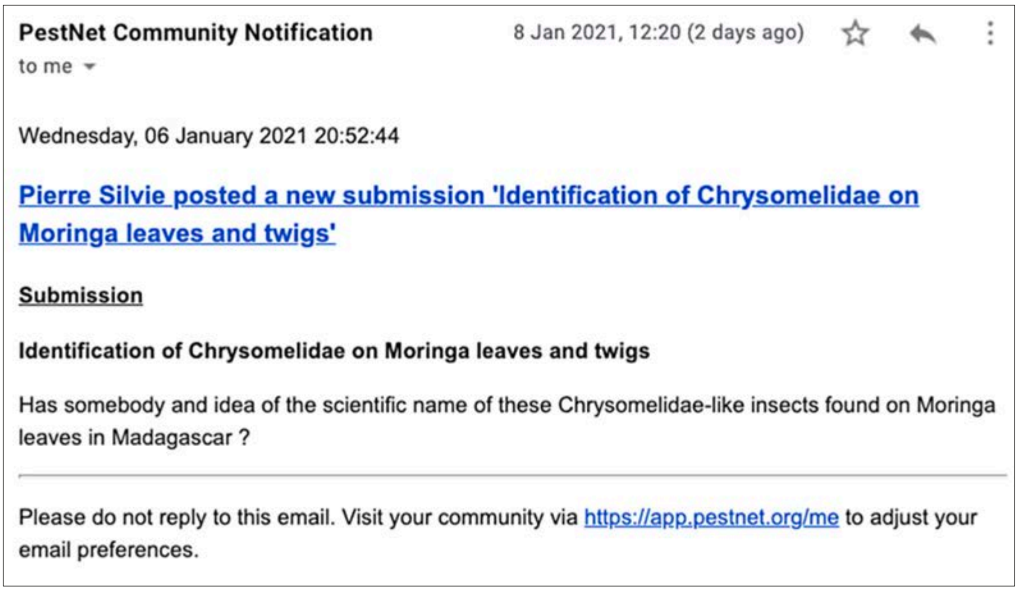
STEP 4a. Make a submission: Once you have been accepted as a member, click on the '+' in the green circle (see image below bottom right).



STEP 4b. Make a submission: Complete the form and click on 'Save'. This submission will go to moderators for approval. Note, **tags are optional.**



STEP 5. Email link to view submissions: Members will receive an email link to view submissions.


PestNet Community Notification 8 Jan 2021, 12:20 (2 days ago)
to me

Wednesday, 06 January 2021 20:52:44

Pierre Silvie posted a new submission 'Identification of Chrysomelidae on Moringa leaves and twigs'

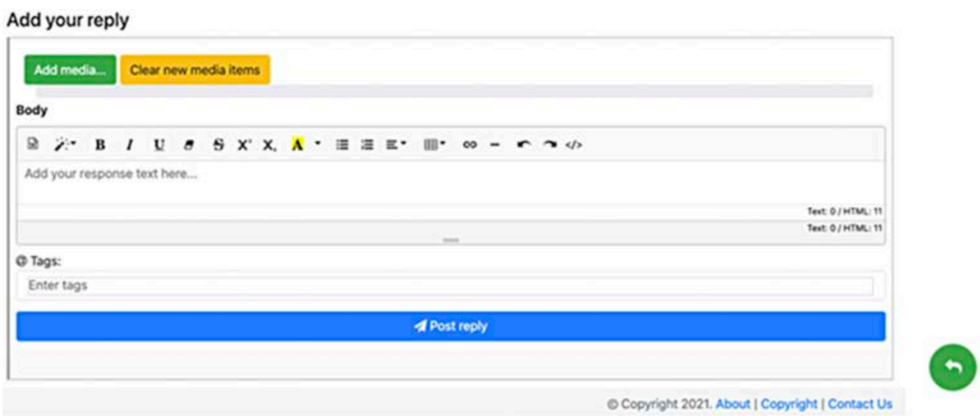
Submission

Identification of Chrysomelidae on Moringa leaves and twigs

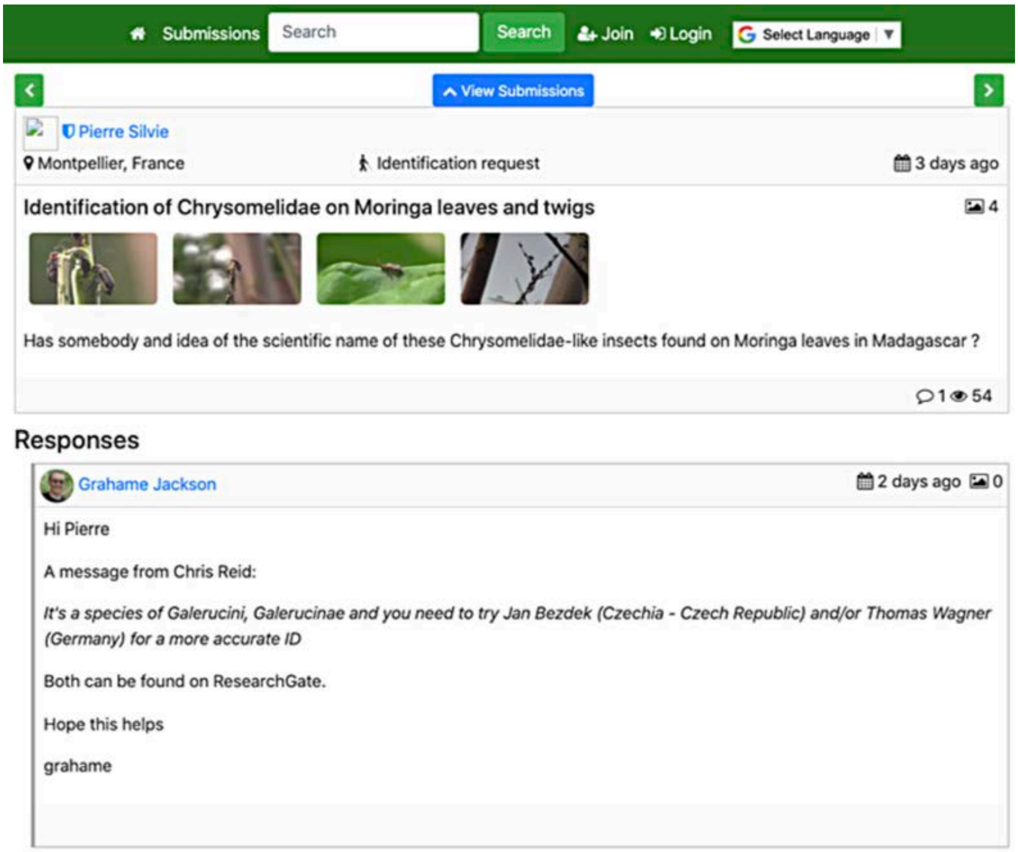
Has somebody and idea of the scientific name of these Chrysomelidae-like insects found on Moringa leaves in Madagascar ?

Please do not reply to this email. Visit your community via https://app.pestnet.org/me to adjust your email preferences.

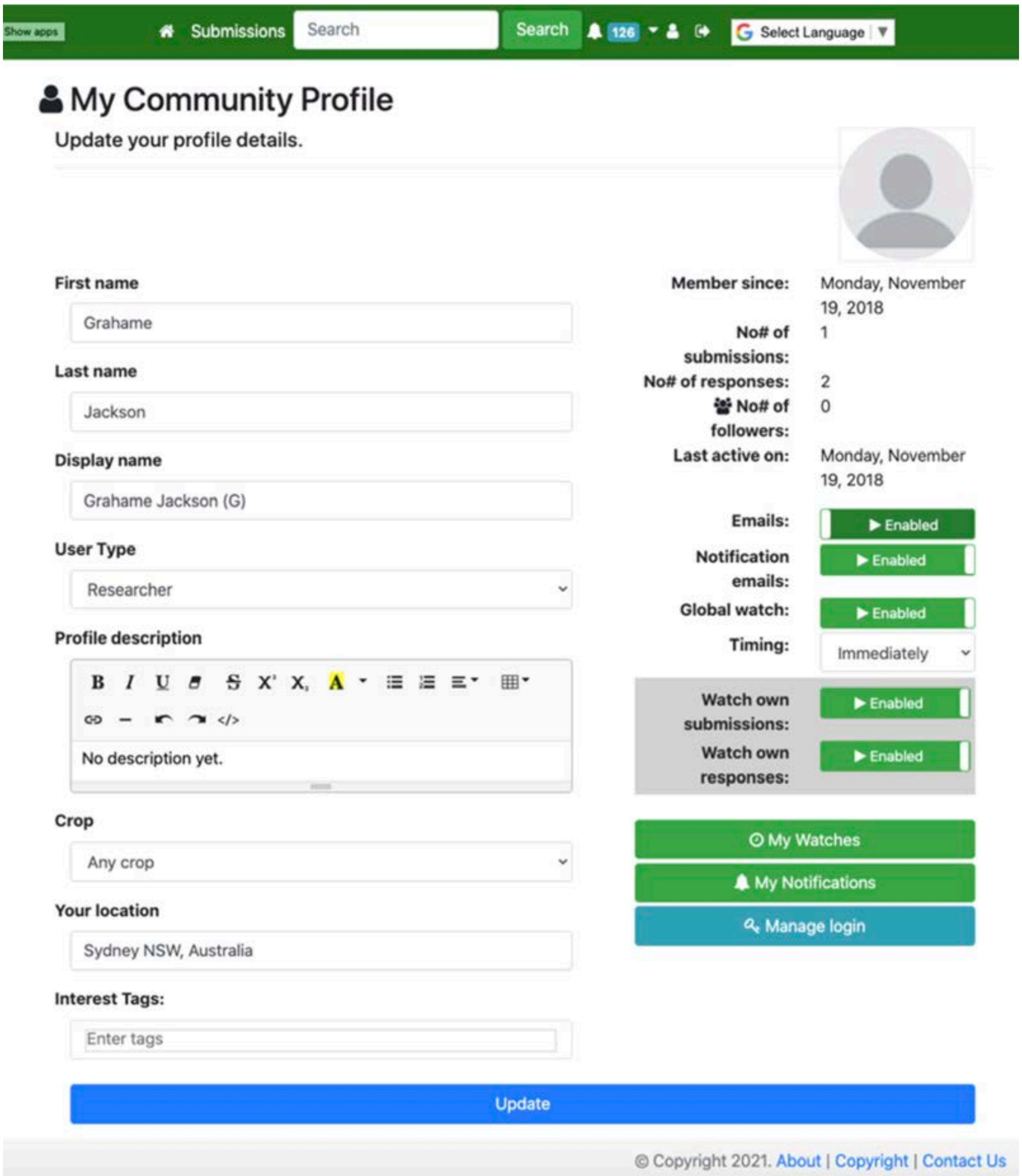
STEP 6. Reply to a submission: Members respond by clicking on the white curved arrow in the green circle (see image bottom right), complete the form and then 'Post reply'.



STEP 7. Response: Members receive a link to the response and can reply.



STEP 8. Managing your PestNet profile (optional) — click on 'small man' symbol next to 'Join'.



Below are the definitions of the default position:

- **emails:** when 'enabled', you will receive ALL emails from PestNet
- **notification emails:** when 'enabled', you receive notifications (see bell and number in the top banner) for all posts and responses other than your own, generated daily and sent in an email (a digest)
- **global watch:** when 'enabled', you watch all the posts (by default)
- **watch own submissions:** when 'enabled', you will be notified if there are responses to any submission you have made
- **watch own responses:** when 'enabled', you will be notified if there are responses to any responses or comments you have made
- **timing:** you will receive notifications depending on the time set: immediately, daily, weekly, etc.

If you do not want all emails, go to 'My Community Profile' and select:

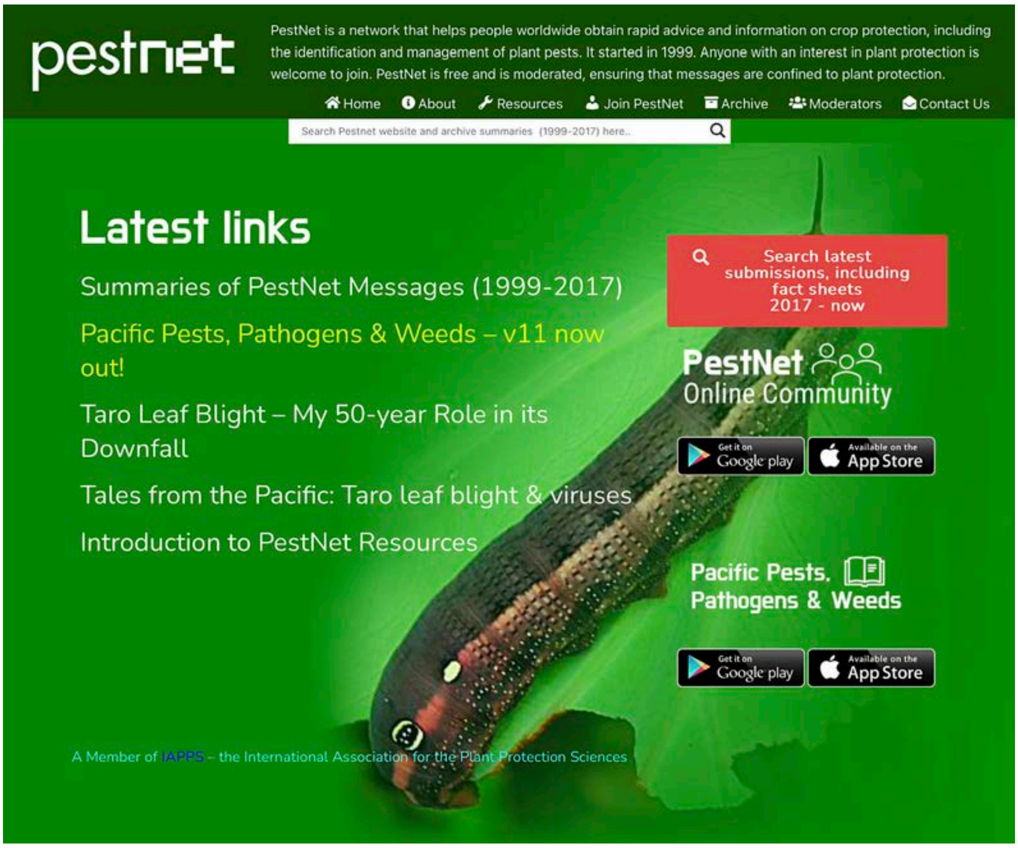
- **emails:** stop – you will not get any emails from PestNet
- **global watch:** stop — then choose 'my watches' to make selections
    - **my watches:** you can select any of the filter items: submissions, responses, tags, users or location
    - **to watch a tag:** click on the tag and then the 'clock' (or for submissions just the 'clock')
    - **timing:** you can determine when you want to receive your watches
- **notification emails:** select 'enable' or 'stop', depending on whether you want to receive emails with a submission or tag that matches your watches.

4.2.2 Accessing fact sheets via PestNet using a computer

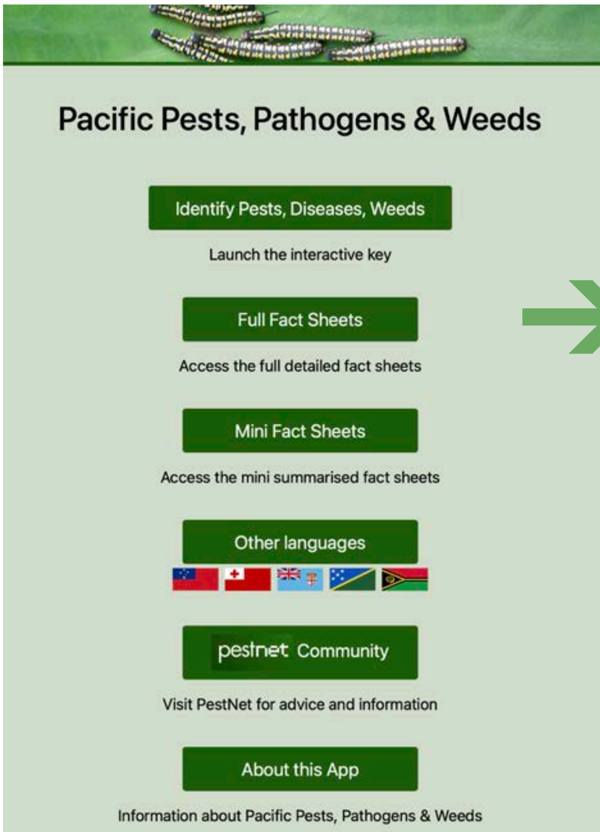
Here we take you through the process of accessing the fact sheets via PestNet's website using a computer. From the fact sheets you can access the PestNet Community. Having a direct link to PestNet from every fact sheet has advantages. It means that should you wish for more information on any pest you can quickly access PestNet to make a submission. If the two apps were separate then you would have to leave the one to access the other.

4.2.2.1 Full and Mini fact sheets

STEP 1. From the PestNet website: click on the link 'Pacific Pests, Pathogens & Weeds — v12'.

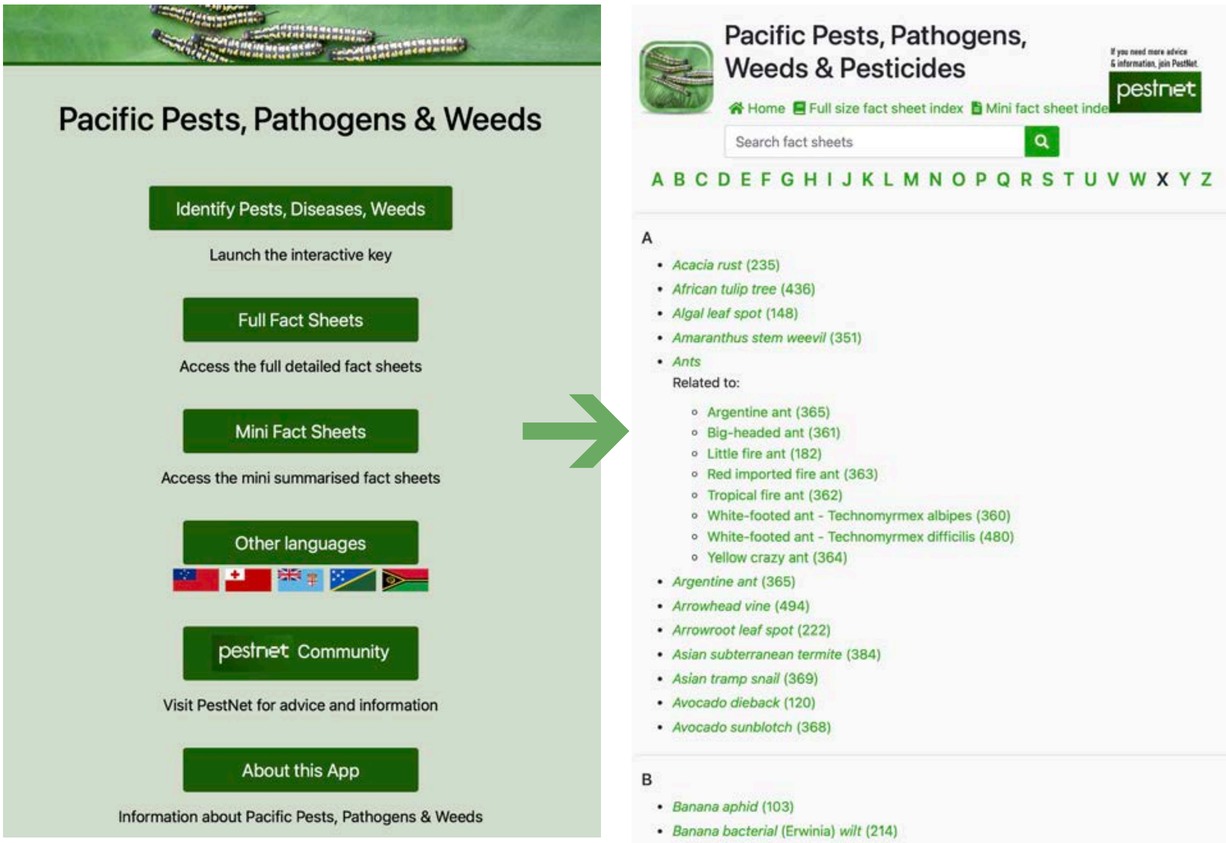


STEP 2. Full Fact Sheet: from the webpage list, click on the button 'Full Fact Sheet' to open the index.

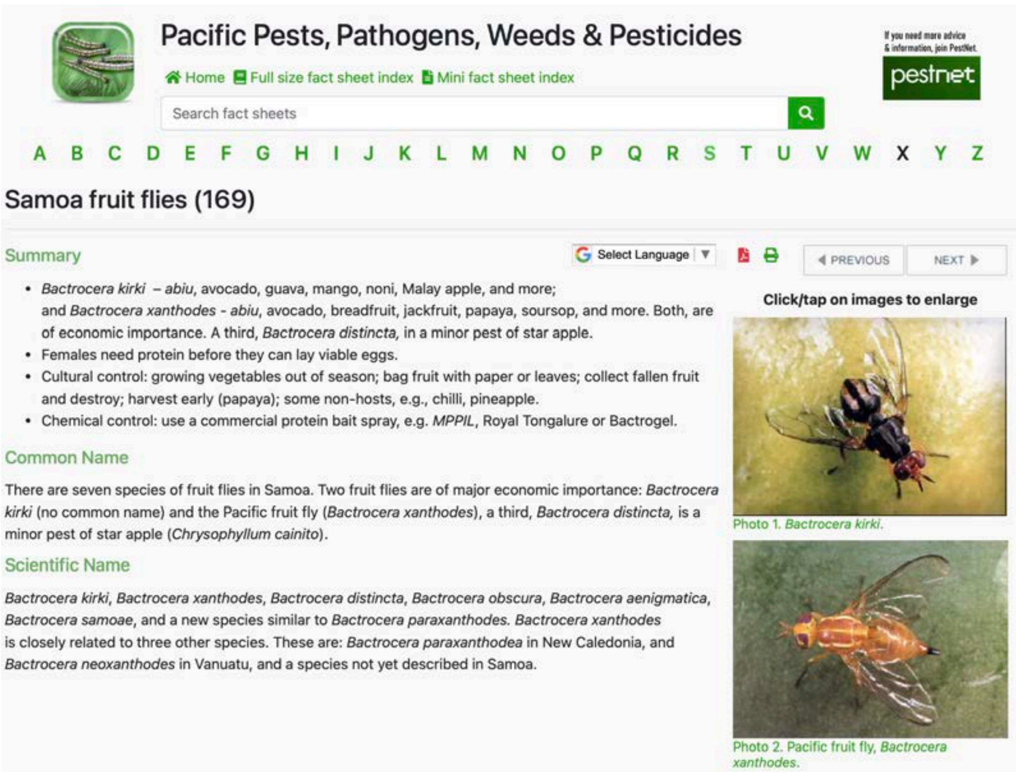


STEP 3. Full Fact Sheet: is divided into 8 sections: Common Name; Scientific Name; Distribution; Hosts; Symptoms & Life Cycle; Impact; Detection & Inspection; and Management.

STEP 4. MiniFact Sheet: from the webpage list, click on the button Mini Fact Sheet' to open the index.

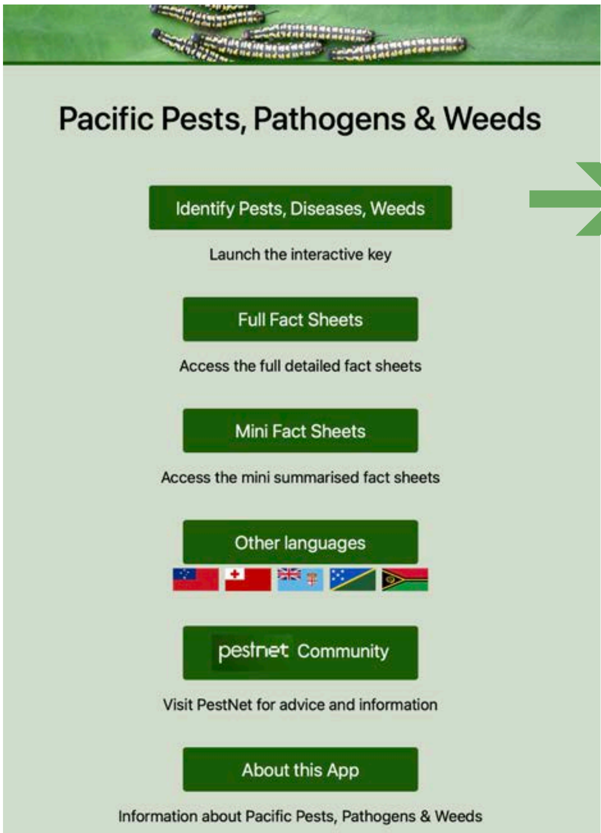


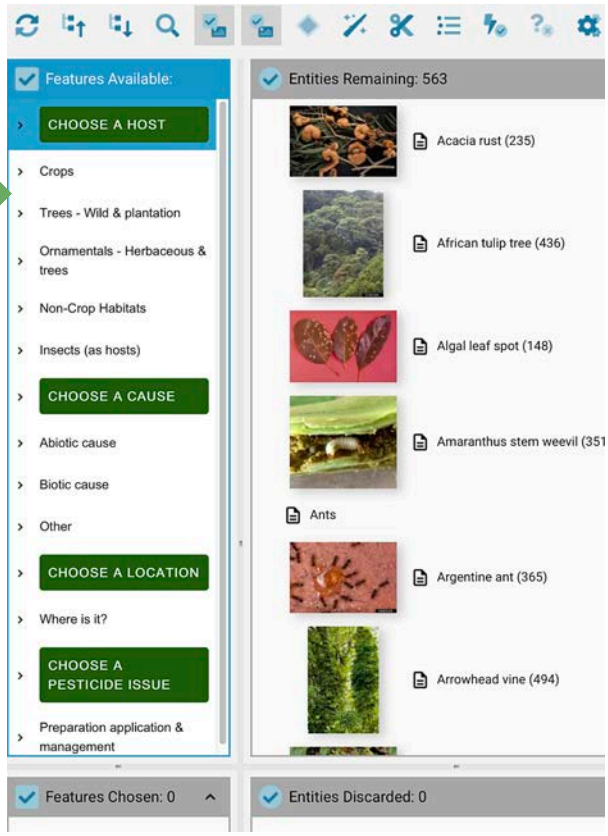
STEP 5. MiniFact Sheet: has a summary, followed by common and scientific names.



4.2.2.2 Identify Pests, Diseases & Weeds

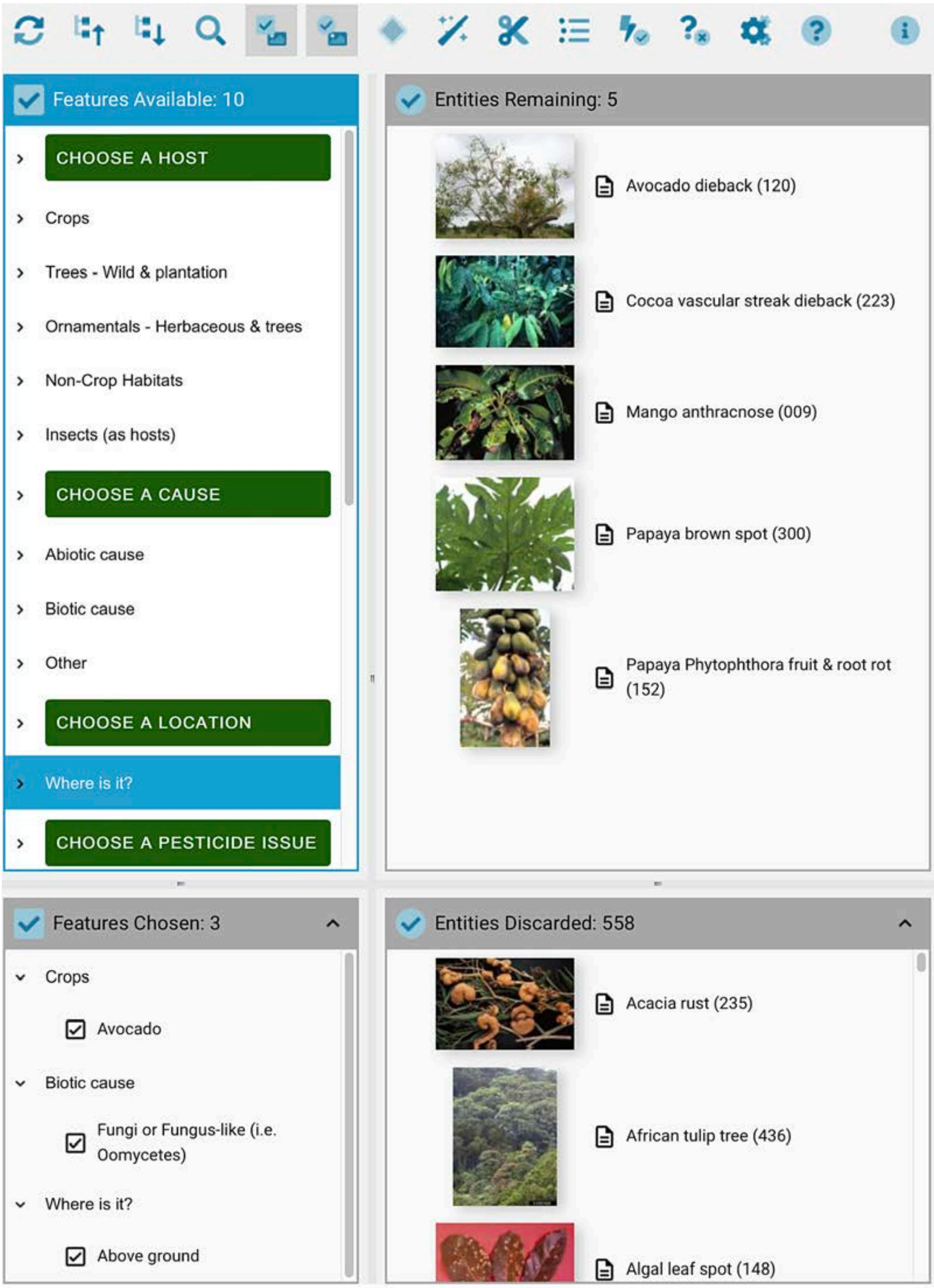
STEP 6. LUCID INTERACTIVE KEY: this key helps you identify a pest of concern. Click on the 'Identify Pests, Diseases & Weeds' button on the webpage list to open the key.





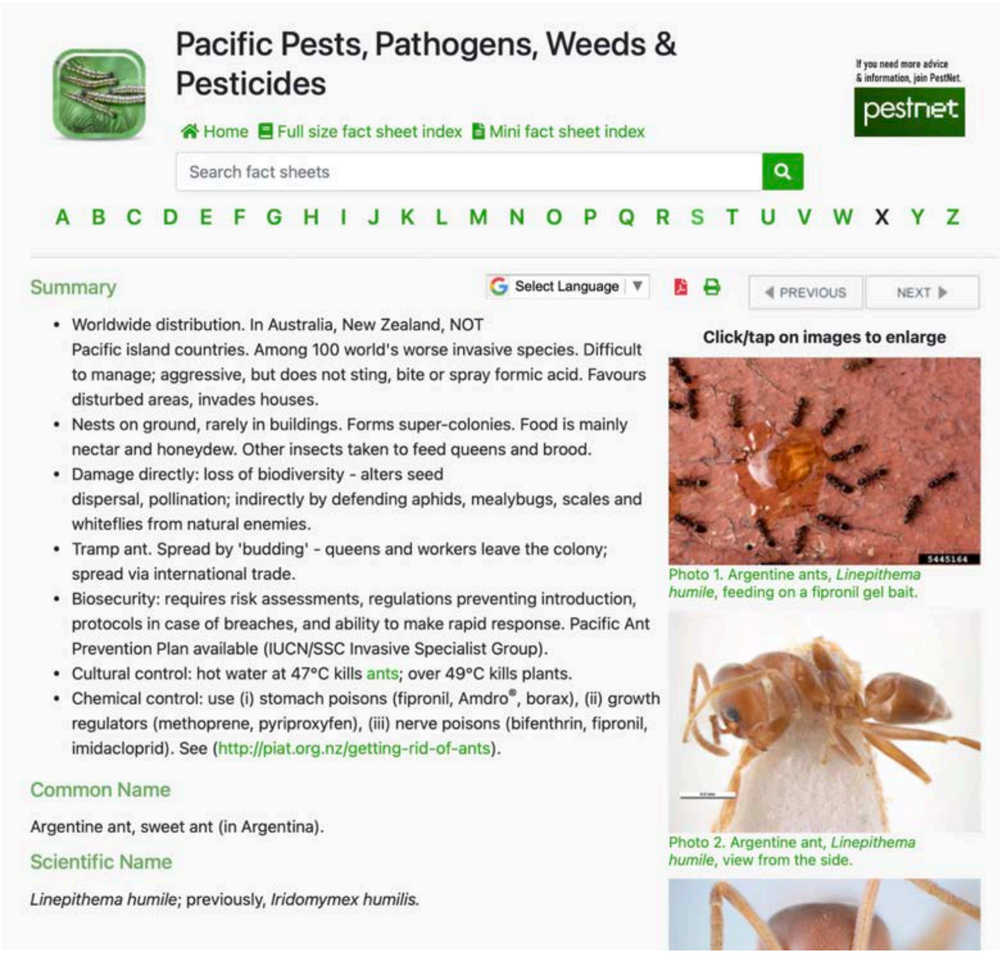
STEP 7. LUCID INTERACTIVE KEY: first 'Choose a Host' (crops, tree, ornamental, etc.) then 'Choose a Cause', 'Choose a Location', or if there is a problem with pesticides, 'Choose a Pesticide Issue'. Each time you choose, the choices show below (left), and the selections at the top (right). The LUCID panel below was used for a disease of avocado caused by a fungus (or fungus-like oomycete) infecting the trees above-ground. The 'possible' are under remaining: top right.

After a selection of possibilities has been chosen, it is then up to the plant health doctor to look through the list to see if any of the symptoms fit the hosts described.

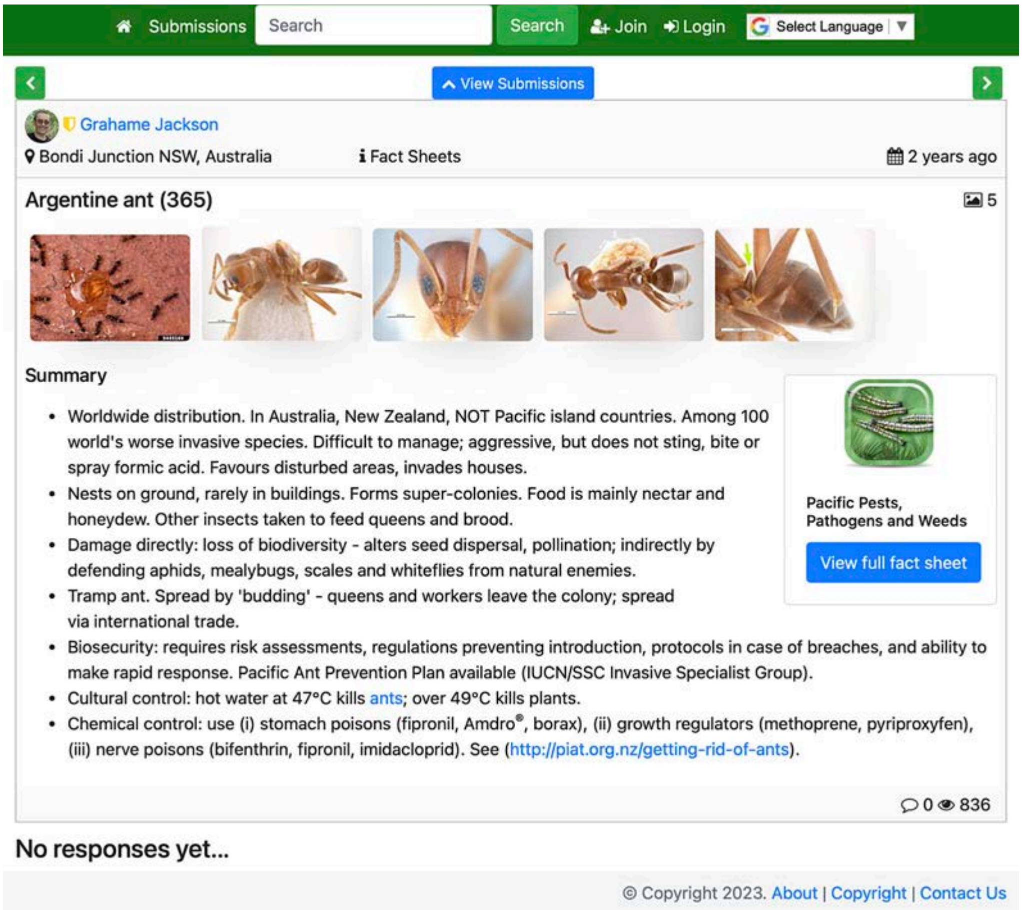


4.2.2.3 From fact sheets to PestNet Community and vice versa

STEP 8. Mini Fact Sheet for Argentine ant: from here, you can go straight to the PestNet Community, click on the 'pestnet' logo top right if you want more information. The same applies to Full Fact Sheets.



STEP 9. Mini fact sheet for Argentine ant: once on 'PestNet Community', you can search the database for information on Argentine ant, view submissions (click on the blue button top of the webpage), send a message to members or go to the 'full fact sheet' (click on the blue button on the middle-right of the webpage).

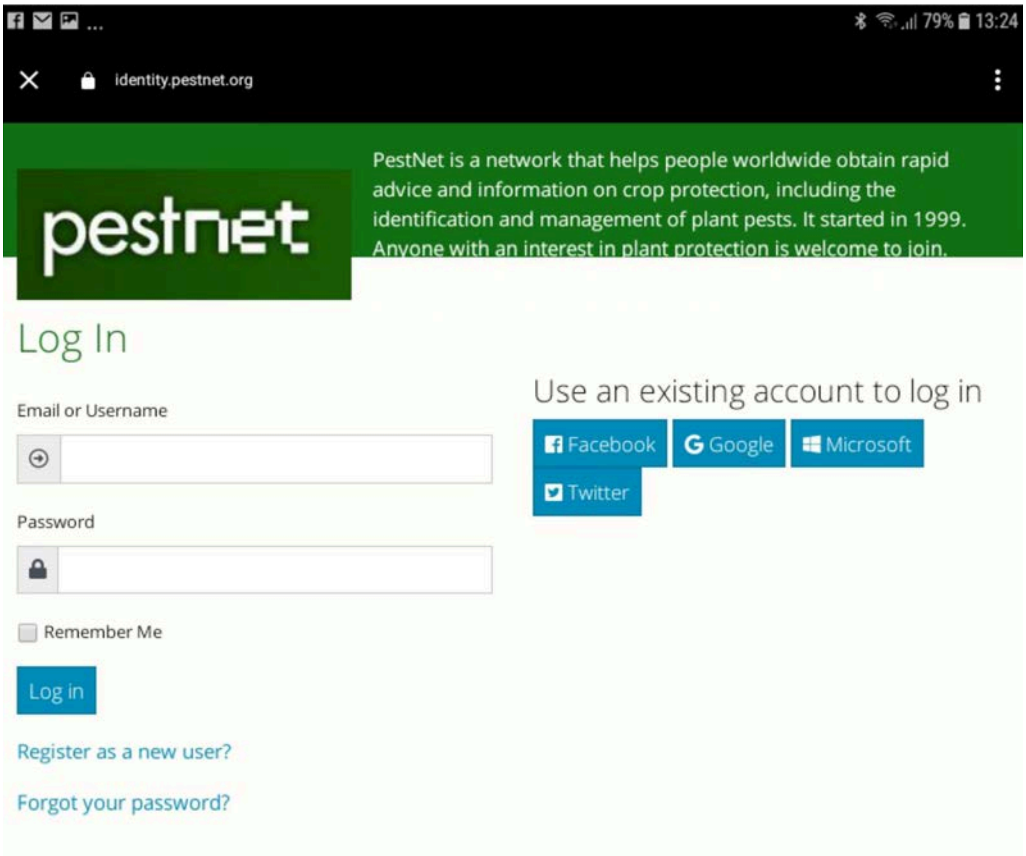


4.2.3 Accessing PestNet on mobile devices: tablets and phones

STEP 1. Download the app from either Google or Apple app store. Note that PestNet and Pacific Pests, Pathogens & Weeds are now together in the one app.

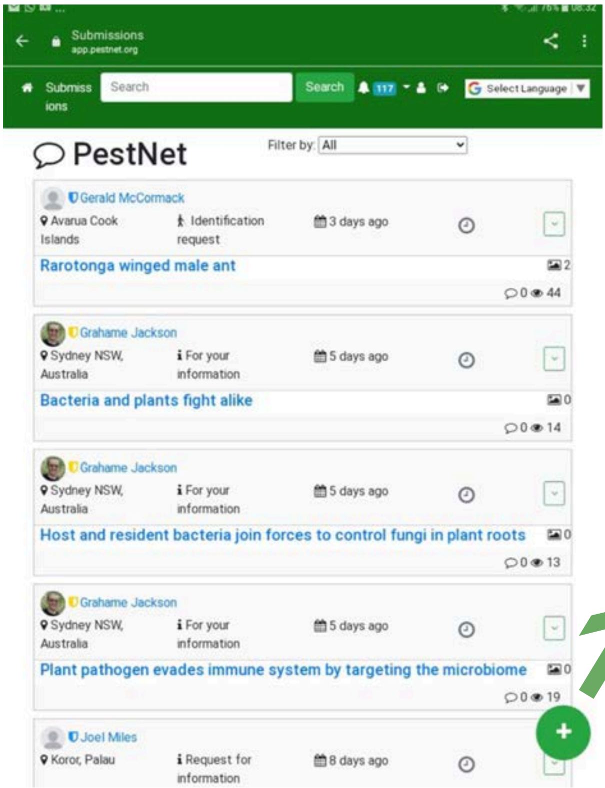
STEP 2. Read and accept the Disclaimer by tapping on 'Continue'. Tap on 'PestNet Community' to go to the 'Welcome Page'.

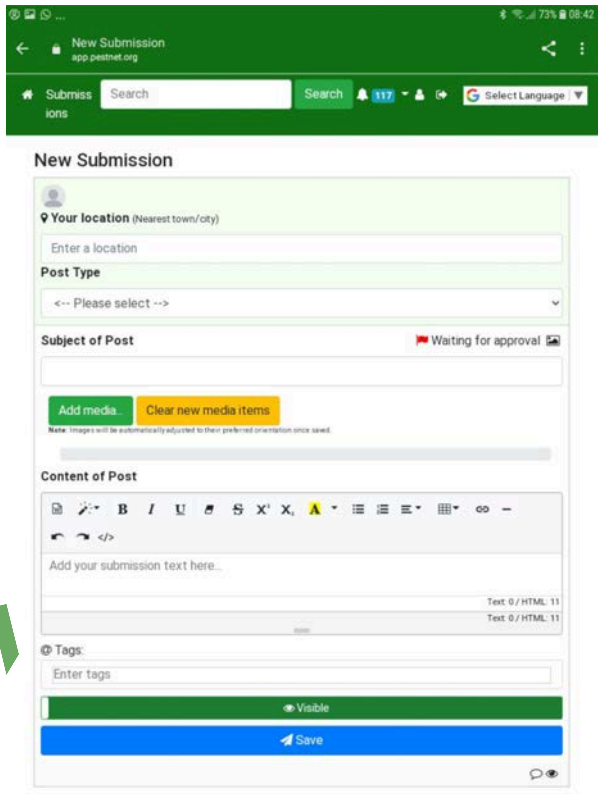
STEP 3. Either view the messages without joining 'View the Community', 'Join' or 'Login'. You need to join if you want to post a submission or reply to one.



STEP 4. Post a submission: tap on the white '+' in the green circle background in the image on the left.

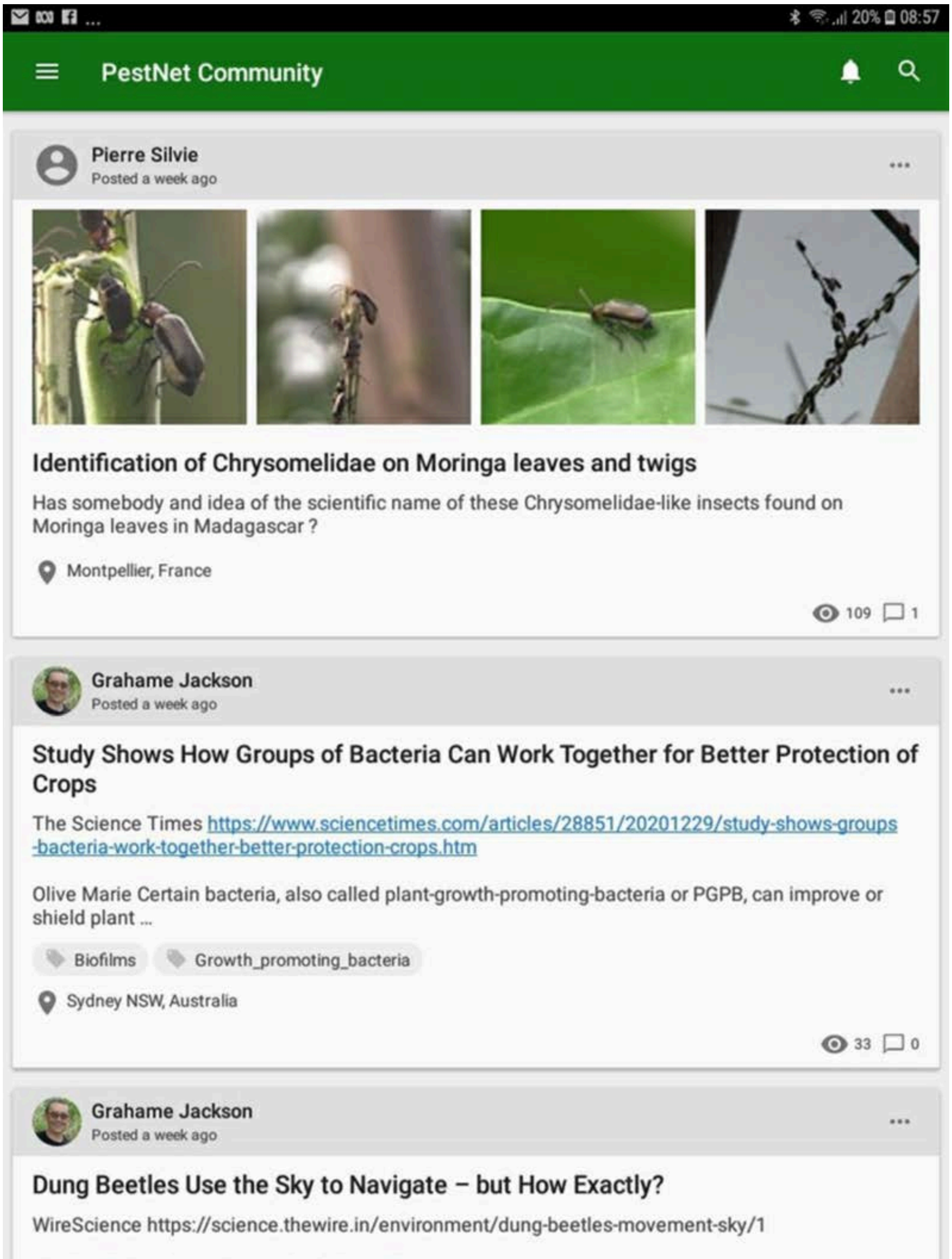
The 'New Submission' form will open for you to complete. Once you have filled out the form, tap on the arrow and 'Save' in the image on the bottom right.



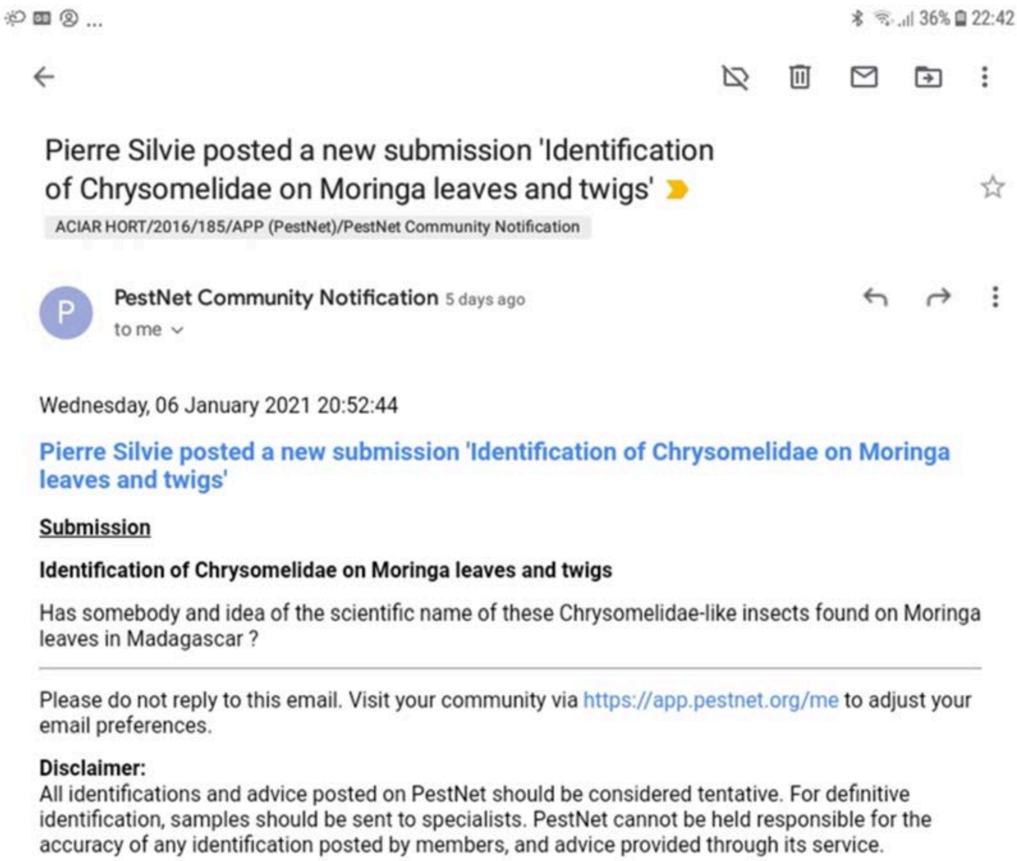


Option to add an image and a tag in this form

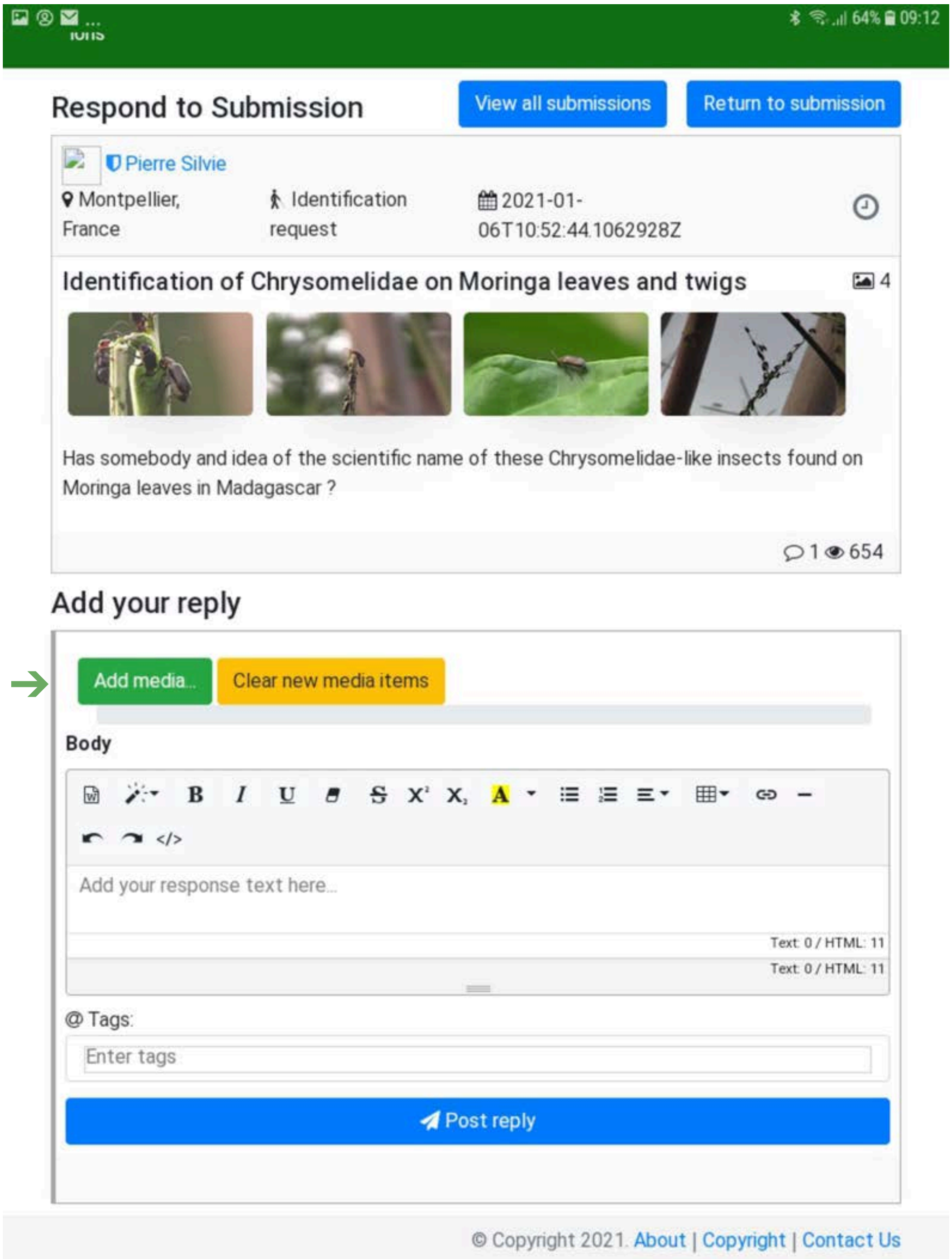
STEP 5. Submissions are cleared by moderators, then added to PestNet and sent to members. Tapping within each submission opens it.



STEP 6. Members get an email with a link to the submission.

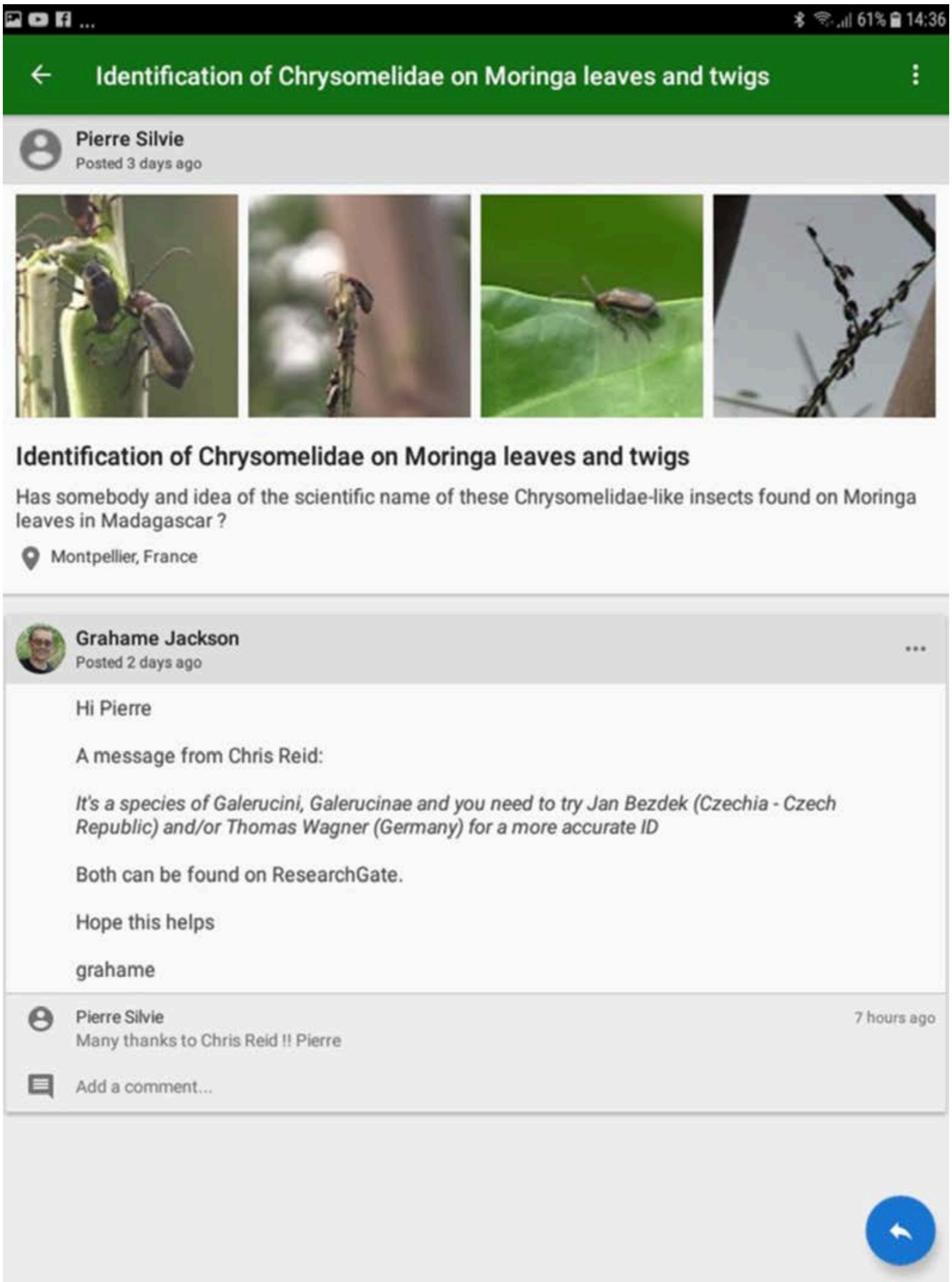


STEP 7. Post a response: tap on the submission of interest, then tap on the white '+' in the blue circle background (bottom right in **STEP 8** on page 223) to reveal the 'Add your reply' form. Fill out the form (below) and then tap on 'Post reply'.

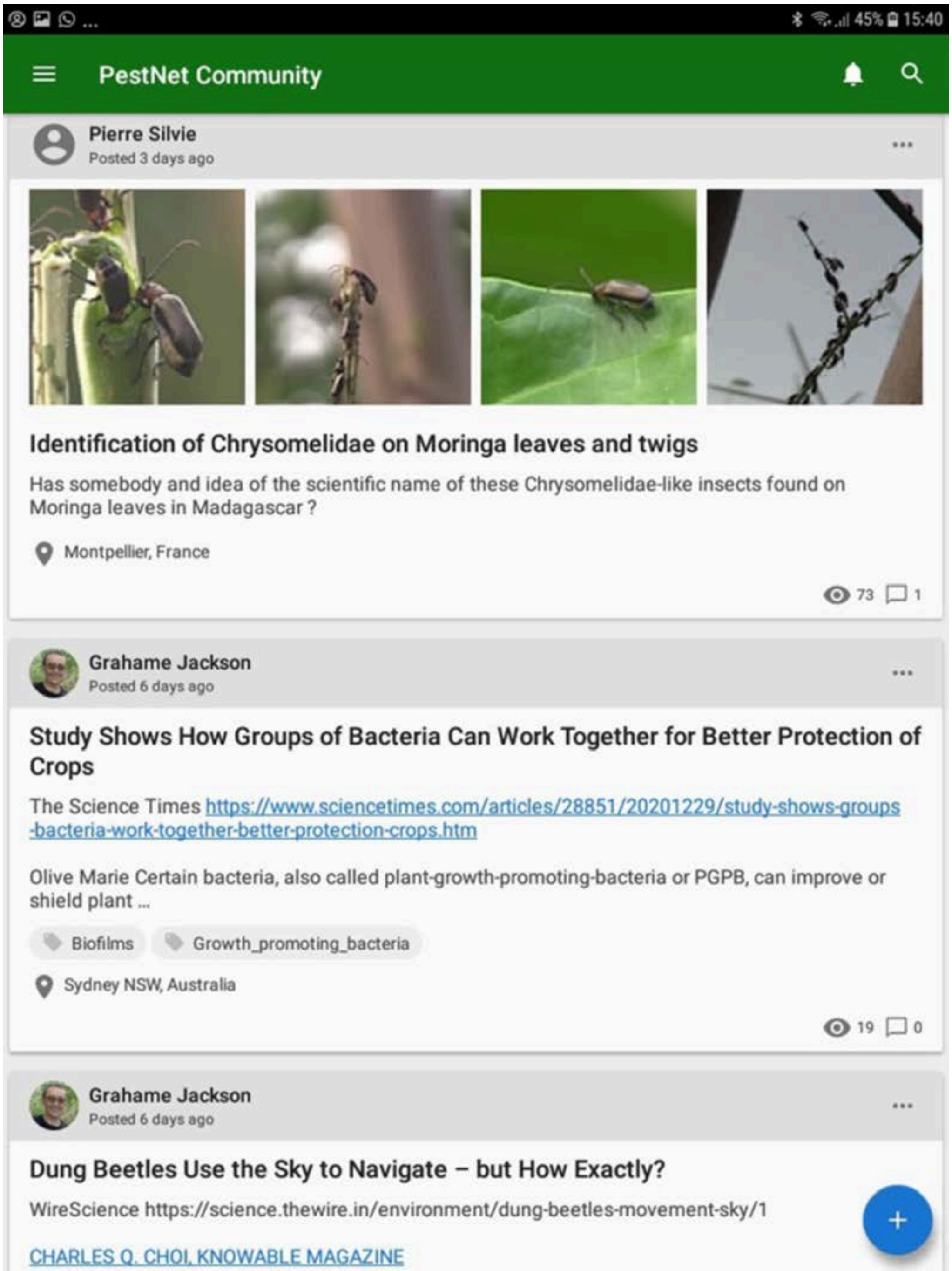


Option to add an image and a tag in this reply form

STEP 8. PestNet shows responses as a 'thread' — one after the other.



STEP 9. Checking responses: from the PestNet list of submissions you can tap on the squarish box (below right) to see a number of responses in this case 1, and the number of views, 73.



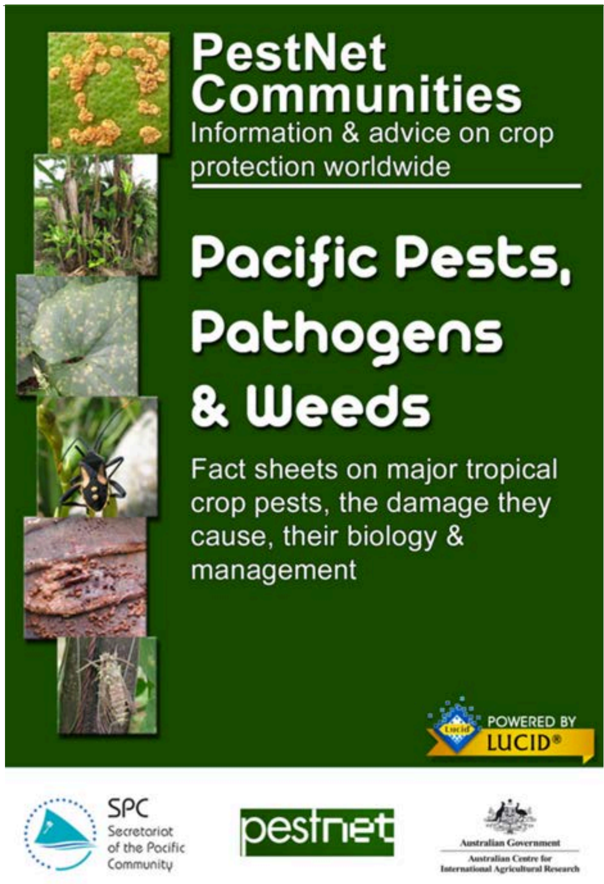
4.2.4 Accessing fact sheets via mobile devices: tablets and phones

The Pacific Pests, Pathogens & Weeds app gives trainees accessible and valuable information on a wide range of plant pests, diseases and weeds found in Pacific islands. Trainees will need access to a smartphone or tablet, and internet access to download the app. Once downloaded from the Google or Apple stores, internet access is no longer needed.

Note, you can access PestNet from within any fact sheet, full or mini, in case you want more information and wish to send a message to the PestNet Community.

You can download the app from both the Google and Apple stores.

4.2.4.1 Full and Mini fact sheets

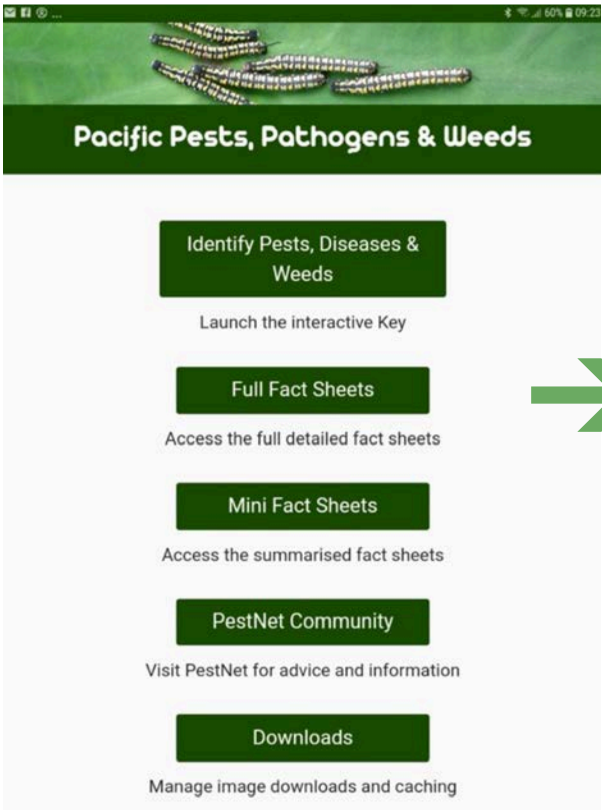


STEP 1. This app contains Full and Mini fact sheets designed to assist plant health doctors to diagnose pests and diseases to give sound management options to farmers.

IMPORTANT: Use the 'Download' button for downloading a complete set of images on the app. Use this feature if you are going to use the app in the field without Wi-fi connection.

The latest edition of the app has a button for 'Other languages' — Fijian and Hindi, Samoan, Tongan, and pidgin languages of Solomon Islands and Vanuatu. The translations cover 20 (mini) fact sheets of common pests.

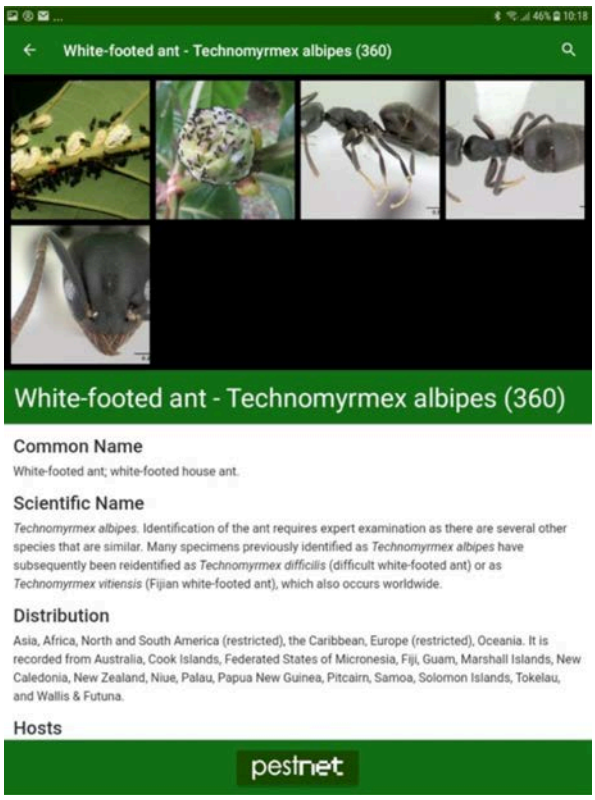
STEP 2. Full or Mini Fact Sheets: this app opens to a screen giving a choice of Full or Mini fact sheets, image downloads, and how to use the app.



STEP 3. Full Fact Sheets: tapping on 'Full Fact Sheets' takes you to a lists of pests, pathogens and weeds in alphabetical order.

For this example, tap on the 'Full Fact Sheets' button (top left) to reveal the list of pests, pathogens and weeds (top right).

For this example, tap on 'White-footed ant' (top right) to reveal it's Full Fact Sheet.

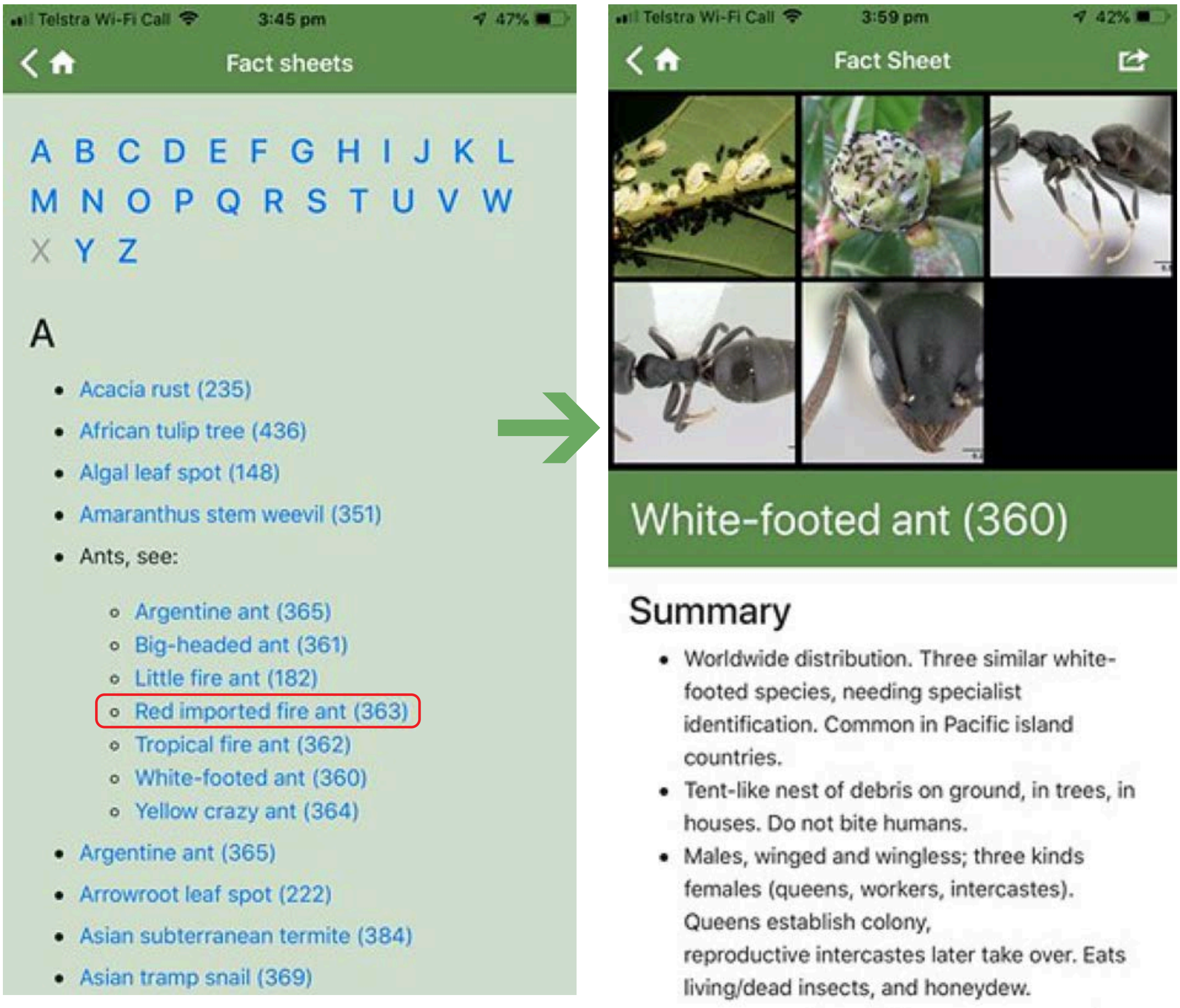


STEP 4. Tapping on Mini Fact Sheets takes you to a list of pests, pathogens and weeds in alphabetical order.

For this example, tap on the 'Mini Fact Sheets' button (image top left in **STEP 2,** page 226) to reveal the list of pests, pathogens and weeds (below left).

Then tap on 'White-footed ant' (below left) to reveal it's Mini Fact Sheet.

In the latest version of the app., Version v12, countries have translated the most common pests brought by farmers to PHCs into local languages.



4.2.4.2 Identify Pests, Diseases & Weeds

STEP 5. Use the LUCID INTERACTIVE KEY. This is especially useful where the pest or disease is described but on another host. For instance, a scale is found on *bele*, but it is described on cassava. Tap on 'Identity Pests, Diseases & Weeds' (image top left in **STEP 2,** page 226) and do the following:

1. Tap on 'Identify Pests & Diseases' button
2. Under Choose a host
   - tap on Crops
   - tap on *bele*
   - scroll up and close 'Crops'
3. Under 'Choose a cause'
   - scroll to 'Biotic cause'
   - tap on 'Insects'
   - scroll up and close 'Choose a cause'
4. Under Choose a location
   - tap on 'Where is it?'
   - tap on 'Above ground'
   - scroll up and close 'Choose a location'.

Trainees can practise by trying to identify the problem on a tomato plant that has wilted and there are small seed-like balls in a white cottony growth at soil level. This is possibly a disease. What is it?

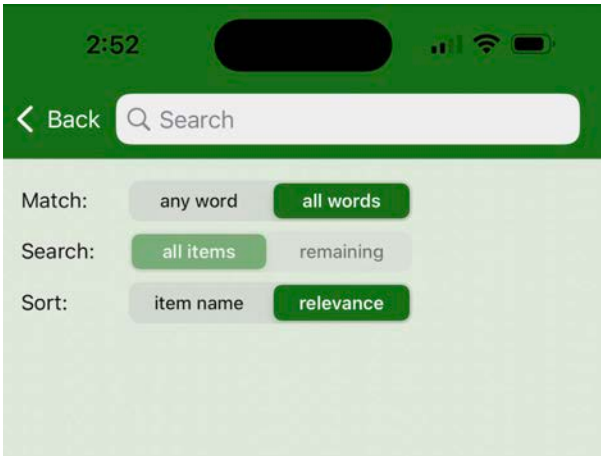
Note at the bottom of the panel there are 'Selection' and 'Remaining' which together with 'Features' track your progress as you make choices.

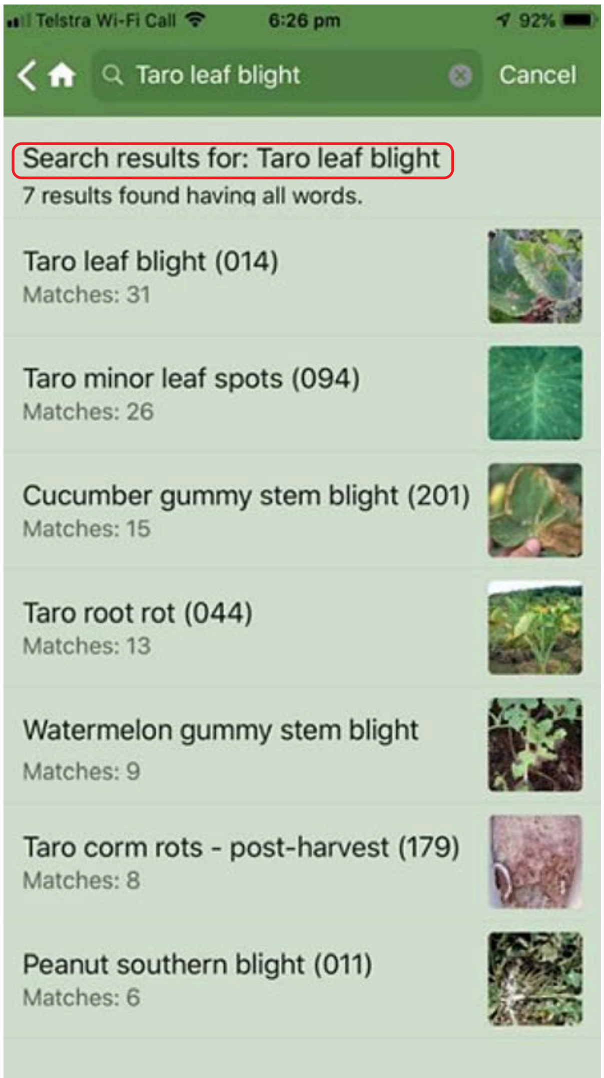
IMPORTANT: Many pests and diseases occur on more than one crop. The pest that the plant health doctor is looking for MAY be described under another crop. For example, if the problem is scale on bele, it would commonly be white peach scale. But there is no fact sheet for bele. The scale is described under cassava, where it is also a common pest. So, how would the plant health doctors go about finding it?

STEP 6. Using the search engine.

The search engine is found by tapping the search button in the fact sheet listing page or tapping on the hour-glass symbol within any fact sheet.

Searching (see below) for Taro leaf blight, for example, when 'all words' is selected results in seven choices, but when 'any word' is selected there are 316! To sort a list alphabetically select 'item name'.





It is important that the trainees become familiar with the search facility. It allows them to:

- quickly see thumbnail photos of all the pests and diseases for each crop
- search on several words together, or the words independently — compare 'taro leaf blight' matched to 'any word' compared to 'all words'
- sort a list alphabetically.

Your trainees should practice using this app with a range of pests and diseases. In a clinic it is very useful AFTER they have gone through the process of identification and diagnosis using the A,B,C and Possible/ Probable processes first

4.3 KoboToolbox and KoboCollect

The software that goes by these names is manufactured by Cornell University specifically for collecting and managing data for surveys, monitoring and evaluation. It is frequently used in difficult environments by UN agencies. It is free to use, and can be found in both Google and Apple online stores.

KoboToolbox is the administrative side of the software. It is used to register, login, to store passwords, to create a survey form, to share it with participants in a project, and to see what the data look like. The last is important. KoboCollect is used to collect the data, as its name implies and, when the phone or tablet is connected to Wi-fi, the data are sent off to a sever and automatically can be viewed on an Excel spreadsheet. Very convenient.

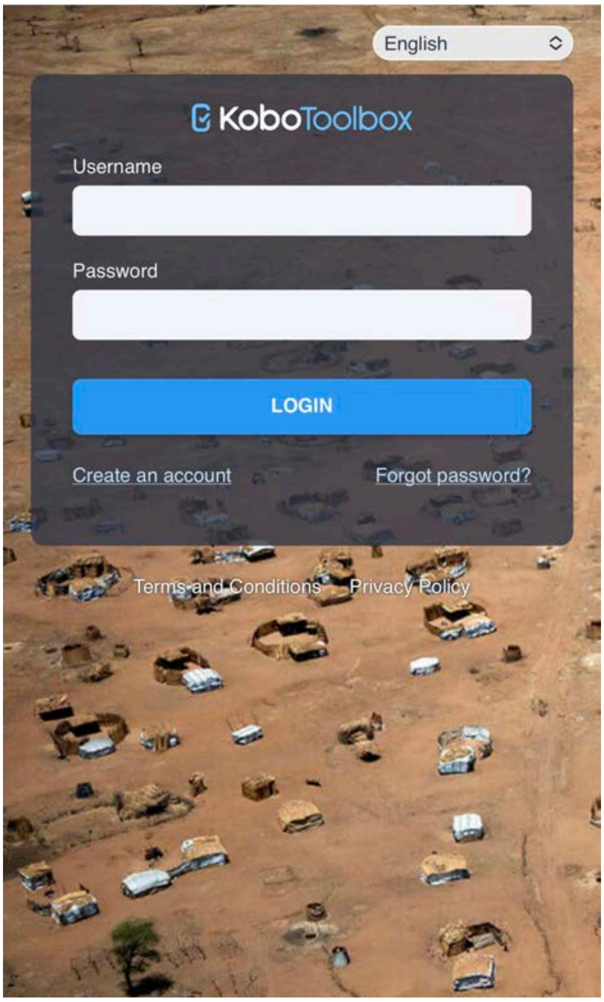
Our project countries, Fiji, Papua New Guinea, Samoa, Solomon Islands, Tonga and Vanuatu, are using the software and find there are several advantages over the use of paper prescription forms; these are listed as follows:

1. The data can be collected off-line on phones or tablets.
2. It automatically goes into an Excel spreadsheet using headings from the form.
3. The digitised form can record a GPS coordinate where the PHC is held; it can also take photographs of high quality.
4. The records of PHCs remain on the KoboToolbox server until removed by the owner. There is a permanent record of them. Paper records are not so well preserved.
5. Keeping the records together on the same server with oversight by whoever has permission to view them is important as it facilitates the interpretation of the results.

There are some problems in the collection of data this way:

1. Experience has shown that when using KoboCollect two people are required to interact with each farmer: one to interview, the other to record the formation. It has been found difficult for one person to do both activities at once.
2. Difficulty in typing on the flat surface of tablets is one reason for the slow entry of information; it is faster by phone but then the size of the form and the text is then a barrier to fast data entry.
3. Because of the above and to avoid lengthy PHCs where two plant health doctors are allocated to each farmer, some countries are using paper forms to collect data and later transposing it to KoboCollect. This is not ideal.

Fig. 4.5 KoboCollect login: https://eu.kobotoolbox.org/accounts/login/
Source: KoboToolbox



Trainees should compare the digitised (KoboCollect) and paper prescription forms, noting the differences that exist, as well as differences in the ways they are used. Using the digitised version during PHC simulations (see Chapter 7 and Exercises 7.3 and 7.4) is important: it is more complex than filling in the paper form, and practice is recommended. It is important too that trainees see the data from the prescription form displayed in columns in an Excel spreadsheet, which can be viewed easily through KoboToolbox. The analysis of the data using software, such as Microsoft Power BI is not covered in this manual.

Fig. 4.6 The top and bottom of the prescription form as it appears in KobotoToolbox. Each country has the same basic form with a different logo; in this case it is that of Fiji.
Source: Ministry of Agriculture and Waterways. Fiji.

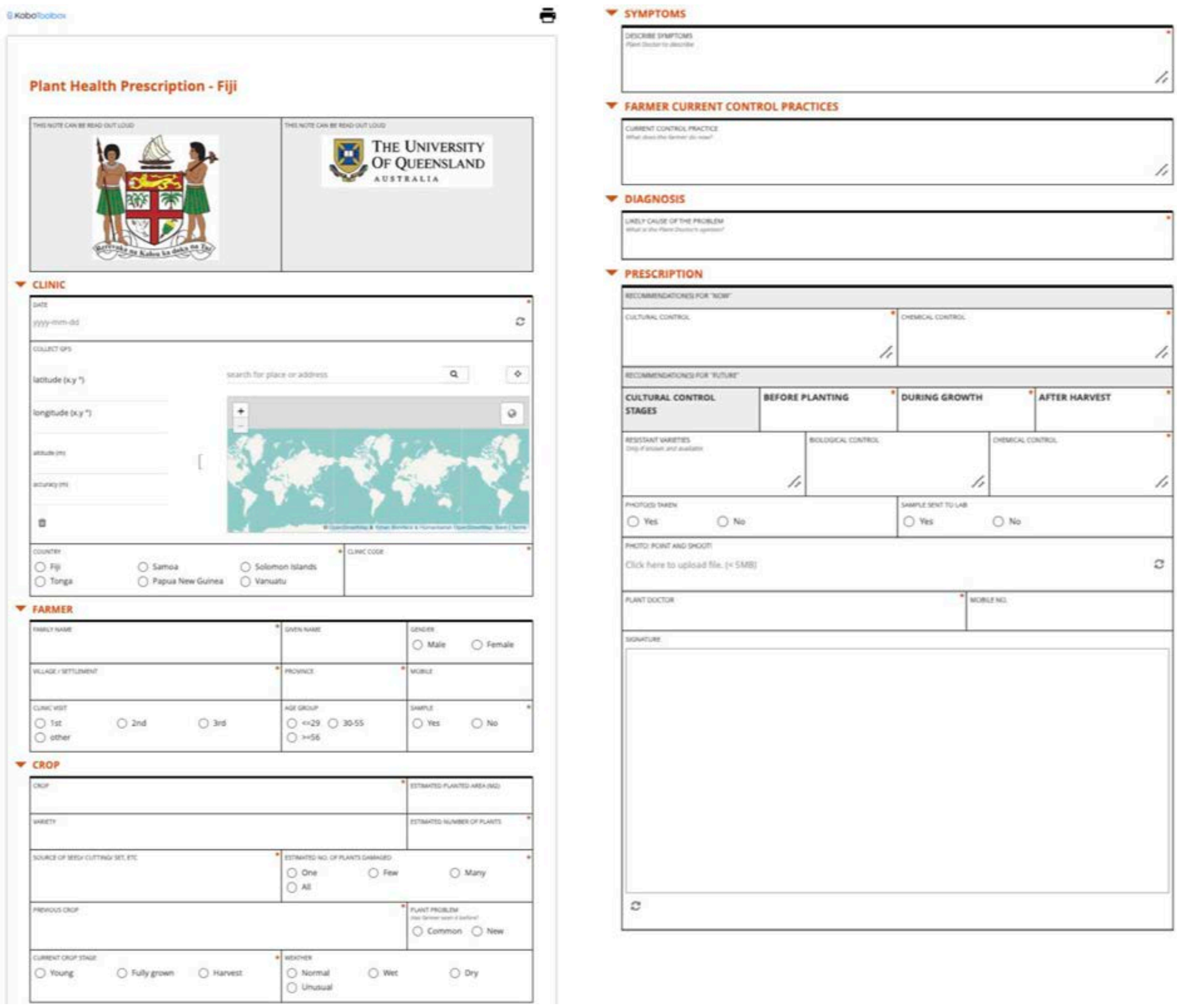


Fig. 4.7 The data from a number of PHCs entered on KoboCollect and then automatically placed in an Excel spreadsheet and hosted by the KoboToolbox server.
Source: Ministry of Agriculture and Waterways. Fiji.

Chapter 5

Integrated Pest and Disease Management Options 1: Cultural and Biological Control

In Chapters 2 and 4, your trainees learned to identify and diagnose plant pest and disease symptoms. Chapters 5 and 6 introduce them to a range of ways farmers can manage agricultural pests and diseases. This chapter covers cultural and biological methods using the ideas and processes of Integrated Pest and Disease Management (IPDM). Chapter 6 focuses on pesticides.

What equipment do I need?

- ❑ samples for class exercises from the field
- ❑ phone or tablet with Pacific Pests, Pathogens & Weeds app
- ❑ butchers or brown paper and marker pens
- ❑ sticky notes or blu-tak
- ❑ hand lens
- ❑ binocular microscope (if available).

5.1 Introduction to using integrated pest and disease management (IPDM)

Pests and diseases are always present, no matter how hard we try to eliminate them! They compete for light, water and nutrients with the crops we grow, and that causes losses of yield and quality. So what can we do? At present, much of the management of pests is done using pesticides. Every year, some 3.5 billion kilograms of chemicals are applied to crops worldwide, worth USD 45 billion. Although chemical use may have peaked, the amount used is still large, and the cost continues to rise. Herbicides form the largest group of chemicals used, followed by insecticides and fungicides.

While there is now increased awareness of the dangers of pesticides, they are likely to remain a major method of pest and disease control for a long time. This is because the world's population is increasing, and so more food is required. As a consequence, more fertiliser is used, which means potentially more plants for pests to eat or diseases to infect. As we learned in Chapter 3, as agriculture becomes more intensive, soils become less healthy and plants become less resilient to attack by pests and pathogens.

Most insecticides are broad-spectrum. They kill all insects, good and bad; they kill bees and other pollinating insects; and they kill birds. They leak through the soil into waterways and kill fish; they add to the expense of crop production and harm humans when applying them. If residues remain on or in the produce, they may cause poisoning, cancers, birth defects or development problems. Some are also endocrine disruptors, which means they can affect hormones in insects and other animals, including human beings.

To make matters worse, resistance to pesticides often occurs, so more has to be applied for the same effect and, as climates warm, pests spread to new areas where, it is speculated, they consume more because of higher temperatures.

In recent years, integrated pest management (IPM) has been suggested as a better option than using pesticides alone. It is a method of pest control that has become very popular and is considered healthier and more environmentally sustainable. To most people, it is about managing insects, because insects are synonymous with 'pests'. However, the method is just as important for diseases, and lately the term IPM has been broadened to IPDM – integrated pest and disease management.

5.2 What is IPDM?

There are many definitions of what IPDM is. Here are a few:

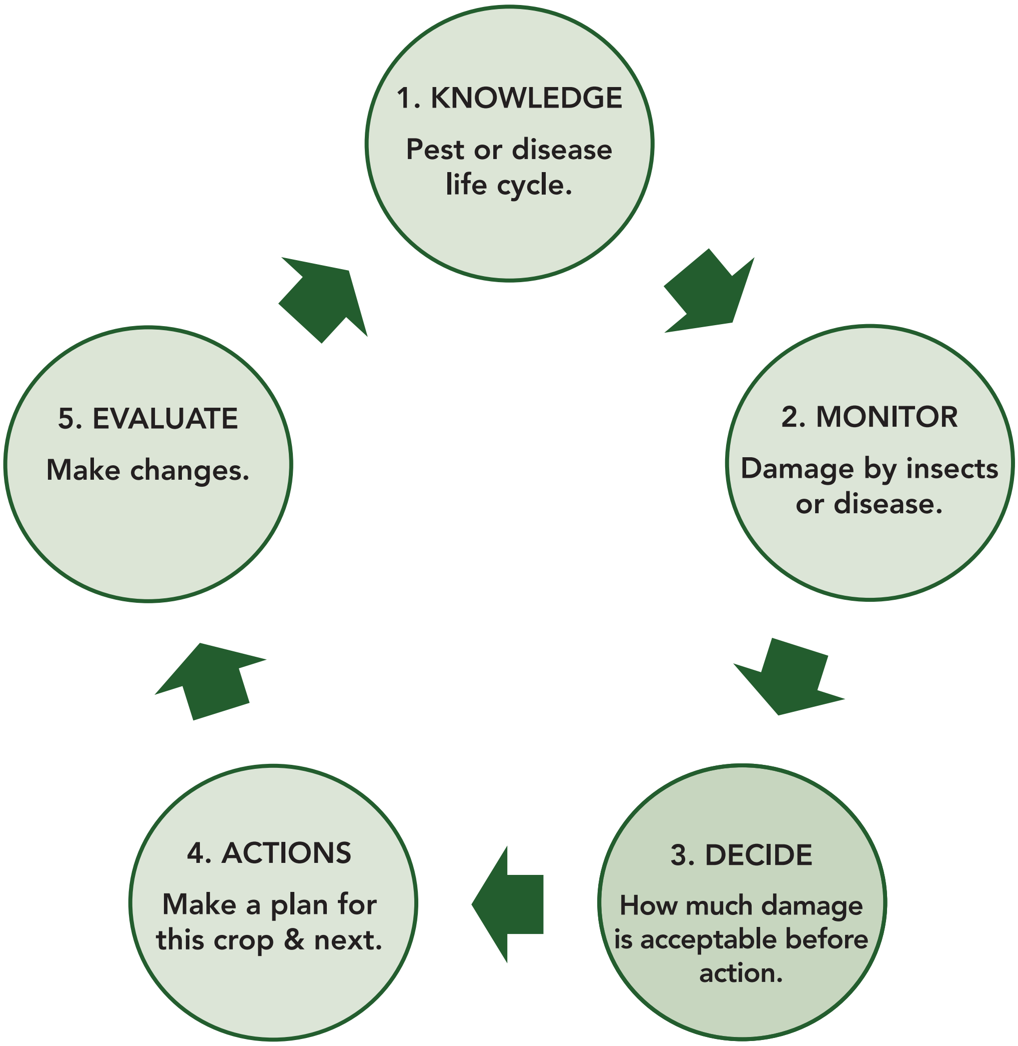
- **IPDM** uses different control measures or options to reduce pest and disease levels in an economical and environmentally sustainable way
- **IPDM** is based on knowledge of pests and life cycles, checking the crop, making plans for action, and evaluating the results
- **IPDM** is a way of encouraging natural enemies: using natural enemies can not be done if you are using broad-spectrum insecticides. IPDM does not preclude the use of insecticides but uses them only as a last resort.

The first definition focuses on costs and the environment, the second on knowledge of life cycles, crop monitoring and making a plan, and the third on promoting biological control methods by protecting natural enemies. No one definition covers them all, IPDM includes all of these, and requires careful observation and knowledge of crops as part of a greater ecosystem.

The most important idea is that it brings together different techniques to control pests and diseases that are least harmful to human beings and the environment. Importantly, for insect pests, it promotes biological control methods.

Fig. 5.1 shows that the IPDM process is a cycle.

Fig. 5.1 The IPDM cycle, indicating the information needed and the actions required for IPDM to be success. *Source: authors.*



It is important to remember that in IPDM, pesticides may be used but only as a last resort

EXERCISE 5.1: What do you already know about IPDM cultural control methods for specific pests and diseases?

1. In groups, trainees should **fill in the table below**, for two pests and two diseases from their region
2. Then **share and discuss** their answers with the class.

An example is given for an insect:

- **diamondback moth** on brassicas, and
- a fungus — ***Elsinoe* scab** on citrus.

	Crop	What IPDM cultural control methods are possible?			
		For large scale	How it works	For small scale	How it works
Insect/mite pest					
Example: Diamondback moth (DBM)	Brassicas	Remove weeds in the Brassica family	Reduce DBM populations that maintain populations between crops	Hand picking caterpillars	Remove pests
1					
2					
Diseases					
Example: Citrus scab *(Elsinoe fawsetti)*	Citrus	Isolate nurseries from orchards	▪ prevents spread of fungus ▪ prune to keep canopy open	▪ isolate nurseries from orchards ▪ prune to keep canopy open	Prevents spread of fungus
1					
2					

5.3 Working through an example of using IPDM

Here is an example of the IPDM process when applied to the green vegetable bug *(Nezara)* on tomato (Fig. 5.2).

Knowledge: what do we know?

- **identify it:** use your knowledge and the identification processes from Chapter 2 and 4
- **look up the fact sheet:** check the colour, its smell and the damage it does — the bug causes white, hard spots where it sucks the fruit (Fig 5.2), see Pacific Pests, Pathogens & Weeds app
- **life cycle:** where does it lay eggs? are there any parasites (black eggs)? how long is the life cycle?
- how do you control it?

[1] Note, that it is much more difficult to apply IPDM to large-scale cropping, which is why pesticides are more often used at this scale.

Monitoring: checking on the pest damage

- **keep a diary and make notes:** is the damage getting worse?
- **go to the garden and check** on the bug twice a week (adults and eggs)
  - look at every one to three plants up to the time of fruiting
  - look at every plant during the time of fruit picking.

Decide: how much damage is acceptable before action?

- Is there more than one bug per plant? From your previous experience (or reading) you know that this will cause crop loss.

Fig. 5.2 Top left, clockwise: Green vegetable bug nymphs; tomatoes with adult green vegetable bug; bug eggs on a tomato leaf; tomatoes with symptoms of green vegetable bug.
Source: Rob Ransom. BuGuide (top left & right).
Wikimedia Commons (bottom right). Extension. University of Georgia (bottom left).

Action: what can you do now & what you can do in the future?

Before planting:

- **soil:** make sure you are planting in healthy soil (see Fact Sheet 486)
- **variety:** consider using a small fruiting variety that may suffer less damage
- **remove weeds** from around the tomatoes
- **location:** do not plant next to infested crops or downwind from other tomato crops
- **keep away from alternate hosts:** e.g. beans, brassicas, cucurbits.
- **biocontrol:** plant flowering plants to attracts parasitoids, e.g. parasitic wasps
- **timing:** plant when there are fewer pests around.

During crop growth:

- keep plants **well-watered** and with nutrients
- **squash** any eggs, nymphs or adults weekly
- **weed** throughout the life of the crop
- **plant a trap crop:** for example, your reading shows that the bug likes yellow, so plant marigolds, chrysanthemums, or mustard around the tomatoes
- **use homemade pesticide sprays:** try chilli and others in Fact Sheet 56
- **protect** fruits by bagging
- **if homemade pesticides do not work**, and the problem persists, only then use commercial sprays — synthetic pyrethroids or preferably biopesticides.

After harvest:

- **collect** the remains of the crop and burn or bury them
- **next crop:** keep weeds to a minimum as bugs hide in weeds
- **next crop:** use wider spaces between plants, so that bugs cannot hide
- **plant next crop in another place:** practise crop rotation.

Evaluation: did the plan work? Make changes if needed

- go over the plan for this season and decide if changes are needed for the next season
- if you used sprays, did they work?
- were they biological sprays?
- were the costs worth it?

EXERCISE 5.2: Using IPDM — working out the steps

The example of the green vegetable bug on tomato shows that for IPDM to work properly, several important steps need to be taken.

These steps are what the plant health doctors need to tell farmers at the PHC. This exercise tests your trainees' knowledge of the IPDM process.

Here are the **steps** needed for IPDM **listed in the incorrect order** below.

- in pairs or small groups, place the steps in the correct order
- discuss your answers with the class.

STEPS IN THE INCORRECT ORDER

A. Go to the garden regularly. Look for damage.

B. Was your plan successful or not? Are any changes needed?
Is it problem likely to be caused by a pest or a disease?
Use the possible/probable approach in Chapter 2.

C. Make a plan of action for the present crop and the next crop:
a) before planting (next crop)
b) during growth of present crop and
c) after harvest of present crop.
If it is a pest, count the pests (can you see natural enemies?).
Is the problem getting worse or not? KEEP NOTES.

D. Decide how much damage is acceptable.

E. Knowledge — identify the pest or disease and know its life cycle.

STEPS IN THE CORRECT ORDER

A.

B.

C.

D.

E.

5.4 Cultural control options for IPDM

The example of the green vegetable bug on tomato in Section 5.3 identified a number of management options that can be used against an insect. Now we will look at these in more detail, and also at some that can be used against plant diseases. The methods involve cultural practices, biological control, as well as the use of pesticides, if necessary, as a last resort.

Good cultural practices are a safe and cheap method of disease control. There are many that can be used and, when several are applied together, they can have a very positive influence on insect pest populations or the incidence of diseases.

It is far better to use cultural practices to prevent or manage pests and diseases, than to use chemical methods (pesticides). It means money does not have to be spent on expensive products which may be harmful to the farmer, to beneficial organisms and to the environment. Also, it reduces the risk of insects becoming resistant to pesticides, which are then of no use, or more has to be applied to achieve control.

Healthy soil

Chapter 3 covered the importance of soil health in detail, and stated that healthy plants are less likely to suffer from pests and diseases than weakened ones. Just as healthy people are less likely to get diseases than unhealthy people, healthy plants are far less likely to suffer from pests and diseases than weakened ones. Healthy soil that is rich in well-decomposed organic matter from compost, has all the essential nutrients and is well-drained, is best for most crops (Fig. 5.3). There are some exceptions, e.g. paddy rice varieties can grow under irrigated (water-logged) conditions where the roots form specialised gas spaces allowing oxygen to be transported from leaves to the roots; taro does the same.

Soil treatment

Nursery soil may contain pests and diseases, so it should be pasteurised with boiling water or steam to prevent pests and diseases from spreading to the field.

Fig. 5.3 Plots of Chinese cabbage in Vanuatu, with and without the addition of chicken manure showing the effect of nutrition on the crop. *Source: authors.*

Healthy planting material

Using healthy planting material – seeds, seedlings, roots and cuttings – is perhaps the most important of all the ways of controlling pests and diseases through cultural practices. There are many examples in the Pacific region of problems occurring because the planting material was infected or infested.

Root crops are especially vulnerable because they are vegetatively propagated, and pests commonly occur in or on the propagating material at planting, e.g. virus and root rot diseases of taro, nematode dry rot of yam, fungal scab and viruses of sweet potato, bacterial blight and scale insects on cassava.

There are also pests and diseases of vegetable and fruit crops that are spread with seedlings, e.g. head cabbage seedlings taken from nurseries with diamondback moth, large cabbage moth, and other caterpillars; watermelon seedlings with spots of gummy stem blight; and passionfruit grafted with scions infected with *Passionfruit woodiness virus*.

Seeds, too, can harbour pathogens, and long beans are frequently planted with *Bean common mosaic virus*. This means that disease outbreaks occur early and, consequently, the damage is greater than if the seed or seedlings were healthy to start with.

In some cases, the diseases are so damaging that healthy 'seed schemes' have been developed to remove the viruses from planting material by heat and tissue culture therapies. In the process, insects and fungal diseases are also eliminated. Seed schemes for avocado, banana, beans, citrus, grape, potato, strawberry and sweet potato are common throughout the world.

Mixed cropping

Many farmers in the Pacific region use mixed cropping. This is a technique in which two or more different types of crops are cultivated together, either in separate rows or mixed. Its advantage is that if one crop fails, there are other crops that can be harvested. Also, mixed cropping may reduce the spread of pests and diseases. Companion plants are sometimes used as part of the mix, e.g. tomatoes planted with onions and marigold, where the marigolds repel some tomato pests.

Crop rotation

Different crops have different pests and diseases, so those of taro, for instance, do not affect yams, and those of yams do not affect sweet potato, and those of sweet potato do not affect beans or cabbages. Therefore, crops are rotated to avoid the build-up of pests and diseases — in and above the soil - that often occurs when one type of crop is planted continuously.

Crop rotation also helps prevent excessive depletion of soil nutrients. Different crops have different nutrient requirements, so that one that needs less nitrogen can follow a crop that needs more. Legumes in rotation help to increase nitrogen in the soil because the bacteria on their roots 'fix' nitrogen from the air, converting it into compounds that plants take in and use for growth. Crop rotation also improves soil structure and fertility if deep-rooted and shallow-rooted plants are alternated. This can increase yields, maximise land use and add to crop and market diversity.

In Pacific islands, after clearing the land by slashing and burning, a common rotation was taro (or yam), one or two crops of sweet potato, cassava and then a bush fallow, often for up to 20 years, depending on the soil fertility and the pressure of the human population on the land. Modern-day population increase means that the fallow period is becoming shorter and shorter, and other ways of keeping soils fertile must be found. This can be done by adding compost, nutrients or mulch, or by growing legumes such as *Mucuna* beans or green manure legume crops that can be ploughed into the soil to increase nitrogen levels.

There has been a lot of interest in recent years in the effect of brassicas, particularly mustards, in crop rotation. When they are chopped finely to break the cells, and are incorporated into the soil, they release compounds called isothiocyanates that are toxic to fungal and bacterial pathogens. When the brassicas are harvested they can be cut off at the stem base so the root stays in the soil, and breaks down to release the toxins. See Chapter 3 for more details.

Table 5.1 shows the different crops that farmers can use to help them draw up options to carry out effective crop rotation. To get maximum benefit from crop rotation it has to be done properly. This is where we can help farmers decide on the correct sequence. Sometimes, without knowing, farmers plant vegetable crops that are all in the same family, such as tomato, eggplant, potato and tobacco, or cucumber, pumpkin, watermelon and squash,

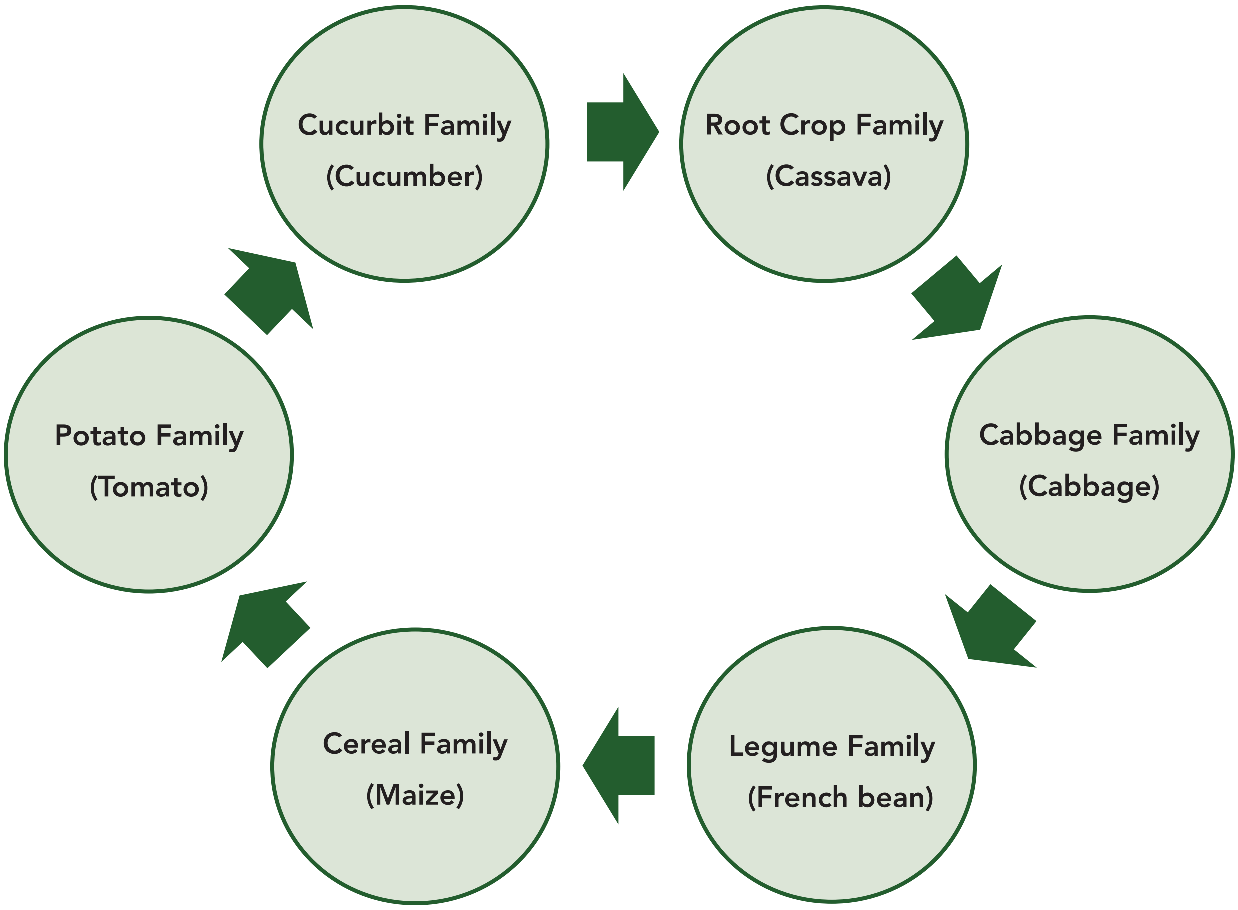
Table 5.1 Common vegetables that belong to the same plant families or groups.

Cucurbit family (Cucurbitaceae)	Cabbage family (Brassicaceae)	Potato family (Solanaceae)	Root crops (not all in the same family)	Cereal family (Poaceae)	Legume family (Fabaceae)	Leafy crops (not all in the same family)
Cucumber	English cabbage	Eggplant	Carrot	Maize	Long bean	Lettuce
Watermelon	Cauliflower	Potato	Taro	Rice	French bean	*Bele* (slippery cabbage)
Pumpkin	Chinese cabbage (Bok choy)	Okra	Yam		*Mucuna* bean	Spinach
Zucchini	Mustard	Chillies	Sweet potato		Other beans	
Bitter gourd	Radish	Capsicum	Cassava			
	Broccoli	Tomato				
		Tobacco				

allowing pests and diseases of these families to build up. Thus it is important for farmers to know which crops are members of the same and different family groupings. Marigolds need to be planted as part of a rotation for nematode control.

It is also important to rotate in the correct sequence, so that plants can benefit from the previous crop. For example, legumes will leave more nitrogen in the soil so should be followed by a crop that needs a lot of nitrogen, e.g. a leafy crop or maize (Fig. 5.4).

Fig. 5.4 An example of a crop rotation cycle. *Source: authors.*



EXERCISE 5.3: Applying crop rotation

- in pairs or small groups, trainees should **fill in the table below** to show which group of crops and examples of each group would be good to use in a crop rotation in different plots.
- they should **give reasons** for their answers and discuss them with the rest of the class.

Cycle	Plot 1	Plot 2	Plot 3	Plot 4
1	Leafy crop e.g.			
Reason why you chose this crop rotation:				
2	Solanaceae crop e.g.			
Reason why you chose this crop rotation:				
3	Root crop e.g.			
Reason why you chose this crop rotation:				
4	Legume crop e.g.			
Reason why you chose this crop rotation:				

Isolation of crops

Isolation prevents pests and diseases spreading. Traditionally, taro and yam were grown in relative isolation within forests. It might have been done to hide the plants from evil spirits, or to protect them from theft or the strong winds and rains of the mountains, but the result was the same; severe pests and diseases were kept in check. This was also the time when the population was relatively low, and most people lived in mountainous inland areas. Today, it is different: the majority of people live on the coast, and populations are much higher. There is less forest, and gardens cannot be hidden, so it is much easier for pests and diseases to spread.

Isolation should also apply to nurseries. Nurseries should be far from field plantings to avoid the chance of infection by pests or infestation from diseases (Fig. 5.5).

Good crop hygiene

Rogueing (removing infected plants) to destroy sources of infestations by insects and mites and infections by diseases (fungi, bacteria, phytoplasmas, viruses and nematodes) can have a huge benefit (Fig. 5.6). It is especially effective if it is done early in the growth of the crop before the problem spreads, and regularly afterwards. It involves burning, burying or hot-composting infected plants.

Removing the remains of the harvested crop is also beneficial. It will reduce fungal growth, spores, bacteria and insects that might otherwise spread to new crops or spread to volunteer (self-grown) plants or weeds, ready to attack the next crop.

Fig. 5.5 Bad practice: Chinese cabbage beds close to the nursery where plants are infested with DBM.

Source: authors.

Fig. 5.6 Bad practice: diseased cabbages left in the field will infect the next crop to be planted nearby. *Source: authors.*

Weeds

Early detection and removal of weeds is important for several reasons:

- they can smother the crop, preventing it from getting sunlight
- they take water and nutrients that would otherwise feed the crop
- they can create conditions that favour the rapid increase of pests and diseases, for instance, by creating conditions of high humidity
- they harbour pests and diseases, which spread from the weeds to the crop.

It is best to remove or cut down weeds before they flower and seed. If you remove weeds before they flower (i.e. before any seeds are produced), you can put them in a barrel of water and leave them for a few weeks. They make good fertiliser!

Companion planting

Companion planting can be thought of as a method of biological, as well as cultural control. Crops are interplanted or surrounded by other plants ('companions') that repel or attract insects for their benefit or improve the soil. The benefits might not be large, but they can be useful in many ways. It is a method that is probably more useful in backyard gardens and small farms than pest control in large areas, although companion plants can be grown along the edges of crops or between rows.

The benefits of companion plants are listed below, with specific examples shown in Table 5.2:

- they may attract beneficial predator insects by providing a nectar source, and they may attract insect-eating birds
- they may attract insects that pollinate crops
- they may produce strong-smelling chemicals that repel or confuse pests
- they may attract pests away from crop plants
- they form a natural break between crops so that pests find it more difficult to travel from crop to crop
- they increase the level of biodiversity in the garden
- they can be used to support each other, e.g. corn stalks can act as support for yams — groups of crops planted together that are mutually beneficial are called 'guilds'.

Trap cropping is a variation of companion planting. *Bixa* (the lipstick tree)

Table 5.2 Examples of companion plants and how they are thought to work.

Companion plant	What does it do?
Coleus (*Solenostemon*)	Planted among taro, possibly as a source of nectar for parasitoid wasps
Marigold (*Tagetes*)	Repels root knot nematodes. It must be planted as a block, not as scattered plants, for several months before the crop is planted
Basil (*Ocimum*)	Repels thrips, flies and mosquitoes
Coriander (*Coriandrum*)	Repels aphids, mites and leaf-eating beetles
Mint (*Mentha* spp.)	Repels aphids, cabbage moths and mice
Plants in the families *Apiaceae* (e.g. carrots) and *Asteraceae* (e.g. daisies)	Attract hoverflies, lacewings and ladybird beetles; note, ladybird beetles (adults and larvae) as well as the larvae feed on plant-sucking pests
Chives and garlic (*Allium*)	Repels some species of aphids and mites
Chives and mustard	Said to be useful in preventing infection from bacterial wilt

is an example from Solomon Islands, where it is has been seen to attract *Riptortus* bugs planted near yard long beans. Another example is planting mustard or Chinese cabbage (bok choy) alongside cabbages to attract diamondback moth and aphids, but the plants must be destroyed before the eggs hatch. In recent years, the FAO has been promoting the 'push-pull system' for the control of the FAW. In this system, maize is intercropped with silverleaf or greenleaf desmodium *(Desmodium uncinatum* or *Desmodium intortum,* respectively). These legume species produce volatiles that repel FAW moths; this is the 'push'. Around the plots of maize, Napier grass (*Pennisetum purpureum*) is planted, a perennial grass that attracts FAW moths; this is the 'pull'.

Timing

Growing crops off-season when there are fewer pests and diseases present is a good strategy, although yields may be affected by sub-optimal environmental conditions. Planting early maturing varieties is a part of this strategy; it works well with, for example, sweet potato, where early maturity is sought by farmers to avoid weevil infestations, and also with yams to avoid lightning/dieback *(Colletotrichum gloeosporioides)*.

5.5 Genetic control

5.5.1 Resistant varieties

Some varieties of Pacific island food crops are more resistant to pests and diseases than others. They have been selected by growers over many hundreds, if not thousands, of years. For example, the so-called 'female' taro varieties in Solomon Islands are resistant to *Alomae*. Some yams are tolerant to lightning/dieback, especially the late-maturing varieties, and there are local, Pacific, varieties of bananas resistant to black Sigatoka disease.

Usually, it is not good to have a crop that is totally resistant to a pest or disease, as this can result in the preferential selection for rare individuals that carry genetic resistance and they become dominant in the population. A level of tolerance is better. A level of tolerance is better. There is some infection, but not enough to be of concern, but sufficient that there is no pressure on the pathogen population to select new strains. An example is the Samoan and Papua New Guinea lines bred for tolerance (not resistance) to taro leaf blight.

We see similar differences in resistance in more recently introduced crops. For instance, among cocoa varieties there are differences in resistance to black pod and canker. In Papua New Guinea, varieties of cocoa have been bred for tolerance to those diseases and also to vascular streak dieback.

The greatest efforts of plant breeders are to be seen in the vegetable industry, where there are now numerous varieties resistant or tolerant to problematic diseases. For instance, there are tomato varieties that are resistant to root knot nematode, bacterial wilt and late blight; cabbages with tolerance to black rot and club root; and zucchinis resistant to several viruses.

Vegetable seed catalogues of all major companies list pest and disease characteristics of their commercial varieties. Pacific countries should take advantage of this, so that farmers have the very best chance of combatting pest and disease problems.

5.6 Biological control

Biological control makes use of the 'natural enemies' that are active all the time, without human influence and mostly without being noticed. There are many types of biological control: predators, parasites (mostly other insects), and also beneficial pathogens — bacteria, fungi, viruses and nematodes (see Chapter 2, Section 2.3.1 'What is a pest?').

Predators that eat pest species are spiders, scorpions, ladybird beetles, lacewings and hoverfly larvae, predatory thrips and predatory mites (Fig. 5.7). They all hunt and kill their prey. Insect-eating birds, lizards and frogs are also useful in controlling pests. If these are present, care should be given to maintaining them. Some farmers keep ducks[2] and chickens that also eat pests.

However, it is the parasitoids — so-called because, unlike parasites, they kill their hosts — that often do most to control pests. Common parasitoids are species of wasps (Fig. 5.8). Parasitoid activities often go on without farmers noticing them, although sometimes the 'mummies' of aphids can be seen on

Fig. 5.7 Syrphids (pale green, slug-like) larvae of hoverflies, and larvae of ladybirds (purple) eating aphids on maize. *Source: authors.*

[2] Indian runner ducks like to eat slugs and snails. These are a good solution for control of the Giant African snail.

leaves; these are the dark, dead, swollen bodies of adult aphids, often with holes where parasitoid wasps emerged. But just because parasitoids go about their beneficial acts mostly unseen does not mean that farmers have no influence on the work that they do.

5.7 Pesticides and IPDM

Pesticides used by farmers are likely to have considerable impact as they will kill parasitoids, the natural enemies of pests.

Farmers need to know that if IPDM is to be successful, they should be very careful about pesticide use and, in particular, the type of pesticide used. Not all pesticides are the same. Many are broad-spectrum, which means they kill all insects. After the pesticide decays in the environment, the pest may come back in larger numbers as their natural enemies have been destroyed.

So, before reaching for a pesticide, farmers need to think whether natural enemies might be present. The difficulty in most instances is to know if there are any, as most natural enemies are minute wasps, too small to be seen by the naked eye.

5.7.1 Biocontrol and biological pesticides

The best solution is to avoid broad-spectrum pesticides. Instead, use those that decay rapidly after use or, if appropriate, use a product derived from bacteria, fungi, or viruses, which cause diseases in the pest. These have a specific biological rather than a chemical action and are known as 'biocontrol pesticides' or 'bio-insecticides'. Several have been commercialised to maximise biocontrol in vegetables (see Fact Sheet no. 472 in the Pacific Pests, Pathogens & Weeds app). A summary of the common ones follows:

5.7.1.1 Bt – Bacillus thuringienisis

Bacillus thuringienisis or Bt, is the best example of a commercialised bio-insecticide. Bt produces very specific protein toxins that kills caterpillar pests. Bt is useful for the control of hornworms, some armyworms,

Fig. 5.8 Adult Diadegma wasp, laying eggs in a larva of diamondback moth.

Source: Mike Furlong. University of Queensland.

diamondback moth, and many other caterpillar pests. Usually, it is more effective against young caterpillars than against those near maturity. The common caterpillar strain is *Bt kurtaki*.

Bt is sold under the name AgChem Bt-a and AgChem Bt-k (in Fiji, Tonga and Samoa) but it is also sold as DiPel® or XenTari®. The toxins in AgChem Bt-a are the same as those in XenTari® and the toxins in AgChem Bt-k are the same as those in DiPel®. These formulations only infect caterpillars, but other strains can infect beetles *(Bt tenebrionis)* and fly larvae *(Bt israeliensis)*.

5.7.1.2 Spinosad

Spinosad contains chemicals from the soil bacterium, *Saccharopolyspora spinosa*. It is sold under the name of Success, and used against a similar range of insects as Bt. Another product, spinetoram, is also from the same bacterium, and closely related to spinosad. It is active against Lepidoptera larvae (caterpillars), thrips, and certain flies, beetles and psyllids.

5.7.1.3 Metarhizium and Beauveria

Fungi are also used as biological insecticides. *Metarhizium* causes green muscardine disease. The fungus has been used extensively in parts of the Pacific against the rhinoceros beetle of coconuts, and also against *Papuana* beetle of taro. In neither cases was it particularity effective. In other parts of the world, it is used against swarms of locusts. To a lesser extent, *Beauveria* is used; this causes white muscardine disease of termites, whiteflies and beetles.

Beauveria is being used in the highlands of Papua New Guinea (and elsewhere) against the coffee berry borer weevil *Hypothenermus*.

Note: products such as 'Green muscle' or Green guard', containing strains of Metarhizium anisopliae have been used against locusts in East Africa and other parts of the world

5.7.1.4 *Trichoderma*

Some fungi are used as biological fungicides. *Trichoderma*, a soil fungus, has been commercialised for use against a number of soil pathogens. It readily colonises the root system of plants, out-competing potential pathogens. To do this, it produces antibiotics against its competitors, as well as parasitising them. There is also evidence that it produces chemicals that increase the resistance of the host plant to root pathogens.

5.7.1.5 Viruses

Viruses can be highly effective natural control agents of several caterpillar pests but commercialisation has been limited. The naturally occurring nuclear polyhedrosis virus is sold under the name of *Gemstar* but mass production is costly, as it has to be multiplied in living insects. The best example of the virus being used in the Pacific region is the use of *Oryctes rhinoceros nudivirus* for the control of *Oryctes,* the rhinoceros beetle — Pacific strain. Unfortunately, there have been reports that the virus is not effective in all places to which *Oryctes* has spread in recent years.

5.7.1.6 Nematodes

There are several *Heterorhabditis* and *Steinernema* species of nematodes, which are used against a variety of agricultural pests. They attack insect larvae, tracking them in soil by following their excretions, carbon dioxide emissions or temperature changes. Once found, the young, called juveniles, enter the insects through natural openings and release a bacterium that kills the insects within one or two days. The nematodes mate, lay eggs and produce many young, which feed off the body of their host, until they are released into the soil, and the cycle starts all over again.

Fig. 5.9 provides a summary of all methods that can be used for management of pest and disease problems.

Fig. 5.9 A summary of all control options for pests, diseases and abiotic factors. *Source: authors.*

MANAGEMENT OPTIONS FOR PESTS, DISEASES AND ABIOTIC FACTORS

CULTURAL

1. healthy soil
2. healthy planting material
3. mixed cropping
4. crop rotation
5. isolation of crops
6. crop hygiene
7. removal of weeds
8. companion planting
9. timing
10. resistant/tolerant varieties
11. aspect/location.

BIOLOGICAL

1. predators, e.g. insects, spiders, scorpions, ducks, chickens, lizards, snakes, frogs, birds, bats
2. parasitoids — insects whose larvae are parasites which eventually kill their hosts, e.g. some wasps
3. biological fungicides, e.g. *Trichoderma, Metarhizium Beauveria*
4. biological insecticides, e.g. Bt, Spinosad, *Oryctes rhinoceros nudivrius*
5. nematodes, e.g. *Heterorhabditis, Steinernema*
6. companion planting.

CHEMICAL (PESTICIDES)

Insecticides, fungicides, herbicides etc. (Chapter 6)

1. home-made
2. commercial.

EXERCISE 5.4: Concept mapping of IPDM

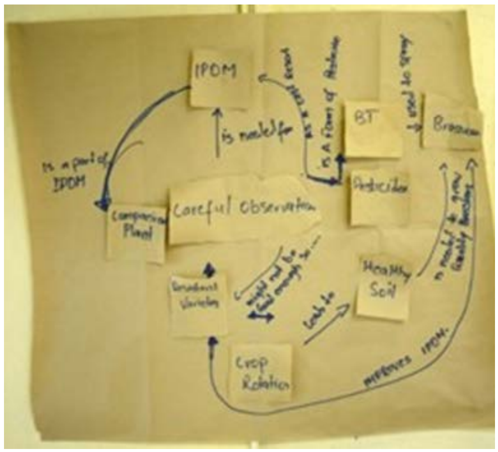
After working through the information on IPDM, your trainees should have a good overview of the concepts. This exercise helps them make the connections between them.

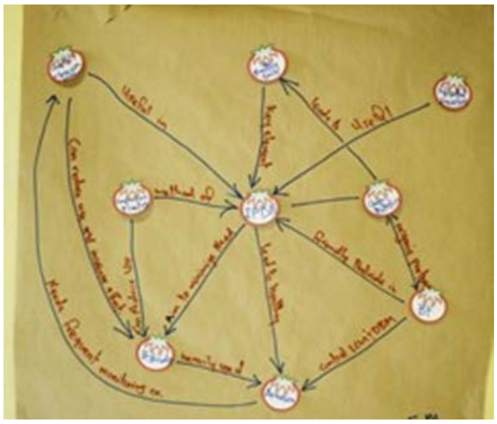
- **in pairs or small groups**, trainees should write each of the following terms (concepts) on a piece of paper or sticky note
- **they should arrange them** and stick them on butchers paper or brown paper to create a concept map, linking the terms
- it is important that they **write the relationship** between the terms on the linking lines
- when they have finished, ask them to **put their map on the wall** and explain the map to the rest of the class.

Here are some suggested terms for a map.

You or your trainees can decide to **add other terms or change them**, depending on the concepts you are teaching

- IPDM
- companion plants
- pesticides
- Bt
- resistant varieties
- healthy soil
- brassica plants
- crop rotation
- careful observation.





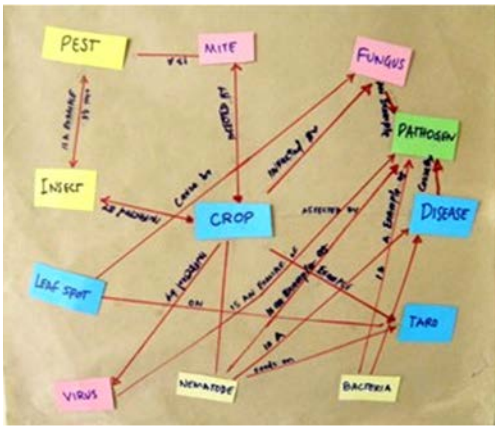


Fig. 5.10 Examples of concept maps from Tonga and Solomon Islands.
Source: authors.

EXERCISE 5.5: Summary of cultural practices for IPDM control of some common pests and diseases

- in pairs or small groups, trainees should use the resources and information covered in this section to **complete the table below**
- they should **use examples they are aware of**
- **indicate with a tick (✓)** which cultural practices they think work to control the pest or disease
- **they should indicate with a cross (✗)** if they think it will not work. When finished, trainees should discuss their ideas with the rest of the class.

Cause	Example	Crop & part affected	CR	GH	F	GD	CP	V	HPM	HP	TC	BC
Pests (insects & mites)	Tomato fruit borer	Tomato fruit	✓	✓	✗	✗	✗	✗	✗	✓	✓	✓
Pathogen (nematodes)												
Pathogens (fungi, bacteria & viruses												

Key

CR: Crop rotation

GH: Good hygiene

F: Fertiliser/compost/organic matter

GD: Good drainage

CP: Companion planting

V: Resistant variety

HPM: Healthy planting material

HP: Hand picking

TC: Trap crops

BC: Biological control

CHAPTER 5 QUIZ: Test your knowledge

Multiple choice. Pick one answer only...

1. In IPDM, pesticides should be used:

A. always
B. never
C. as a last resort
D. only if the farmer can afford them.

2. The adult in the picture below is most likely to be:

A. a beetle
B. a wasp
C. a lacewing
D. a fly.

3. In order, a companion plant, a bio-insecticide and a beneficial organism are:

A. taro, DBM, Trichoderma
B. Chinese cabbage, kocide, ladybird
C. coconut, pyrethrum, Trichogramma
D. marigold, Metarhizium, spider.

4. An example of good crop rotation would be:

A. lettuce, cabbage, broccoli, bean
B. cucumber, squash, potato, cassava
C. potato, tomato, eggplant, capsicum
D. bean, cabbage, cassava, cucumber.

5. Rogueing means:

A. using bio-insecticides
B. destroying infected plants
C. using companion plants
D. planting resistant varieties.

6. In IPDM, monitoring involves:

A. deciding whether the problem is caused by a pest or a disease
B. using the best pesticide for the pest
C. checking the level of damage and looking for bugs and eggs
D. identifying the pest or disease

7. The correct sequence for applying IPDM is:

A. monitoring, evaluation, making a plan, identification of pest or disease
B. evaluation, monitoring, identification of pest or disease, making a plan
C. making a plan, identification of pest or disease, monitoring, evaluation
D. identification of pest or disease, monitoring, decide amount of damage acceptable, making a plan

8. Which plants are all in the same plant family?

A. cabbage, bok choy, broccoli, chilli
B. potato, cassava, taro, sweet potato
C. bitter gourd, pumpkin, cucumber, squash
D. capsicum, chilli, eggplant, bean

9. The best way to control a soil-borne bacterial infection is:

A. to use a resistant variety if it can be obtained
B. to spray with a pesticide
C. to find a virus that attacks the bacteria
D. to add compost to the soil.

10. Which of the following is NOT thought to be a characteristic associated with companion planting?

A. companion plants can provide food for parasitoids
B. companion plants may have a smell that repels pests
C. companion plants put copper into the soil
D. companion plants may repel root knot nematodes.

Chapter 6

Integrated Pest and Disease Management Options 2: Using pesticides

This chapter covers a range of pesticides and how to use them safely.

What equipment do I need?

- ❑ pesticide labels (for Exercise 6.2)
- ❑ PNG videos on Safer Use of Pesticides
- ❑ photos of pests and diseases from PNG Highlands (for Exercise 6.6)
- ❑ knapsack sprayer and nozzles
- ❑ butchers paper or brown paper
- ❑ marker pens
- ❑ samples from farm or garden.

6.1 Introduction to using pesticides

In Chapter 5, your trainees learned about cultural practices of managing plant pests and diseases within an IPDM system. They also learned that in an IPDM approach, pesticides are used as a last resort because of the many problems with their use. The reality is that large-scale pesticide (chemical) use throughout the world is likely to continue for some time. If pesticides are to be used, it is best not to use those which are broad-spectrum as they kill all harmful insects as well as those that are beneficial. Some pesticides are allowed in organic farming as well. In this chapter we look at a range of pesticides and how to use them safely.

The definition of a pesticide is a substance that is made to kill pests, such as insects, weeds, pathogens, mites, rodents, snails and slugs. Sometimes they are referred to as chemicals. Because they are poisonous, pesticides should be used only in IPDM when cultural controls do not work. Pesticides can be divided into two groups: homemade (Table 6.1) and commercial (Table 6.2). Homemade pesticides are made from materials usually readily available in the home or from local plants. Commercial pesticides MUST be made up according to the manufacturer's instructions.

6.2 Homemade pesticides

Many farmers and people living in urban areas make their own pesticides because it is cheaper to do so. However, there are drawbacks. The recipes, and hence the active ingredients in the sprays, vary a great deal. We have not tested them for the problems that exist in the Pacific region, so we don't know if our recommendations are going to work. For instance, chilli is recommended against caterpillars and other kinds of insects, but the type of chilli to use, whether it is affected by age, how much to use and which caterpillars are controlled, are unknowns.

There is also the safety factor. Just because a spray is home-made, it does not mean that it is safe to use. Some ingredients are toxic; for example, tobacco contains nicotine, which is poisonous to mammals. There is also the possibility of spreading viruses that may be present in tobacco leaves used as a pesticide. So, take care when these products are being made, and when they are being used.

Treat all homemade pesticides as poisons; never assume they are harmless. Be sure to test any homemade spray you make on just a few plants before spraying the entire garden.

6.2.1 Safe handling of home-made pesticides

When handling home-made pesticides:

- **select fresh, healthy plant parts** to use as pesticides; reject plants with mould on them
- **dry plant parts properly** for future use — keep in an airy container (not a plastic container) in a shady dry place
- **do not use household cooking utensils** or drinking water containers for preparing plant extracts — clean all tools well after using them
- **avoid contact with crude extracts** during preparation; wear protective clothing when applying — if you do not have rubber gloves, cover your hands in plastic bags
- **keep plant extracts away from children**, house pets and other animals.
- harvest all mature and ripe fruits on trees **before spraying**
- **always test the plant extract** on a few infested plants before large-scale spraying
- **wash your hands after handling** the plant extract and wash your clothes as well
- if there is left-over spray, **dispose of it properly** (see Section 6.3.1).

Table 6.1 Homemade pesticides, including some commonly bought products, where they are used, their active ingredients and their purpose.
The list is from Solomon Islands and also indicates where used elsewhere.

HOMEMADE PESTICIDES							
Type of pesticide	**Fiji**	**Samoa**	**Solomon Islands**	**Tonga**	**Active ingredient**	**Purpose**	**Remarks**
Ash	✓	✓	✓	✓	Potassium and calcium carbonates (alkali)	Grasshoppers and beetles	
Baking soda		✓			Sodium bicarbonate (alkali)	Used against powdery mildew fungi, and also against ants	Also used to rid apples of pesticide residue
Beer	✓	✓	✓	✓	Alcohol	Slugs and snails as bait	Also used as fruit fly bait in Australia
Chilli	✓	✓	✓	✓	Capsaicin	Ants, aphids, caterpillar, mealybugs	
Derris	✓		✓		Rotenone	Caterpillars, grasshoppers, aphids, spider mites, planthoppers, beetles	Rotenone is a fish poison
Fu'u (*Barringtonia* species)			✓		Saponins	Caterpillars, aphids and more	Fish poison used in Solomon Islands
Garlic	✓		✓		Allicin	Caterpillars, mites, thrips, and possibly some fungal diseases	
Glircidia	✓		✓		Dicoumarol (interferes with vitamin K)	Aphids, caterpillars, whitefly, and also a rat poison	May need to mix bark with maize and boil and then allow to ferment
Hot water	✓	✓	✓	✓	Heat	Ants, nematodes in yam cuttings for planting and to sterilise nursery soil	
Marigold	✓		✓	✓	a-therthienyl	Insects and is a repellent planted for control of (root knot) nematodes	*Tagetes patula*, *Tagetes erecta*, and *Tagetes minuta*
Milk					Milk fat	Powdery mildew fungi	Use full cream (whole milk) at full strength
Neem	✓	✓	✓		Azadirachtin	Caterpillars, grasshoppers and many more; some fungi and nematodes	Mature seeds have higher active ingredient
Papaya					Papain (enzyme breaks down proteins)	Thrips	Hand soap, not detergent
Soap	✓	✓	✓	✓	Sodium stearate (alkali)	Scale insects, mealy bugs, aphids, and mites	Soap made from coconut oil is ideal
Soursop	✓	✓	✓		Acetogenins	Aphids, caterpillars, (e.g. DBM), planthoppers, grasshoppers	
Tobacco			✓		Nicotine	Caterpillars, aphids and more	
White oil					Smothers pests	Powdery mildew fungi and also many sucking insects, especially scales, aphids, and mites	

6.2.2 Preparing home-made pesticides

Homemade pesticides can be used in many different ways to control pests. Read through the following recipes with your trainees.

Chilli: active against aphids, caterpillars, mealybugs, scales

1. Take 1 cup dry or 2 cups fresh chillies.
2. Crush to a fine paste.
3. Put the paste into a bucket with 1 litre of water and rub with your hands (wear rubber gloves or cover hands with plastic bags) — soak for at least one hour, squeeze and strain.
4. Make up to 1 litre of water.
5. Add 1 teaspoon of grated hand soap.

Soursop or custard apple: active against aphids, caterpillars, (diamond back moth), plant hoppers, grasshoppers

1. Boil 500 g of fresh leaves in 2 litres of water until the water is reduced to 0.5 litre.
2. Dilute to a total of 10 litres of water.
3. Strain and add 10 teaspoons of grated hand soap.

OR

1. Take 2 handfuls of seeds and grind to a fine powder.
2. Mix with 4 litres of water and soak overnight.
3. Strain and add 4 teaspoons of grated hand soap.

Tobacco: active against caterpillars, aphids, beetles

1. Crush 5 large leaves.
2. Add 1 litre of water and leave overnight.
3. Make up to 2 litres with water.
4. Strain and add 4 teaspoons of grated hand soap.

Garlic: active against caterpillars, mites, thrips, and possibly some fungal diseases

1. Scrape 4 garlic cloves and soak them overnight in a small amount of vegetable oil.
2. Make up to 2 litres with water.
3. Strain and add 4 teaspoons of grated hand soap.

Neem: active against caterpillars, aphids, grasshoppers, whiteflies, beetles, scale insects (either killing or repelling them). It stops insects from feeding

Leaves:

1. Put 1 kg of leaves and 5 litres of water in a bucket and leave overnight.
2. Remove the leaves — *retain the water.*
3. Pound and squeeze the leaves.
4. Add the 5 litres of water used for soaking the leaves overnight.
5. Strain and add 5 teaspoons of grated hand soap.

Mature seeds:

1. Wash and remove the dry husk.
2. Take 12 handfuls of dry seeds (or use 500 g for each litre of water).
3. Grind them to a fine powder.
4. Mix the powder in 12 litres of water and soak overnight.
5. Strain and add 10 teaspoons of grated hand soap.

Derris: active against caterpillars, grasshoppers, aphids, spider mites, plant hoppers, beetles. (Note, this is very toxic to fish)

1. Take 2 roots of derris (20 cm long and as thick as a small finger) and crush well.
2. Put the crushed roots in a bucket and cover them with water; leave overnight.
3. Make up to 2 litres with water.
4. Train and add 4 teaspoons of grated hand soap.

Marigold: active against insects and is a repellent (planted for control of nematodes)

1. Collect 2.5 kg leaves/flowers; pound and mix with enough water to cover them.
2. Strain through a cloth and make up to 18 litres of water; add 4 teaspoons of grated hand soap.

Gliricidia: active against aphids, caterpillars, whitefly

1. Grind or pound 0.5 kg leaves.
2. Soak overnight in water.
3. Make up to 20 litres with water.
4. Strain and add 5 teaspoons of grated hand soap.

Papaya: active against thrips — active against other insects and is a repellent (planted for control of nematodes)

1. Shake 1 kg of leaves in one litre of water and squeeze through a cloth.
2. Add 4 litres of soap solution (100 g soap/25 litres water).

Soap: active against scale insects, mealybugs and aphids

Note: Use hand soap, not washing detergent

- Put 5 tablespoons of soap into 4 litres of water .

or

- 2 tablespoons of dishwashing liquid in 4 litres of water.

Ash: active against grasshoppers and beetles

1. Take ash from a fire (make sure it is cool).
2. Beat it to make it fine.
3. Put it in a coarse cloth or a strainer.
4. Shake thinly over each leaf.

Hot water: active against ants, nematodes in yams, and used to sterilise nursery soil

- **ants** – use hot water to destroy nests, but be careful not to pour hot water onto the roots of small plants that might be growing close to the nests — you will kill the plants!
- **soil** – use hot water to sterilise soil: pour it over the soil you have placed in seed boxes or over nursery soil that is spread thinly on the ground
- **yams** – use hot water to kill nematodes in yams with dry rot, before cutting and planting — dip the whole yam in hot water at 51 degrees centigrade for 10 minutes (use a thermometer and clock – do not guess!).

White oil: active against powdery mildew fungi and many sucking insects, especially scales

1. Pour 3 tablespoons (1/3 cup) cooking oil into 4 litres of water.
2. Add ½ teaspoon detergent soap.
3. Shake well and use.

Milk: active against powdery mildew fungi

1. Use full-strength milk, diluted to 10% (1 part milk, 9 parts water).
2. Add a few drops of dishwashing liquid as milk does not spread over the leaf surface by itself.

Beer: active against slugs and snails

1. Place beer in a shallow pan/saucer with edges even with the ground.
2. Snails and slugs will crawl in for a taste and drown.

Baking soda (sodium bicarbonate):

1. As a fungicide

1. Dissolve one or two tablespoons of baking soda in 4.5 litres of water.
2. Spray once a week.

- Sodium bicarbonate can be an effective way of controlling fungal growth. It is registered by the US Environmental Protection Agency as a bio-pesticide.
- Sodium bicarbonate increases the alkalinity of the surface of the leaves so that it becomes unfavourable for the growth of fungi. It might also leave a protective layer.
- Sodium bicarbonate can be used on cabbage, cucumber, lettuce, melon, squash and tomato. It is also useful for most ornamentals, although it is advisable to test a few leaves first before you spray the whole plant, as herbs and other tender-leafed plants may show signs of burning.

2. An insecticide for soft bodied insects such as aphids and a fungicide for vegetables

1. Combine five cups of warm water with:
    - 2 teaspoons baking soda
    - 2 teaspoons dishwashing liquid
    - 1 ½ teaspoons of vegetable oil
    - ½ teaspoons of natural vinegar
2. Blend until the mixture is white and foamy, then spray it on the plants right away with a hand sprayer. Agitate the sprayer as you go. Try to cover the leaves of your plants and give any bugs a good shower of the spray, so that it covers their exoskeleton and suffocates them.

6.3 Commercial pesticides

As discussed in Chapter 5, pesticides, in particular commercial products, should be used only as a last resort under the IPDM framework. When working with commercial pesticides, trainees must be aware of the dangers, not only to crops but also to those who are applying them and their families. When using commercial pesticides, trainees should make sure that the labels are read carefully and checked to make sure they are the right product.

Commercial pesticide manufacturers create these products to make a profit. So some manufacturers may try to increase their sales by giving a new name and packaging to a 'new' pesticide, which may not be new at all, but just using the same active ingredients as many older products.

It is important to understand and be aware of the active ingredients in commercial pesticides, so that money is not wasted on gimmick products and more importantly, to avoid contributing to pesticide resistance in crops.

Before going further, test your trainees' prior knowledge of commercial pesticides asking them to complete Exercise 6.1.

6.3.1 The pesticide label — an important document

Pesticide labels should provide all the information about how to use the chemical. Trainees should understand that once they have bought a pesticide, they must always READ, UNDERSTAND and FOLLOW label directions.

The label should have information on:

- the type of product
- what it contains
- the crops it may be used on
- the pests it may be used against
- how it may be applied
- personal protective equipment
- transport
- storage
- disposal after use
- environmental concerns
- what to do in emergencies.

Trainees should not be surprised if they can't find all the information they need on the label: it might be missing! If it is not present, it may be because there was not enough space for all the details.

EXERCISE 6.1: What do you already know about commercial pesticides?

- **Purpose** column: trainees should describe their use
- **Type of pesticide** column insert:
  - F (fungicide)
  - I (insecticide)
  - H (herbicide) or
  - M (molluscicide)
- trainees should list the **active ingredient**
- check answers in Table 6.2.

Pesticide name	Purpose	Type of pesticide	Active ingredient
Attack			
Sundomil			
Glyphosate			
Kocide			
Confidor			
Orthene			
Agazone			
Suncloprid			
Talendo			
Blitzem			
Steward			
Prevathon			
Others:			

Often the label is divided into three panels or sections are laid out in a row or column: left, central and right. BUT NOT ALWAYS! The central panel may be above the other two instead.

6.3.1.1 Central panel

The central panel contains information on common and trade names, what is in the product, what it is used for, as well as the risks involved in using it.

The information usually consists of all or some of the following:

- **warnings:** it might catch fire, keep it away from children, it can damage the environment, particularly fish and bees
- **trade name:** the name given by the company, e.g. Attack or Bravo
- **common name:** a name recognised internationally, e.g. pirimiphos-methyl and permethrin (Attack) and chlorothanonil (Bravo)
- **concentration of the active ingredient**: the number of grams per litre, e.g. 475 g/litre pirimiphos-methyl and 25 g/litre permethrin (Attack)
- **what it is:** insecticide, fungicide, herbicide, etc.
- **what it is used for:** for example: "A broad-spectrum insecticide for use on avocados, citrus, flowers and ornamentals, glasshouse tomatoes ..."
- **formulation:** how the chemical is made, e.g. an emulsifiable concentrate — EC; a wettable powder — WP; granule — G; or dust — D:
    - *EC* — the chemical is dissolved in a liquid (solvent plus surfactants) that forms fine droplets when mixed with water
    - *WP* — the chemical is made into a solid, finely ground, and then forms a suspension when mixed with water
    - *G* — a mix of chemical, inert substances (called fillers) and binding substances, then made into pellets, e.g. Furidan pellets are put in the top of coconut palms to control *Oryctes*
    - *D* — a mix of chemical and inert substances (called fillers)
- **net content:** the total weight (g or kg), or volume (litres) of the pesticide product.

6.3.1.2 Right panel

The right panel contains information on precautions and first aid if contamination or swallowing occurs. It may contain some of the items listed below:

- **hazard class:** the World Health Organisation has a set of hazard classes for health, based on eating or drinking the chemical and its effect on skin (tested on rats):
    - 1a — extremely hazardous
    - 1b — highly hazardous
    - II — moderately hazardous
    - III — slightly hazardous
    - U — unlikely to present acute hazard.

Table 6.2 Common commercial pesticides used in the Pacific Islands (as of 2023).

BOUGHT PESTICIDES							
Common or trade name	**Fiji**	**Samoa**	**Solomon Islands**	**Tonga**	**Active ingredient**	**Purpose**	**Remarks**
Insecticides & miticides							
Attack	✓	✓	✓	✓	Pirimiphos-methyl/ permethrin	Caterpillar, aphids	Broad-spectrum – kills beneficial insects as well
Bt	✓	✓	✓	✓	*Bacillus thuringiensis*	Larvae of Lepidopterous insects, armyworms, fruit and pod borers	Selective for caterpillars
Match	✓	✓		✓	Lufenuron	DBM in cabbage	Growth inhibitor
Steward	✓	✓		✓	Indoxacarb	Caterpillars, pod borer, armyworm, centre grubs, cutworm, leafroller, leafminers	Low toxicity on non-target insects
Prevathon	✓	✓		✓	Rynaxypyr or chlorantraniliprole	Caterpillars, pod borer, armyworm, centre grubs cutworm, leafroller, leafminers	Selective for caterpillars
Multiguard	✓	✓		✓	Abamectin	Broad mite, caterpillars	Broad-spectrum – kills beneficial insects as well
Bifenthrin	✓	✓	✓	✓	Bifenthrin	Caterpillar, aphids, leafminers, thrips, mites and taro beetle	Broad-spectrum – kills beneficial insects as well
Confidor		✓	✓	✓	Imidacloprid	Sucking insects like aphids, leafhoppers, thrips, whitefly, mealybugs, scale insects and taro beetle	Broad-spectrum – kills beneficial insects as well as taro beetle; toxic to bee
Suncloprid	✓			✓	Imidacloprid	As above	As above
Farmers' Imidacloprid	✓	✓			Imidacloprid	As above	As above
Orthene	✓	✓	✓	✓	Acephate	Chewing and sucking insects like caterpillars, aphids, thrips, leafminers, leafhoppers, cutworm on vegetables and fruits	Broad-spectrum – kills beneficial insects as well
Malathion	✓	✓	✓	✓	Malathion Bactralge	Leafhoppers, aphids, thrips, whitefly, mealybugs and spider mites	Broad-spectrum – kills beneficial insects as well
Karate			✓	✓	Lambda-cyhalothrin	Caterpillars, leafhoppers, aphids, thrips, whitefly, mealybugs and spider mites	Broad-spectrum – kills beneficial insects as well
Suncis	✓		✓	✓	Deltamethrin	Caterpillar, beetles, thrips, whitefly on fruits and vegetables.	Broad-spectrum – kills beneficial insects as well
Fungicides							
Taratek/ Bravo	✓			✓	Chlorothalonil and Thiophanate methyl	Broad-spectrum	Protective and systemic
Manzate	✓	✓	✓	✓	Mancozeb	Broad-spectrum	
Kocide	✓			✓	Copper hydroxide	Broad-spectrum	
Sundomil	✓	✓	✓	✓	Mancozeb	Broad-spectrum	
Talendo				✓	Chlorothalonil and Thiophanate methyl	Broad-spectrum	Protective and systemic
Kotek	✓	✓	✓	✓	Mancozeb	Broad-spectrum	

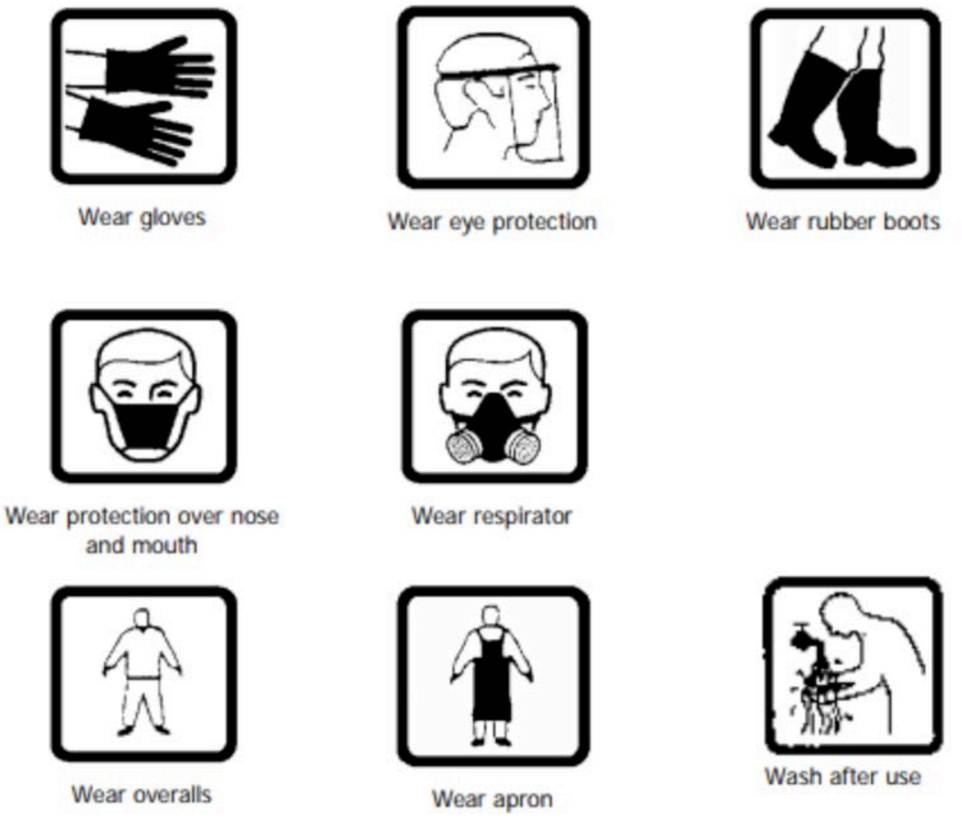
…continued over page

Table 6.2 Continued…

BOUGHT PESTICIDES							
Common or trade name	**Fiji**	**Samoa**	**Solomon Islands**	**Tonga**	**Active ingredient**	**Purpose**	**Remarks**
Herbicides							
Glyphosate/ 360/450/ Roundup	✓	✓	✓	✓	Glyphosate	Perennial, woody weeds	Systemic
Paraquat		✓	✓	✓	Paraquat	Annual and grass weeds	Contact
Bactericide							
Kocide	✓			✓	Copper hydroxide	Broad-spectrum	Protective and systemic
Molluscicide							
Blitzem	✓	✓	✓	✓	Metaldehyde	Snails and slugs	Banned in UK in 2021

Fig. 6.1 Precautionary advice pictograms

Source: FAO/WHO Guidance on good labelling practice for pesticides (Second revision).



The hazards are sometimes shown in the form of pictures at the bottom of the label (see Fig 6.1).

- **storage:** store the product in its original container, tightly closed, and away from heat, food and out of reach of children, preferably in a locked cupboard — note that in New Zealand, there are different rules depending on the amount of product stored in one place
- **protective clothing:** this covers the equipment and clothing that should be worn when mixing and applying pesticides, e.g. masks (including respirators) and goggles to protect mouth and eyes, gloves, boots, hat and overalls — after spraying, remove the clothing and wash your hands and face — wash the clothes used when spraying separately from normal everyday clothes — do not eat, drink or smoke when spraying
- **disposal:** notes on how to clean the sprayer and dispose of any remaining chemical residue (usually by spraying on soil at the side of the field, away from humans, livestock and waterways) — there are also notes on how to dispose of the pesticide container, either by burying it or sending it to a landfill (Fig. 6.2) — do not re-use the container
- **first aid:** what to do and who to contact if the product is swallowed, skin or hair is contaminated, or the chemical is splashed into the eyes — usually, a doctor would be called, clothing removed, and skin and eyes flushed with water — depending on the pesticide, the label will say whether vomiting should be induced or not — if inhaled, victims should be moved to fresh air, and given CPR if the heart stops beating

You should always go to the field with another person in case there is an accident

- **spillage:** what to do if a spill occurs — wear protective clothing, cordon off the area, prevent the chemical from entering drains, absorb it with inert material (soil, sand or sawdust), and place it in bins for disposal in a landfill. — wash the contaminated area with water
- **transport:** how the chemical should be transported, especially whether public vehicles (buses, etc.) can be used.

6.3.1.3 Left panel

This panel gives information on recommended use and how to apply the pesticide:

- **crops/pests used for:** a list of pests and diseases for which the chemical is recommended in a country — most Pacific island countries do not have a registration scheme specifically naming the crops on which the chemical can be used
- **how to mix and apply:** some chemicals need to be pre-mixed before they are added to the tank of the sprayer and mixed with a larger volume of water — the application of a chemical is usually given by either:
  i. X g/litre of product, sprayed until run off, or
  ii. X kg/ha using Y litres of water (adjusted for young and fully developed crops).

  When to start spraying is often given, and the interval of application, e.g. apply the chemical every 2-3 weeks
- **pre-entry period:** the period after applying the chemical when it is safe to re-enter the crop
- **pre-harvest interval (commonly called the withholding period):** the number of days between the last application of a chemical and the crop harvest — this is very important information — it ensures that the harvest does not have residues that affect its market acceptability
- **compatibility:** two chemicals can sometimes be mixed together and used as one — some companies will say if specific mixtures are safe (usually their own!).

Fig. 6.2 The incorrect way to discard a pesticide container, thrown to the side of the garden after use. *Source: authors.*

EXERCISE 6.2: Understanding the pesticide label

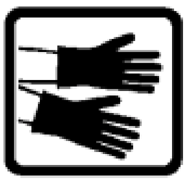
Understanding a pesticide label is critically important for the correct and safe use of pesticides. This exercise focuses your trainees on how to understand the label.

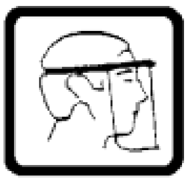
- a range of **commonly used pesticide labels** are on the following pages
- make sure each group (pairs or threes) has a **different label to work with**
- trainees should **carefully read their label** and answer the following questions
- they should **write their answers on brown paper or butchers paper** so that they can be held up and read out to the class — if your trainees cannot find all the answers on one label, they should look at others.

1. What kind of pesticide is it? (i.e. fungicide, insecticide, herbicide etc.)
2. What is the pesticide used for?
3. What is the common name of the pesticide?
4. What is the trade name of the pesticide?
5. Is the label divided into separate panels? If so, what information does each of these panels give you?
    - centre panel?
    - left panel?
    - right panel?
6. What is an emulsifiable concentrate (EC)?
7. What is a sticker?
8. What is a spreader?
9. What is meant by 'compatibility'?
10. What should you avoid doing when spraying, but do immediately after spraying?
11. What clothing is recommended when preparing the spray and spraying?
12. What is the recommended way to store the pesticide?
13. What does 'run-off' mean?
14. Is there a hazard number on the label? What is it and what does it mean?
15. What should you do after spraying and before eating, drinking or smoking?
16. Can you wash the sprayer or empty the container in the river? If not, why not?
17. Where are the best places to put the container when it is empty?
18. Is it recommended that you induce vomiting if a person has drunk the pesticide?
19. If you spill the pesticide, what should you do?
20. Can you give livestock feed that has been sprayed with the pesticide?
21. What is meant by the pre-harvest interval (also known as the withholding period)?
22. What do these pictograms mean?

a) 

b) 

c) 

d) 

6.3.2 Pesticide labels

The pesticide labels on pages 270–275 are for training purposes only. They do not constitute endorsement or product support.

HARMFUL
NOT TO BE TAKEN
KEEP OUT OF REACH OF CHILDREN

Precautions
1. Product is poisonous if swallowed.
2. Will irritate the eyes and skin.
3. Facial skin contact may cause temporary facial numbness.
4. Sensitive workers should use protective clothing.
5. Avoid contact with eyes and skin.
6. Do not inhale spray mist.
7. When preparing spray, wear cotton overalls buttoned to the neck and wrist and a washable hat, elbow- length PVC gloves, face and shield.

First Aid
1. Remove contaminated clothing and bathe the patient.
2. Wash the patient body thoroughly with plenty of soap water.
3. Identify, as accurately as possible, the product(s) associated with exposure. If possible, ask the patient. Store the container, label and leaflet to show to the doctor.
4. If breathing has stopped, provide artificial respiration.
5. No specific antidote. Treat symptomatically.

Directions for Storage
1. Store in a cool place.
2. Do not store the product in the rooms of your home.

Spillage and Disposal
1. For small spills, take up with sand or other absorbent material and place into containers for later disposal.
2. Do not reuse container.
3. Wash contaminated area with soap and water.
4. Dispose of container into an approved sanitary landfill.

VEGIE GUARD

Vegie Guard is an effective broad spectrum insecticide to control sucking pests in vegetables and plantation crops. This product is a non-systemic with contact and ingestion action.

Insecticide For Agricultural Uses

Composition Content

Active ingredient : Indoxacarb ....150g/L of product
Insert ingredient : ....up to 1 Litre product
Total .... 100% w/w

Net Content: 100ml HARMFUL WHO Toxicity Class: II

Application Method:

Crops	Dosage	Target pests	PHI (days)
Cabbage, cauliflower, broccoli	16 ml of product in 16 L of water 20 ml of product in 20 L of water	Diamond backmoth, Cabbage White Butterfly	3 days
Lettuce	16 ml of product in 16 L of water 20 ml of product in 20 L of water	Soybean looper	3 days
Asparagus	12-16 ml of product in 16 L of water 15 – 20 ml of product in 20 L of water	Lesser cornstalk borer	7 days
	8 ml of product in 16 L of water 10 ml of product in 20 L of water	Fall armyworm	
Avocado	6.4 – 10 ml of product in 16 L of water 8.0-12.5 ml of product in 20 L of water	Soybean looper	-
Pepper	8 ml of product in 16 L of water 10 ml of product in 20 L of water	Tobacco budworm	3 days
Corn/Maize	6.4 – 9.6 ml of product in 16 L of water 8.0-12 ml of product in 20 L of water	Fall armyworm	7 days
Tomato	9.6 ml of product in 16 L of water 12mlofproductin20Lofwater.	South American tomato pinworm	3 days

AGCHEM PTE LIMITED

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Factory:Lot5,WailadaIndustrialEstate.
PrivateMailBag,Lami,Fiji.
Phone:3361499,3361867Fax:3361307
Email:info@agchem.com.fj
REGISTEREDUNDERTHEFIJIPESTICIDEACTNO.41OF1971
REGISTRATIONNUMBER:I896/207F/85

SUNDAT
SUNDAT (S) PTE LTD
Manufacturer:
SUNDAT (S) PTE LTD
26 Gul Crescent
Singapore 629532

Precautions
1. Keep out of reach of children. Harmful if swallowed, inhaled or absorbed through skin. Avoid contact with skin, eyes, and clothing. Avoid breathing vapor or spray mist.
2. Wear protective gloves/ protective clothing/ face protection.
3. Use only outdoors or in a well-ventilated area.
4. Avoid release to environment.
5. Keep away from domestic animals and food supplies.

First aid
In case of poisoning, call physician or Poison Control Centre immediately. Have patient lie down and keep quiet.
1. If inhaled: move person to fresh air. If person is not breathing, give artificial respiration, preferably by mouth-to-mouth, if possible. Call a poison control center or doctor for further treatment advice.
2. If on skin or clothing: take off contaminated clothing. Rinse skin immediately with plenty of water for 15–20 minutes. Call a poison control centre or doctor for treatment advice.
3. If in eyes: Hold eye open and rinse slowly and gently with water for 15–20 minutes. Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. Call a poison control centre or doctor for treatment advice.
4. Keep the patient calm, comfortable and warm.
5. If swallowed: Call a poison control centre or doctor immediately for treatment advice. Do not induce vomiting unless told to do so by a poison control center or doctor. Do not give any liquid to the person. Do not give anything by mouth to an unconscious person.
6. Take container, label or product name and Pest Control Product Registration Number with you when seeking medical attention.
7. Treat symptomatically. No specific antidote.

Spillage and Disposal
1. Absorb spill with inert material, vacuum or sweep up and place into a disposable container.
2. Do not reuse container.
3. Dispose of container into an approved sanitary landfill.

CAUTION
KEEP OUT OF REACH OF CHILDREN
ATTEND SPECIAL INSTRUCTIONS BEFORE USE

FOLISPRAY

Composition content:
Active ingredient: Tebuconazole..................43% w/v
Inert ingredients ....Balance
Total ....100% w/v

FUNGICIDE
For use in Tobacco, Green Beans, Banana, Citrus, Potato and Wheat.

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AGCHEM PTE LIMITED
Lot 5, Wailada Industrial Estate, lami
Private Mail Bag, Lami, Fiji Islands
Phone: 3361499, 3361867
Fax: 3361307
Email: info@agchem.com.fj

AGCHEM PTE LIMITED

Manufacturer:
SUNDAT (S) PTE LTD
26 Gul Cresent
Sigapore 629532

Net Content: 1 LITRE
REGISTERED UNDER THE FIJI PESTICIDE ACT No.41 OF 1971
REGISTRATION No. **PF 146/220 M/85**

Compatibility
Tebuconazole 43% w/v SC is incompatible with alkaline reaction products, and should not be mixed with products that are emulsifiable concentrates. In case of a need to use Tebuconazole in a mixture with other products, it is advisable to perform a small-scale test to assess the physical, chemical and of the components and the possible phytotoxicity for crops.

Application method

CROP	DISEASE	DOSAGE 16Ltr	DOSAGE 20Ltr
Tobacco	Brown Spot , Alternaria Leaf Spot	7mls	9mls
Green Beans	Rust	11mls	14mls
Banana	Leaf Spot (yellow sigatoka), Leaf Speckle, Black Sigatoka	7mls (add 192mls W/Oil	9mls (add 240mls W/Oil)
Citrus	Navel end rot	7mls	9mls
Potato	Early Blight (Alternaria solani)	Ground Application: 7mls	9mls
		Arial Application: 10-14mls	12-18mls
Wheat	Stripe Rust (Septoria nodorum), Stem Rust, Leaf Rust, Blotch, Yellow Leaf Spot	5mls or 9mls	6mls or 12mls
	Septoria Tritici Blotch	9mls	12mls

Pesticide labels continued...

Biological Insecticide

AgChem Bt. K

GENERAL INSTRUCTIONS:

This product is a microbial insecticide with stomach action, no contact and system action. After feeding by sensitive insects, the crystal protein in the product is transformed into molecules with toxin activity under the action of alkaline midgut fluid and special protease, and binds to specific receptors on midgut cell membrane, resulting in the death of target pests due to antifeedant, paralysis, intestinal perforation, hunger and septicaemia.

Crops	Target pest	16L knapsack rate	20L knapsack rate
Kale	Diamondback moth	8 grams – BT. K	10 grams – BT. K
Chili	Tobacco budworm	8 grams – BT. K	10 grams – BT. K
Cruciferous vegetables	Cabbage caterpillar	8 grams – BT. K	10 grams – BT. K
Rice	Rice leaf roller	8 grams – BT. K	10 grams – BT. K
Rice	Yellow stem borer	8 grams – BT. K	10 grams – BT. K
Corn	Fall armyworm	8 grams – BT. K	10 grams – BT. K
Wild rice stem	Yellow stem borer	8 grams – BT. K	10 grams – BT. K
Cowpea	Legume pod-borer	8 grams – BT. K	10 grams – BT. K

AGCHEM PTE LIMITED

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Agchem Pte Limited.
Factory: Lot 5, Wailada Industrial Estate.
Postal: Private Mail Bag, Iami, Fiji.
Phone Bus: 336 1499, 336 1867
Fax: (679) 336 1307
Email: info@agchem.com.fj
REGISTERED UNDER THE FIJI PESTICIDE ACT NO.41 OF 1971
REGISTRATION NUMBER: I 897/87 C/85

ACTIVE INGREDIENT:
Bacillus thringiensis subsp. Kurstaki 32000IU/mg, wettable powder

Supplier :
Wuhan Kernel Bio-tech Co., Ltd. China

Net Weight 500g

HARMFUL

Pesticide labels continued…

AgChem Bt. K continued…

PRECAUTION

Avoid contact with skin, eyes or clothing.

Wash hands before eating, drinking, using tobacco or using the toilet

PERSONAL PROTECTIVE EQUIPMENT (PPE)

Applicators and other handlers must wear:

*** Long-sleeved shirt and long pants or overall**

*** Chemical-resistant gloves, such as barrier laminate, or nitrile rubber, or neoprene rubber or viton**

*** Gumboots**

ENVIRONMENTAL HAZARDS

Do not apply directly to water, or to where surface water is present or to interdial areas below the mean high water mark.

Do not contaminate water when cleaning equipment or disposing equipment washwaters.

FIRST AID

If on Skin *Take off contaminated clothing

* Rinse skin immediately with plenty of water for 15-20 minutes

* Call a poison control centre or doctor for treatment advice

If in Eyes * Hold eyes open and rinse slowly and gently with water for 15-20 minutes

* Remove contact lenses, if present, after the first 5 minutes, then continue rinsing the eye.

* Call a poison control centre or doctor for treatment advice

STORAGE

*Store in a cool place away from food and feeds

*Keep out of reach of children and food stuffs.

NOTE TO PHYSICIAN

Contains petroleum distillate: vomiting may cause aspiration pneumonia

Precautions

1. Product is poisonous if swallowed.
2. Will irritate the eyes and skin.
3. Facial skin contact may cause temporary facial numbness.
4. Sensitive workers should use protective clothing.
5. Avoid contact with eyes and skin.
6. Do not inhale spray mist.
7. When preparing spray, wear cotton overalls buttoned to the neck and wrist and a washable hat, elbow- length PVC gloves, face and shield.

First Aid

1. Remove contaminated clothing and bathe the patient.
2. Wash the patient body thoroughly with plenty of soap water.
3. Identify, as accurately as possible, the product(s) associated with exposure. If possible, ask the patient. Store the container, label and leaflet to show to the doctor.
4. If breathing has stopped, provide artificial respiration.
5. No specific antidote. Treat symptomatically.

Directions for Storage

1. Store in a cool place.
2. Do not store the product in the rooms of your home.

Spillage and Disposal

1. For small spills, take up with sand or other absorbent material and place into containers for later disposal.
2. Do not reuse container.
3. Wash contaminated area with soap and water.
4. Dispose of container into an approved sanitary landfill.

Tatagomaki

1. Ena rawa niko gaga ke gunuvi.
2. Ena mitamila na matamu se na yagomu ke tauva na wainimate oqo.
3. Ena rawa ni nunu na matamu ke terega na wainimate .
4. Me daramaki nai sulu ni tataqomaki.
5. Kakua ni tauva na mata se kuli ni yago.
6. Kakua ni ceguva na cawa ni suisui.
7. Ena gauna ni ului, mo daramaka nai sulu me taqomaka na yagomu kei na ligamu, vakaqaniliga rapa kei na tataqomaki ni mata.

Veivuke Taumada

1. Luvata nai sulu sa terega na mainimate ka sili.
2. Me vakasilivi vinaka ene sovu kei na vai.
3. Raica na Vuniwai ke yaco e dua na leqa ka kauta vua e dua nai lavelave na wainimate.
4. Ke sa tasogo na nona i cegu, me soli vua nai cegu ni veivuke taumada.

Kena Maroroi

1. Maroroi ene dua na vanua vinaka.
2. Kakua ni maroroi ene dua na rumu ni nomu vale.

Kena Vakarusai

1. Buluta ene nuku ke tasova vakalailai na wainimate oqo, qai takiva kina dua na vokete me vakarusai.
2. Kakua ni vakayagataka tale na kava lala.
3. Savata vinaka ena sovu kei na wai na vanua e tasova kina na wainimate.

HARMFUL
NOT TO BE TAKEN

KEEP OUT OF REACH OF CHILDREN
READ LABEL CAREFULLY BEFORE OPENING

AGCHEM PTE LIMITED

NEEM OIL

Active Constituent:

Active ingredient: Azadirachtin .... 10 g/L of product
Inert ingredients .... up to 1 Litre product
Total .... 100% w/w

Neem Oil is an organic insecticide suitable for controlling a broad spectrum of pests in variety of food crops. Reduces the level of the insect hormone Ecdysome by disrupting the insect's molting process so that the immature larvae cannot develop into adults.

HARMFUL

Net Content: 1 Litre

Compatibility: Incompatible with acidic and alkaline pesticides and fertilizers

Application method

Crops	Pests	Dosage (mL/16 L of water)	Dosage (mL/20 L of water)	PHI
Brassica and Leafy Vegetables	lepidoptera	46-120 ml	58-150 ml	Can be applied up to and including the day of harvest
	beetles, weevils, thrips	61-120 ml	76-150 ml	
Root and Tuber Vegetables	beetles, weevils, thrips	29-64 ml	36-80 ml	
	lepidoptera	61-120 ml	76-150 ml	
Tobacco	beetles, weevils, thrips, lepidoptera	73-120 ml	91-150 ml	

Key Product Facts

- Natural product, absolutely non-toxic.
- Exhibits various Behavioral Responses such as Antifeedant, Feeding Deterrent, Repellent, Oviposition Deterrent etc.
- Illustrates Physiological Responses such as Insect Growth Regulator, Molting Inhibitor, Reproduction Inhibitor, Antifertility etc.
- Effective on all larva stages, pupae, and adults.
- 100% bio degradable and environment friendly.
- Completely safe for humans and beneficial insects like honey bee.
- Can be mixed with other synthetic pesticide and also enhances their action.
- Broad-spectrum insecticide, effective for over 600 species of pests.
- Possess fungicidal and miticidal properties.

AGCHEM PTE LIMITED

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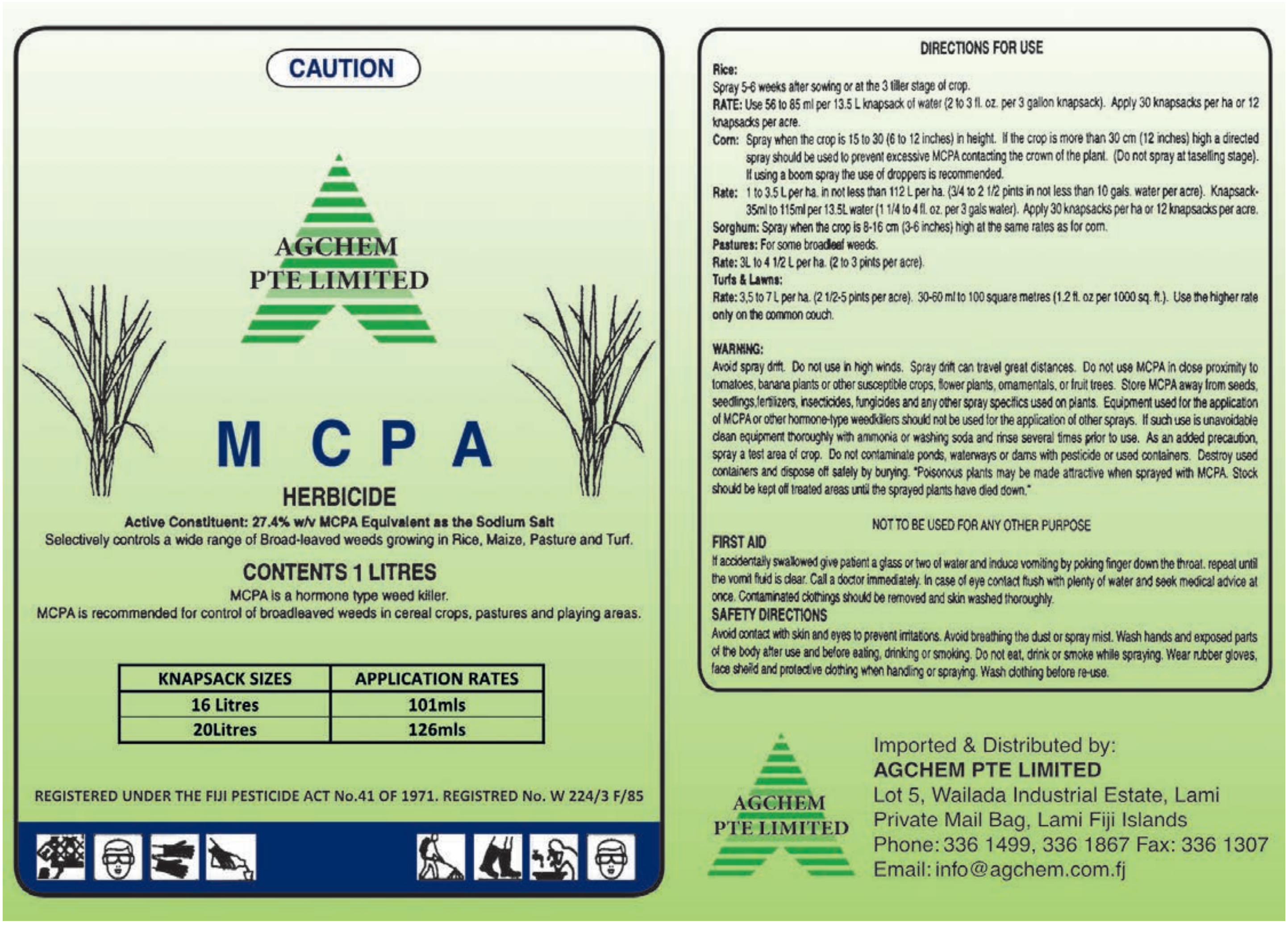
Factory: Lot 5, Wailada Industrial Estate.
Private Mail Bag, Lami, Fiji.
Phone: 3361499, 3361867 Fax: 3361307
Email: info@agchem.com.fj
REGISTERED UNDER THE FIJI PESTICIDE ACT NO.41 OF 1971
REGISTRATION NUMBER:

SUNDAT (S) PTE LTD

Manufacturer:

Pesticide labels continued...



Pesticide labels continued...

Precautions

1. Product is poisonous if swallowed.
2. Will irritate the eyes and skin.
3. Facial skin contact may cause temporary facial numbness
4. Always wear protective clothing.
5. Avoid contact with eyes and skin.
6. Do not inhale spray mist.
7. When preparing spray, wear cotton overalls buttoned to the neck and wrist and a washable hat, elbow-length PVC gloves, face and shield.

First Aid

1. Remove contaminated clothing and bathe patient.
2. Wash the patients body thoroughly with plenty of soap and water.
3. Identify, as accurately as possible, the product(s) associated with the exposure. If possible, ask the patient. Store the container, label and leaflet to show to the doctor.
4. If breathing has stopped, provide artificial respiration.
5. No specific antidote. Treat symptomatically

Directions for Storage

1. Store in a cool place.
2. Do not store the product in the rooms of your home.

Spillage and Disposal

1. For small spills, take up with sand or other absorbent material and place into containers for later disposal.
2. Do not reuse container.
3. Wash contaminated area with soap and water.
4. Dispose of container into an approved sanitary landfill.

CAUTION

NOT TO BE TAKEN
KEEP OUT OF REACH OF CHILDREN
READ SAFETY DIRECTIONS BEFORE OPENING OR USING

AGCHEM PTE LIMITED

HORTIGUARD

Composition of Content

Active Ingredient:

Abamectin	1.8%
Inert Ingredients	98.2%
Total	100%

For Agricultural use to control Leaf miners, Mites, Aphids and Thrips on Ornamental plants, Lawns and Crops like Capsicum, Eggplant Cottons, Citrus, Cabbage, Strawberries, and Tomatoes.

Contents 1L

CROPS	PESTS	RATES		PHI	COMMENTS
		16LTR	20LTR		
Apples, Pears and Fruit trees	Red spider mite and Europen red mite	5.6ml + 40ml white oil	7ml + 50ml white oil	7 dys	Apply as a full spray when pest is noticed and repeat whenn necessary. Resistance to various pesticides may be encountered.
Cabbage	Diamond back moth Pieris Rapae.	3.5ml - 3.7ml	4.4ml - 4.6ml		Add 2000 - 3000 times of water and spray
Tomatoes Capsicum Eggplant	American leaf miner Red spider mite	9.6ml 9.6ml	12ml 12ml	3 3	Apply at first signs of infestation as a full cover spray. Repeat applicat ion every 7 days or as needed to maintain control. Apply when pest is noticed and repeat when necessary. Resistance to various pesticides is evident. Full cover application.
Citrus	Thrips	1.6ml - 3.2ml + 48ml white oil	2ml - 4ml + 60ml white oil	7	Apply at first signs of thrip presence Use higher dosage rate when climate condions are favourable for thrip infestation. Apply as a light cover spray. Repeat when necessary DO NOT apply more than 3 sprays or 2 consecutive sprays per season. DO NOT apply captan or sulphur sprays within 14 days before or after abamectin (white oil application will suppress lowveld and red mite).

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Lot 5, Wailada Industrial Estate, Lami
Private Mail Bag, Lami Fiji Islands
Phone: 336 1499, 336 1867 Fax: 336 1307
Email: info@agchem.com.fj

SUNDAT

Manufacturer:
Sundat (S) PTE Limited
26 Gul Crescent, Singapore.

Registered Under the Fiji Pesticide Act No. 41 of 1971.

Registered No. **I 776/221 F/85**

Suncis 25 EC Insecticide.

GENERAL INSTRUCTIONS

APPLICATION

Suncis 25 EC is a contact spray. Through, even coverage is essential.

EQUIPMENT Ground Spray

Standard low volume boom or high volume equipment may be used.

COMPATIBILITY

Suncis 25 EC may be mixed with most formulations of fungicides and insecticides such as dimethoate, methamidophos, pirimicarb, methomyl liquid, mancozeb, metalaxyl, and chlorothalonil, where these products are required for additional insect control or control of diseases. Suncis 25 EC may also be mixed with X - 77 Sticker.

MIXING

Add the required quantity of Suncis 25 EC to the spray tank with agitators in motion. Where other products are to be mixed, add these after Suncis is mixed in the tank.

PROTECTION OF LIVESTOCK

. Dangerous to bees. Do NOT spray on any plants in flower while bees are foraging.

. Some repellent effect may be apparent for approximately 2 days.

PROTECTION OF WILDLIFE, FISH, CRUSTACES AND ENVIRONMENT

. Dangerous to fish. Do not contaminate dams, ponds, water ways or drain with chemical or used container.

STORAGE AND DISPOSAL, PROTECTION OF OTHERS

Store in original container tightly closed and in a cool, well ventilated area Do not store for prolonged periods in direct sunlight. Triple rinse containers before disposal and add rinsing to tank mix or disposal pit Destroy empty containers by breaking, crushing or puncturing them. Bury containers to a depth of 50cm or more at a municipal or private sanitary land fill type tip that does not burn its refuse.

Manufactured by:
SUNDAT (S) PTE LTD
26 GL CRESCENT
SINGAPORE 2262

AGCHEM LIMITED

Imported and Distributed in Fiji by:
AGCHEM LIMITED
Lot 5, Wailada Industrial Estate, Lami, Fiji
Private Mail Bag, Lami, Fiji
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Fax: (679) 3361307 Email: info@agchem.com.fj
REGISTERED UNDER THE FIJI PESTICIDE ACT No.41 OF 1971
REGISTERED No. 144/129F/85

HARMFUL

GAGA
ME KAKUA NI GUNUVI. ME RA KAKUA NI TARA NA GONE. WILIKA VINAKA NA I VAKARO NI BERA NIKO DOLAVA.

NOT TO BE TAKEN
KEEP OUT OF REACH CHILDREN
READ SAFETY DIRECTIONS BEFORE OPENING

Suncis

25 EC INSECTICIDE

A synthetic pyrethoid insecticide for the control of caterpillars, beetles, thrips, white butterfly, diamondback moth on a broad range of fruit and vegetables. It is fast acting light stable and has moderate persistence on plants.

Active Ingredient

Deltamethrin 2.5%
Inert Ingredients 97.5%

NOT TO BE USED ANY PURPOSE OR IN ANY MANNER CONTRARY TO THIS LABEL UNLESS AUTHORITIES UNDER APPROPRIATE LEGISLATION

PRECAUTIONS

Wear rubber gloves, face shield and protective colthing when handing the chemical.

HARMFUL

Crop	Pest	Knapsac Rate		Withholding Period
Cabbage	Diamondback Moth	18L 7mls	20L 8 mls	7 Days
Tomato	Tomato Fruitworm Looper Caterpiller	7mls	8mls	3 Days
Ornamental	Looper Caterpiller Tomato Fruitworm Thrips	7mls	6mls	
Beans	Looper Caterpiller	6mls	8mls	3 Days
Cucumber Squash Water Melon	Aphids	16mls	20mls	3 Days
Maize Sweetcorn	Greasy Cutworm Corn Earthworm	8mls	10mls	7 Days

SAFETY DIRECTIONS

Product is harmful if absorbed by skin contact, inhaled or swallowed. Facial skin contact may cause temporary facial numbness, Avoid contact with eyes and skin. When preparing spray wear elbow-length PVC gloves and face shield. If product spills on skin, immediately wash area with soap and water. After use and before eating, drinking or smoking, wash hands, arms and face thoroughly with soap and water. After each days work wash contaminated clothing, gloves and faces shield.

FIRST AID

If skin contact occurs, remove contaminated clothing and wash skin thoroughly with clean water. Remove patient from contaminated area. If splashed in eye wash thoroughly in clean running water for at least 13 minutes. If swallowed rush to nearest health center or doctor. Apply artifical respiration if not breathing.

ADVICE TO PHYSICIAN

No antidote is available and treatment should be symptomatic. Chemical pneumonitis is resulting from aspiration of the solvent into lungs is a hazards that occurs when liquid formulations are used Do not induce vomiting. Empty the stomach only on the advice of a Physician and only with equipment that will not cause aspiration into lungs. If convulsions occur diazepam (10-20mg for an adult) should be administered slowly, intravenously or rectally and repeated if necessary.

FIRST AID

If Swallowed cause vomiting by giving a glass or two of water and then poking finger down the throat.

[illegible]

VEIQARAVI TAUMADA

Ke gunuvi me sagai me lualua ni gunvi oti e dua na bilo wai oqo me tarai na nona i tilotilo. Laki raica e dua na Vuniwai.

PRECAUTIONS

Wear rubber gloves, face sheild and protective clothing when handling the chemical.

[illegible]

TATAQOMAKI

Daramaka na qaniliga rapa. Taqomaka na yagomu ena i sulu vakarautaki ni ko vakayagataka na wainimate.

CONTENTS
1 LITRE

6.4 Applying pesticides — the important steps in spraying

- *do not spray on windy days*
- *take another person with you when spraying in case of an accident, a spill or poisoning*
- *always wear proper protective clothing.*

6.4.1 Before spraying

The nozzle

Check you have the correct nozzle for the pesticide you are going to use. The nozzle is the most important part of the sprayer.

What does the nozzle do?

- nozzles break liquids into droplets
- nozzles send liquids out in a pattern
- the pattern for killing weeds is quite different from the pattern for spraying pests and pathogens
- nozzles control the width of the spray
- some sprayers have a pressure control knob inside, which regulates the pressure of the spray.

Check you have the correct nozzle for the pesticide you are going to use.

Types of nozzles

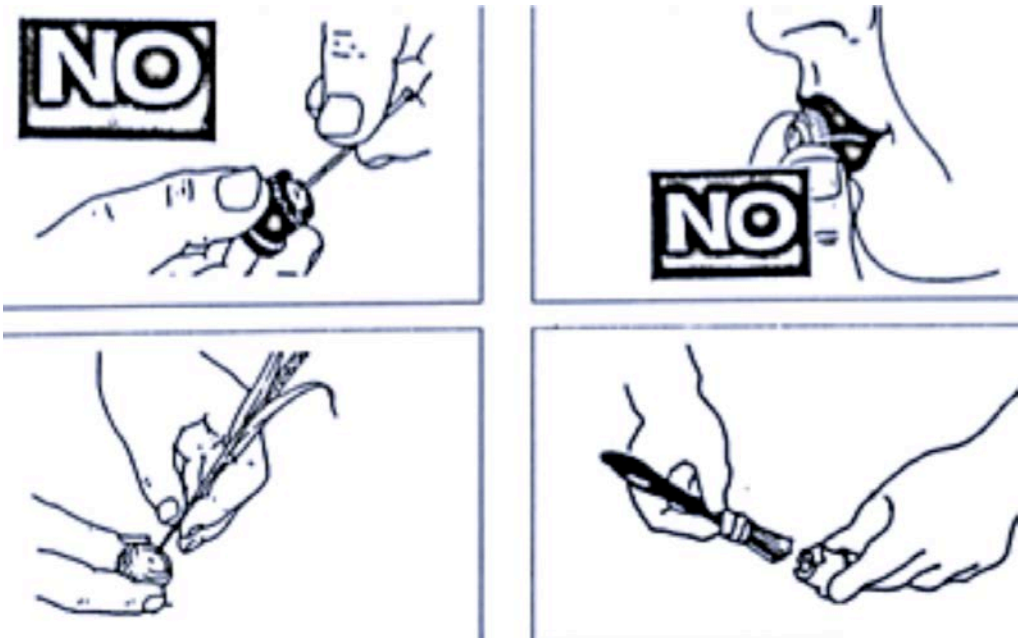
- flat fan or anvil (also known as flood) for herbicides
- hollow cone for insecticides or fungicides.

Fig. 6.3 Types of spray pattern produced by a hollow cone, a flat fan and an anvil nozzle. *Source: Laser Industrie. France.*

Before using the nozzle

1. Check that the nozzle is clean
2. Remove the nozzle from the sprayer and wash in water
3. Tap to unblock
4. If still blocked, use a piece of grass to unblock (Fig. 6.4). Never use a nail!

Fig. 6.4 How to clean a nozzle: use a piece of grass rather than a nail or a brush. *Source: JC Lowe, JMH Parker. Plant Protection in the Pacific Islands. SPC.*



Spraying herbicides

- use a flat fan or anvil (also known as a flood) nozzle (Fig. 6.3)
- the pressure should be low
- apply as a 'light rain'
- the droplets should fall on the TOP of the leaves
- the droplets are larger than those of insecticides or fungicides, lowering the chance of drift and damage to crops.

Spraying insecticides and fungicides

- use a hollow cone nozzle (Fig. 6.3)
- the pressure should be high
- apply as a mist
- the droplets are small forming a cloud
- they give better coverage as they flow AROUND the plant.

The sprayer

- check the straps. Are they worn? If they are, replace them
- check the tank. Are there leaks? Put water in the sprayer, check when upright, on the side and upside down. Do not use if there are any leaks
- check the handle — open and close the trigger; it should start to spray and stop quickly
- consult the PNG videos on 'Safe Use of Pesticides' for personal protective equipment (PPE) and maintenance of the sprayer.

Personal protective equipment (PPE)

Remember that pesticides are poisons, so you must protect yourself when spraying. Ideally, you should wear the following:

- lightweight overalls
- gloves
- boots
- goggles, face mask and a cap.

If you don't have all these, protect yourself with a long-sleeved shirt and long trousers used only for spraying, and boots and gloves. Wear the shirt over the gloves, and the trousers over the boots.

Making up sprays

Do not guess! Read the label, making sure that the concentration of spray is correct.

Example 1: Spraying cabbages with lambda cyhalothrin (the name of the product is KARATE).

The label tells you to add 10 mls Karate per 10 L of water and apply at the rate of 400–500 ml per ha (Fig. 6.5).

You have a 15 L knapsack sprayer, so you need 15 mls — about 3 teaspoons of Karate.

How much Karate spray should you spray on the cabbages?

1. Pace out the length and width of a bed of cabbages — let's say the length is 25 m and the width is 4 m — the area is 100 m²
2. To find out how much Karate is needed for a 100 m² bed:
    - divide the rate of Karate/ha by the number of m²/ha and multiply by the area of the bed. Use the higher rate of 500 ml/ha
    - 500/10000 x 100 = 5 ml
    - look at the label, this tells you to mix Karate at 10 ml/10 L water — so, for 5 ml you need 5 L water. This is the amount for a 100 m² bed
    - now, spray the 100 m² bed with 5 L water (we use water first to test that you are walking at the right speed to deliver the right amount of spray).

Check:

- ✓ Did you spray more or less than 5 L?
- ✓ If you sprayed more, repeat with water at a slower pace.
- ✓ If you sprayed less, repeat with water at a faster pace.

3. When you have the correct pace, refill the tank with 15 L of water, add 15 ml Karate, shake the tank, and spray the cabbages on all the beds at the pace you selected from your tests.

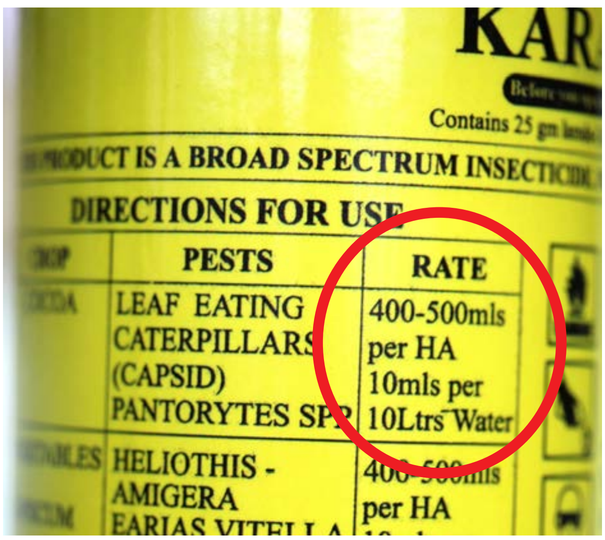


Fig. 6.5 Amount of Karate per ha and rate per L in knapsack sprayer. *Source: authors.*

Example 2: Spraying tomatoes with chlorothalonil. The name of the product is Eko.

The label tells you to add 34 ml of Eko per 20 L of water (Fig. 6.6). But the label does not say how much Eko per ha. Usually, for tomatoes, this is 1.8–2.3 L/ha.

You have a 15 L knapsack sprayer, so you need 25 ml — about five Coca-Cola tops of Eko.

How much Eko spray should you spray on the tomatoes?

1. Pace out the length and width of a bed of tomatoes. Let's say the length is 25 m and the width is 4 m. The area is 100 m².
2. To find out how much Eko is needed for a 100 m² bed, do the following:
    - divide rate of Eko/ha by number of m²/ha and multiply by the area of the bed — use the lower rate of 1800 ml/ha
    - 1800/10000 x 100 = 18 ml
    - look at the label — this tells you to mix Eko at 34 ml/20 L water — so, for 18 ml you need 10.6 L water — this is the amount for a 100 m² bed
    - now, spray the 100 m² bed with 10.6 L water (we use water first to test that you are walking at the right speed to deliver the right amount of spray).

Check:

- ✓ did you spray more or less than 10.6 L?
- ✓ if you sprayed more, repeat with water at a slower pace
- ✓ if you sprayed less, repeat with water at a faster pace.

3. When you have the correct pace, refill the tank with 15 L of water, add 25 ml Eko (five Coca-Cola tops), shake the tank, and spray the tomatoes on all the beds at the pace you selected from your tests. Later, when the plants are mature, increase the amount per bed to 14 L (this is the higher rate of 2300 ml/ha (see above).

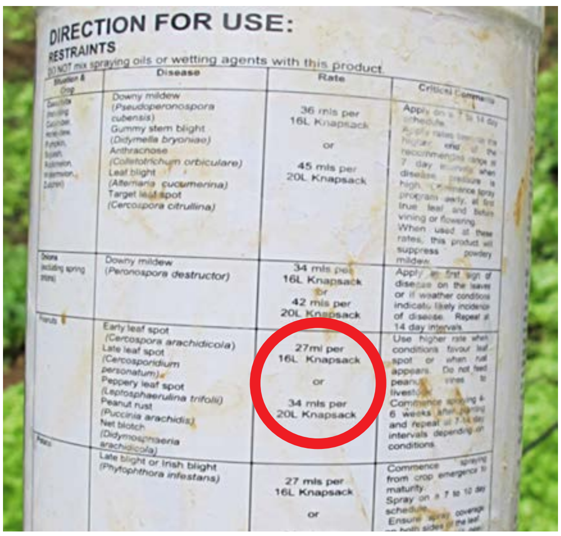


Fig. 6.6 Amount of Eko per 16 and 20 L knapsack sprayers. *Source: authors.*

A quick practical method for calibration

If extension staff and farmers find the methods of calibration too complicated, then do the following:

i. Add water to the hydraulic knapsack sprayers (according to the volume of each machine).

ii. Add insecticide or fungicide to the water according to the volume of sprayer and the size of bottle top chosen (Figs. 6.7, 6.8 and Table 6.3).

iii. Spray crops to just before run-off as shown in the following section (6.4.2 and Fig. 6.10).

The amounts of KARATE and Eko to add are given in Table 6.3.

Fig. 6.7 Measuring pesticides (liquids): 5 ml Coca-Cola bottle top (left); 4 ml beer top (right). *Source: authors.*

Table 6.3 The number of bottle tops of Karate or Eko (capacity 5 ml or 4 ml) to add to three knapsack sprayers (10, 15 and 20 L water) to formulate the pesticides according to the manufacturer's instructions.

Volume of knapsack sprayer (L)	Total no. mls Karate	No. Coca-Cola 'tops'	No. beer 'tops'	Total no. mls Eko	No. Coca-Cola 'tops'	No. beer 'tops'
10	10	2	2 ½	17	3 ½	4
15	15	3	4	25	5	6
20	20	4	5	34	7	8

If you are using a pesticide that is a powder, then use the tops (lids) as either 2.5 g or 2 g measures. Calculate the number of tops required depending on:

i. the size of the top

ii. the volume of the knapsack

iii. the concentration indicated on the pesticide label (Fig. 6.8).

Fig. 6.8 Measuring pesticides (powders): 2.5 g (Coca-Cola bottle top (left); 2 g beer bottle top (right). *Source: authors.*

6.4.2 During spraying

Trainees should know that it is important to spray at the right time and during the right weather conditions. If this is not done, the crops will not be treated effectively, and there is a danger to health.

When is it best to spray?

Spray either early in the morning or late in the afternoon, when the wind is less strong. If it is windy, do not spray. If the wind is only light, spray down wind.

Always use a spray shield to prevent chemical drift.

For small plants (near the ground), e.g. cabbages, your sprayer should be fitted with a hollow cone nozzle, and you should spray 50 cm above the crop (Fig. 6.9).

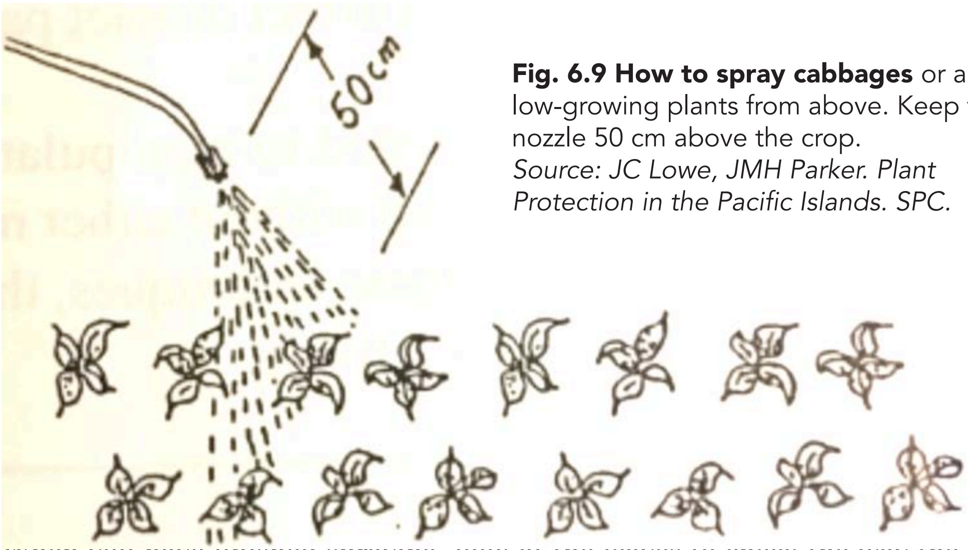


Fig. 6.9 How to spray cabbages or any low-growing plants from above. Keep the nozzle 50 cm above the crop.
Source: JC Lowe, JMH Parker. Plant Protection in the Pacific Islands. SPC.

When you have finished spraying, look at the leaves to check the way the droplets have landed. You want small droplets covering all the leaf. If you spray too much, the droplets come together and fall off the leaf (Fig. 6.10).

For taller plants, e.g. tomatoes, your sprayer should be fitted with a hollow cone nozzle, and you should angle the lance sideways, moving it up and down and around the plants so that the spray covers both sides of all the leaves. Keep the nozzle about 50 cm from the plants as you spray (Fig. 6.11).

If an accident happens, refer to the label. In case of a spill, cover the chemical with sand, sawdust or soil, and bury it away from the house at the edge of the garden or field.

6.4.3 After spraying

- clean the tank immediately after use so that the chemical does not dry on the inside
- open the tank, remove the strainer, fill with 1.5 L of water, replace the cap and shake
- pour onto an area that has been sprayed, or the ground nearby
- add another 1.5 L of water and spray to clean the hose, lance and nozzle.

After spraying, remove your clothes and shower. Wash the clothes separately from other clothing. And DO NOT eat or drink after spraying until you have washed.

Fig. 6.10 Pattern of droplets on a leaf sprayed with too much pesticide run-off (left) and the correct amount (right).
Source: JC Lowe, JMH Parker. Plant Protection in the Pacific Islands. SPC.

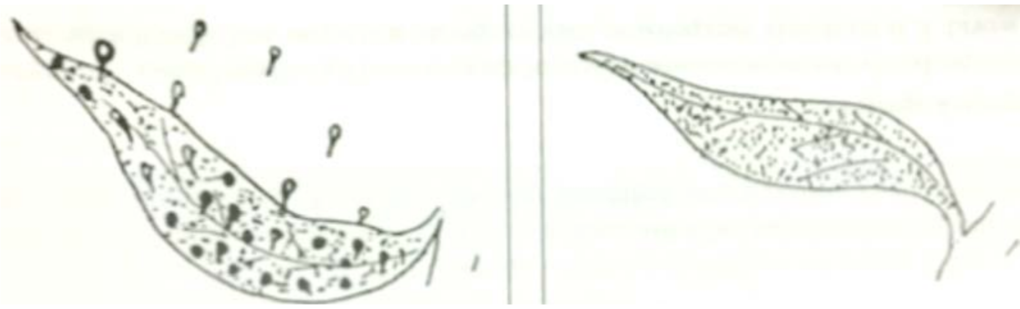


Fig. 6.11 How to spray tomatoes or any other bush from the side. Keep the nozzle 50 cm from the crop.
Source: JC Lowe, JMH Parker. Plant Protection in the Pacific Islands. SPC.

EXERCISE 6.3: Making up a pesticide for spraying

Trainees should use the following information to determine how much pesticide is needed:

- the pesticide label (Eko) tells you that you should apply Eko in 400 L of water per ha
- Eko is made up at 34 ml per 20 L sprayer (see Fig. 6.6)
- the farmer has a 5 square chain tomato field
- area: 5 square chains is equivalent to 0.2 ha (25 sq chains = 1 ha, 5/25)
- spacing: 0.5 m x 1 m
- the farmer has a 15 L knapsack.

By themselves, trainees should answer the questions below:

1. How many knapsack sprayers are needed to spray 1 ha of tomato?
2. How much (Eko) chemical will you need to spray 1 ha of tomato?
3. What advice would you give the farmer about the amount of chemical (Eko) … that he/she will use?
4. Check your answers with a partner and then discuss with the whole class.

EXERCISE 6.4: Important factors in spraying

In pairs or small groups, trainees should write down at least four important things that they need to know before, during and after spraying. Discuss answers with the class.

Spraying	Important things you need to know
Before spraying	1. 2. 3. 4.
During spraying	1. 2. 3. 4.
After spraying	1. 2. 3. 4.

6.5 Pesticides and organic farming

Organic farmers have a restricted range of pesticides they can use. This is because these farmers and their certifying bodies believe that many bought and even some home-made pesticides are harmful to humans, animals and the environment. Hence, some of the pesticides may not be as effective as bought ones, and not all have been scientifically tested.

Organic certification is carefully regulated. The Pacific Organic Standards (2008) are available at https://www.organicpasifika.net/poetcom/membership/pacific-organic-standard/. This document provides excellent information on organic farming in the Pacific region.

Some of the pesticide and growth regulators allowed in organic farming are listed and detailed in Table 6.4.

Table 6.4 Pesticides and growth regulator inputs allowed in organic farming. Always check with POETcom for latest information on organic standards if farm is organic certified.

Input	Purpose	Remarks
Chitin	Nematicide	
Coffee grounds	Insect repellent	Have a strong smell
Corn gluten meal	Pre-emergent herbicide	
Milk, casein	Fungicide	For powdery mildews
Gelatine	Insecticide	
Lecithin	Fungicide	
Vinegar	Herbicide, bactericide, fungicide	
Neem	Insecticide	
Caster oil	Rodenticide, insecticide, insect repellent, bird repellent	Care should be taken; it is very toxic
Grapefruit seed oil	Fungicide	
Chilli	Insecticide	
Tithonia (African sunflower)		
Marigold (*Tagetes* sp.)	Insecticide and repellent of root knot nematodes	
Papain (from *Papaya*)	Thrips	
Jatropha	Insecticide, molluscicide	
Pongamia glabra	Insecticide	
Propolis	Insecticide	
Pyrethrum (*Chrysanthemum cinerariaefolium*)	Insecticide	The synergist (carrier) piperonyl butoxide used in commercial pesticides must not be used
Quassia *(Quassia amara)*	Insecticide	
Derris elliptica, *Lonchocarpus* sp., Rotenone	Insecticide	Studies show a (unconfirmed) link between rotenone and Parkinson's disease so use should be limited, and safety measures observed
Ryania (*Ryania speciosa*)	Insecticide	

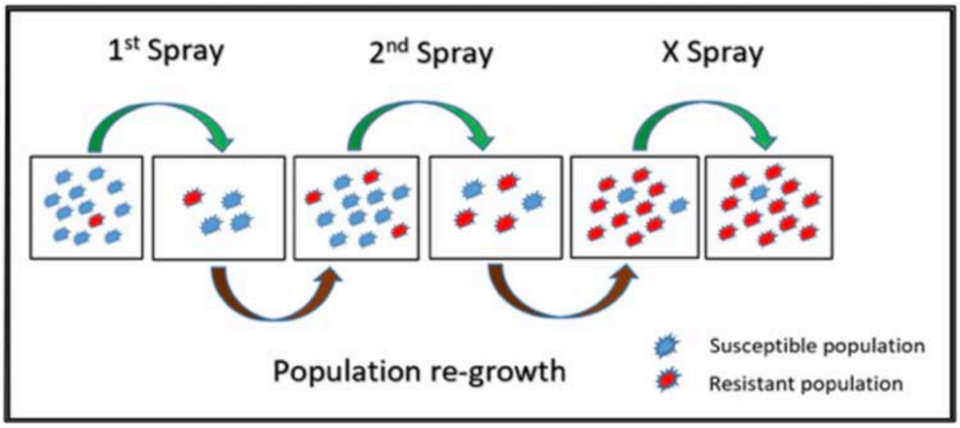
Table 6.4 continued…

Input	Purpose	Remarks
Sabadilla	Insecticide	
Seaweed	Root diseases of sunflower and tomato	
Tobacco tea	Insecticide	Safety measures need be taken to reduce skin contact. Pure nicotine must not be used
Mineral clays (e.g. Bentonite, vermiculite, perlite, zeolite)	Insecticide	Form a barrier to attack on the plant – used in orchards
Copper salts (e.g. sulphate, hydroxide, oxychloride, octanoate)	Fungicide, bactericide	Maximum 8 kg/ha copper per year (on a rolling average basis)
Light mineral oils (paraffin)	Insecticide, herbicide, fungicide	
Diatomaceous earth	Insecticide	
Lime sulphur (calcium polysulphide)	Fungicide	
Potassium bicarbonate	Fungicide	
Potassium permanganate	Fungicide, molluscicide, bactericide	
Quicklime silicates (e.g. Sodium silicate, quartz)	Fungicide, molluscicide, bactericide	
Sodium bicarbonate	General post-harvest insecticide and fungicide for banana	
Sulphur	Insecticide, miticide, fungicide	
Fungal and bacterial preparations (e.g. *Bacillus thuringiensis*, Bt)	Insecticide	Used against caterpillars
Iron phosphate	Molluscicide	
Calcium hydroxide	Fungicide, molluscicide, bactericide	
Salt (sodium chloride)	Molluscicide, herbicide, insecticide, bactericide	
Sodium carbonate (washing soda)	Insecticide	Scale insects, mealy bugs, aphids, and mites
Soft soap	Insecticide	Scale insects, mealy bugs, aphids, and mites
Pheromones (in traps and dispensers only)	Insect traps	Traps for fruit-fly and substances as required by regulations are permitted

6.6 Pesticide resistance management

Some pests develop resistance to pesticides if they are not used appropriately. This happens when the same pesticide is used repeatedly against the same pest in a crop. It is due to random genetic mutations that occur within the pest population; by chance, some of these mutations allow individuals to survive exposure to the pesticide. If the same pesticide is used repeatedly, individuals with the mutation that allows them to survive become the dominant type as the susceptible individuals are killed by the pesticide (Fig. 6.12).

Fig. 6.12 Diagram showing how insect pest resistance to pesticides builds up. *Source: authors.*



Insecticides are grouped according to how they kill pests, i.e. their mode of action (MoA). The chances of a pest population becoming resistant to a pesticide can be reduced by making sure that a pesticide with the same MoA is not used repeatedly against successive generations of the pest. We must ensure that the pesticides used have different MoAs, as well as being the least harmful to natural enemies.

The 'Groups' mentioned in Fig. 6.13 (6, 11, 22 or 28 and 15) identify pesticides based on their chemical characteristics and the way in which they kill insects (i.e. their MoA). The trade names and common names are: Multiguard (abamectin); Ag Chem Bt *(Bacillus thuringiensis);* Prevathon (chlorantraniliprole); Steward (indoxacarb); and Match (lufenuron).

A critical feature of the approach is that insecticides that kill insects in different ways are rotated to slow the development of resistance. Fig. 6.13 shows how this strategy can be implemented to reduce the probability of the diamondback moth (DBM), a pest of cabbages, developing resistance to pesticides.

In lowland regions of the Pacific islands, DBM can complete a generation (from egg to adult) in approximately 18 days. To make sure that successive generations are not exposed to the same type of insecticides, different insecticides should be used in the 'windows', as indicated in Fig. 6.13. In this strategy, Bt is used at the leafy stage, as this is the most sensitive stage of the crop. Bt has the added advantage that it is harmless to natural enemies.

Fig. 6.13 Insecticide resistance management strategy for diamondback moth in the Pacific region, using pesticides with different ways of killing the pest (MoAs).

Group 5 — spinosyns (affect nerves [acetylcholine neurotransmitter])

Group 6 — avermectins (affect nerves [chloride channels])

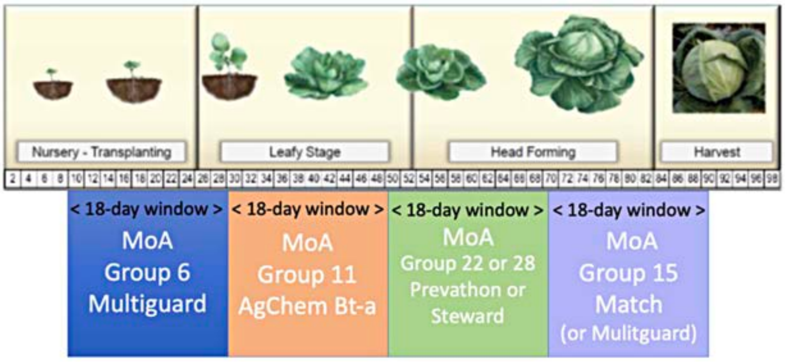
Group 11 — *Bacillus thuringiensis* products (affect mid-gut of caterpillars)

Group 15 — benzolureas (affect chitin synthesis in cuticle)

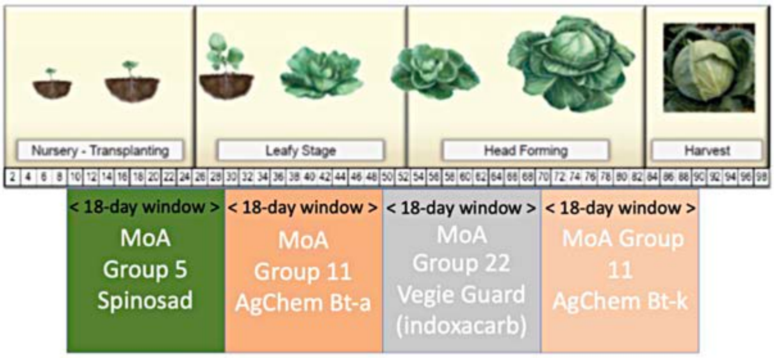
Group 22 — oxadiazines (affect nerves [sodium channels])

Group 28 — diamides (affect muscle).

i. Original strategy — based on availability of IPM compatible insecticides when Bt was introduced.



ii. Revised strategy — based on availability of additional IPM compatible insecticides. *Source: Mike Furlong. University of Queensland.*



EXERCISE 6.5: Advantages and disadvantages of using pesticides

Trainees have now covered Chapters 5 and 6 on management of pests and diseases through cultural control and use of pesticides.

- In pairs or small groups, they should discuss and write down what they now know about the **advantages and disadvantages of using pesticides**, compared with other methods included in IPDM. An example is given below.

Advantages of using pesticides	Disadvantages of using pesticides	Safer alternatives
Example: ▪ they are cheap	▪ they are toxic to beneficial insects	▪ crop rotation

EXERCISE 6.6: Using trainees' knowledge to identify and develop a management strategy for a farmer

Now that your trainees have studied the identification, diagnosis and management of pests and diseases, they need to put their knowledge into practice.

Practice and experience are essential; becoming a competent plant health doctor is complicated and takes work!

This is an important exercise, as it prepares your trainees for plant health clinics and is a good introduction to Chapter 7: Running a plant health clinic.

This exercise is in five parts. Allow your trainees plenty of time to work on it.

1. Identify and diagnose the problem.
2. Ask the farmer questions about the problem.
3. Manage the problem — make a plan.
4. Completing the Prescription Form.
5. Discuss and reflect.

Trainees should work in pairs. Allocate two of the photos from Papua New Guinea highlands to each pair. The pictures show samples of problems a farmer might bring to a plant health clinic. The crops are:

- tomato (4 photos)
- zucchini (2 photos)
- chinese cabbage (1 photo)
- cabbage - caterpillars (2 photos)
- cabbage - yellow spots (2 photos).

Part 1: Identifying and diagnosing the problem

Trainees should now work through the process of identification and diagnosis of the problem in their photos. They should use all the information from the manual, Fact Sheets in the Pacific Pests, Pathogens & Weeds app, as well as their own experience.

Remind trainees to use the identification and diagnosing process in Chapter 2:

1. Is it A, B, or C? (Abiotic, Biotic or Confused).
2. Possible and probable?
3. They should check with the fact sheets in the Pacific Pests, Pathogens & Weeds app only after they have done steps 1 and 2.

EXERCISE 6.6: part 1

1. Tomato

EXERCISE 6.6: part 1

2. Tomato

EXERCISE 6.6: part 1

3. Tomato

EXERCISE 6.6: part 1

4. Tomato

EXERCISE 6.6: part 1

1. Zucchini

EXERCISE 6.6: part 1

2. Zucchini

EXERCISE 6.6: part 1

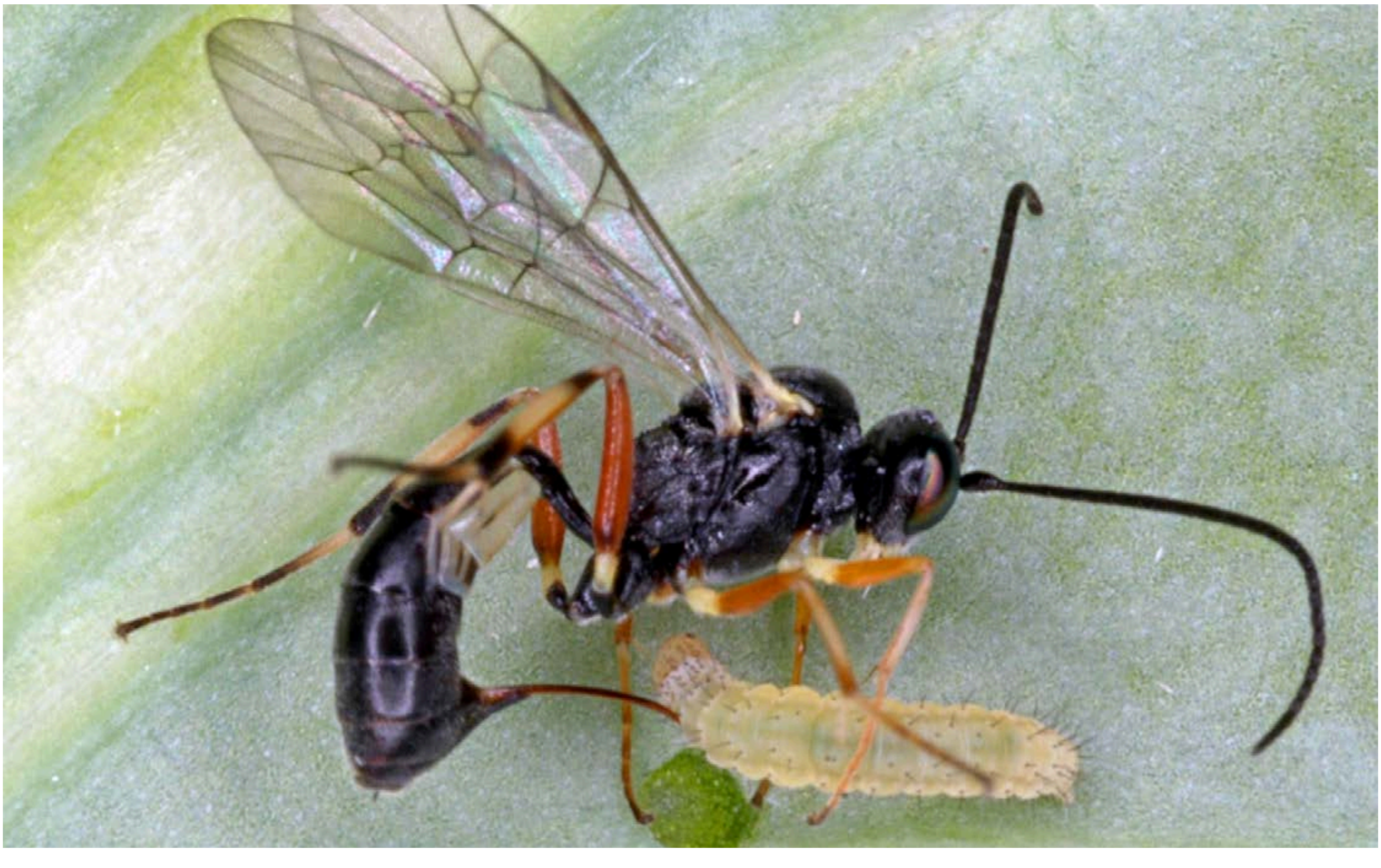
1. Chinese cabbage

EXERCISE 6.6: part 1

1. Cabbage

EXERCISE 6.6: part 1

2. Cabbage



EXERCISE 6.6: part 1

3. Cabbage

EXERCISE 6.6: part 1

4. Cabbage

EXERCISE 6.6: Using trainees' knowledge to identify and develop a management strategy for a farmer

Part 2: Identifying and diagnosing the problem

As well as examining the sample, at a clinic, plant doctors will need to ask the farmer questions to provide more information about the pest or disease.

1. Trainees should make a list of questions they would ask the farmer.
2. Each pair should now show the class their photos, read out their questions and discuss their diagnosis.

Part 3: Managing the problem — making a plan

Next, trainees should discuss and write down all the different ways the problem could be managed, using:

- biological control
  - are there any natural enemies that are important to preserve which might be killed with some pesticides?
- cultural control — what can be done?
  - before planting
  - during growth
  - after harvest
- resistant varieties
  - these can only be recommended if they are known to be available in the country
- chemical control
  - homemade pesticides
  - commercial pesticides.

Part 4: Completing the Prescription Form

Trainees should now complete the plant health clinic Prescription Form (next page). They can make up the farmer's details. Stress that they should fill in ALL parts, using clear handwriting.

Part 5: Discussion and reflection

Discuss and reflect on the exercise as a class. What worked well? What is difficult to do? What can be done better? What training is still needed?

This exercise should now be repeated using real samples from a garden or field. Practice is essential.

The Plant Health Clinic Prescription Form

CLINIC		
Date:	❑ Fiji ❑ PNG ❑ Samoa ❑ Tonga ❑ Solomon Islands ❑ Vanuatu	Code:
FARMER		
Family Name:	Given Names:	Sex: ❑ M ❑ F
Village/Settlement:	Province:	Mobile:
No. of previous clinic visit:	Age: ❑ < 29 ❑ 30-55 ❑ > 56	Sample: ❑ Yes ❑ No

CROP	
Crop:	Estimate planted area (m²):
Variety:	Estimate no. of plants:
Seed source:	Estimate no. of plants damaged: ❑ Few ❑ Many ❑ All
Previous crop:	Plant problem: ❑ Common ❑ New
Crop stage:	Weather: ❑ Unusual ❑ Normal ❑ i) Wet ❑ ii) Dry

DESCRIBE WHAT YOU SEE (if no sample, write what the farmer tells you)

WHAT CONTROL MEASURES HAS THE FARMER TRIED?

WHAT DO YOU THINK IS THE CAUSE OF THE PROBLEM?

YOUR RECOMMENDATIONS

WHAT CAN THE FARMER DO NOW?

CULTURAL CONTROL	CHEMICAL CONTROL

WHAT CAN THE FARMER DO IN FUTURE (WHEN GROWING THE SAME CROP)?

CULTURAL CONTROL		CHEMICAL CONTROL (remember natural enemies)
Before planting:	Any resistance varieties?	
During growth		
After harvest:		

Photo(s) taken: ❑ Yes ❑ No	Sample sent to lab? ❑ Yes ❑ No

Plant doctor:	Signature:	Mobile no.:

CHAPTER 6 QUIZ: Test your knowledge

Multiple choice. Pick one answer only…

1. Which of the following are all fungicides?

A. Manzate, milk, baking soda, malathion
B. Sundomil, Kotek, Kocide, Talendo
C. Glyphosate, neem, Blitzem, pyrethrum
D. Confidor, Orthene, Bt, Manzate

2. A sprayer nozzle suitable for fungicides should:

A. be an anvil type and the spray should form a light rain
B. be a flat type and the spray should form a mist
C. be a hollow cone type and the spray should form a mist
D. be a flat type and the spray should form a cloud

3. A pesticide label says that it should be made up at a concentration of 10 ml pesticide to 10 L water. The concentration of the pesticide is:

A. 10%
B. 1%
C. 0.1%
D. 0.01%

4. A farmer has 10 ha of a crop to be sprayed. The pesticide label tells her that the spray should be 30 ml pesticide per 20 L water and the crop should receive 400 L per ha. How many ml of the pesticide should she use to make up the spray to spray the whole crop properly?

A. 4000 ml
B. 600 ml
C. 6000 ml
D. 2400 ml

5. Buildup of insecticide resistance in a pest can be prevented by:

A. alternating the spraying between an insecticide and a fungicide
B. spraying early in the morning
C. using the correct type of nozzle for spraying
D. making sure the same type of insecticide is not used all the time

6. Which of these pesticides are not allowed in organic farming?

A. copper fungicides
B. tobacco
C. castor oil
D. Glyphosate

7. Which action should you NOT do if you accidentally spill some pesticide?

A. cover the area with sand
B. make sure you wash yourself and your clothes thoroughly
C. get the dog to lick it up
D. keep children away from the spill

8. Pesticide resistance in insects is caused by:

A. a genetic mutation that is passed on to new generations of the insect
B. a fungicide being used by mistake
C. a virus getting into the insect
D. using the wrong crop rotation

CHAPTER 6 QUIZ: Test your knowledge continued...

Multiple choice. Pick one answer only...

9. Which of the following information is NOT usually found on a pesticide label?

A. the type of product
B. which pests are resistant to it
C. what it contains
D. what crops it may be used on

10. An emulsifiable concentrate:

A. is the same as a wettable powder
B. is incompatible with all other pesticides
C. cannot be mixed with water
D. forms a milky liquid when mixed with water

11. A pesticide withholding period means:

A. how long before it is safe to enter the crop after spraying
B. the period during which animals are not allowed to graze on the crop at any time
C. the number of days between the last application of a pesticide and crop harvest
D. how long before a pesticide is allowed into a country

12. Copper can be used to control:

A. phytoplasmas and viruses
B. nematodes and mites
C. snails and insects
D. bacteria and fungi

13. Pests in a small farm or garden are best controlled by:

A. ignoring them
B. using pesticides as soon as they are seen
C. encouraging beneficial insects and spiders
D. using insecticides and fungicides weekly

14. Pesticides allowed in organic farming:

A. come only from plants
B. are the same as commercial pesticides only weaker
C. are controlled under organic standards
D. are always safe.

Chapter 7

Running a Plant Health Clinic (PHC)

This chapter covers the whole process of planning, conducting and reflecting on a plant health clinic.

What equipment do I need?

Stationery

- ❑ prescriptions forms
- ❑ Farmer Feedback Forms
- ❑ notebooks, marking pens, pens and pencils
- ❑ labels
- ❑ butchers or brown paper.

On phone or tablet

- ❑ camera
- ❑ KoboCollect app
- ❑ Pacific Pests, Pathogens & Weeds app
- ❑ social media app (see Chapter 4).

Equipment

- ❑ knife/scissors
- ❑ hand lens
- ❑ bottles for insect capture
- ❑ water and bucket for washing roots
- ❑ plastic bags to keep samples fresh for discussion and reflection after the clinic
- ❑ newspapers for wrapping samples for identification
- ❑ cardboard (paper) box
- ❑ uniforms
- ❑ Isopropyl alcohol for preserving insects.

Do not use a Stanley knife blade or scalpel — they are dangerous and snap easily

Other essentials

- ❑ tarpaulin
- ❑ table and chairs
- ❑ banner
- ❑ samples from the field
- ❑ samples brought in by farmers
- ❑ materials for wrapping and sending away 'unknowns':
    - newspaper
    - 70% alcohol or isopropyl alcohol
    - small glass tube
    - toilet or tissue paper
    - self-sealing plastic bags
    - dry silica gel or calcium chloride.

7.1 Introduction to running a plant health clinic (PHC)

There are a number of important points for plant health doctors to think about when preparing to run a PHC and to implement it successfully, as well as reviewing and reflecting on it afterwards.

If there is time, it is a good idea to run a practice clinic with extension staff (and research and biosecurity staff if resources allow), especially if there has not been a PHC in the area before.

Exercises 7.1, 7.2, 7.3 and 7.4 are designed to take your trainees through the whole process of running a clinic in class before the actual clinic takes place. These exercises cover the topics listed below.

1. What do we need for a successful plant health clinic?
2. How to use social media app as a plant doctor.
3. Filling out the Prescription Form.
4. The KoboToolbox and KoboCollect apps.
5. The Farmer Feedback Form.

Preparation needs to be done several days or weeks in advance of the clinic. Good awareness is essential! Without it, farmers will not come, or they will not bring samples.

Fig. 7.1 Clinics in action in Fiji (left) and Samoa (right). *Source: authors.*

EXERCISE 7.1: What do we need to run a successful PHC?

This exercise helps your trainees think about everything they will need for a successful clinic.

- in pairs or threes, on butchers paper or brown paper, trainees should use a marker pen to **divide the paper into three columns** and write 'before', 'during' and 'after' as headings
- **ask trainees to brainstorm** and write down in each column all their ideas about running a clinic before, during and afterwards, without looking at the answers in the manual
- when ready, **one group should give their ideas**, starting with 'before'
- after that group has spoken, the other groups should **just add anything that has been left out** (otherwise it will take too long, be repetitive and people might get bored) — an example is given for you
- now, **trainees should read the checklist** at the beginning of this chapter **very carefully** and add anything they may have missed to their list.

What do we need?		
Before the clinic	**During the clinic**	**After the clinic**
Identify a good location for farmers	Pacific Pest, Diseases & Weeds app	Samples brought by farmers

Exercise 7.2: Social media apps — how to use them

Trainees should have already joined their country social plant health doctor media group as described in Chapter 4.

WhatsApp, Viber and Messenger groups are very useful for Unknowns or Confused samples seen during the clinic.

Trainees should take a picture of a pest, disease or nutrient deficiency and send it to their social media group.

It is important that trainees send photos that are in focus.

They should give their name, place of work and information about the crop and the problem.

Ask trainees:

- What do you think the problem is?
- If you received a reply, is it what you thought it was?
- If not, what is it?
- Was this helpful? Why or why not?
- Share your photos and any feedback from their plant health doctor social media group with the class.

Trainees should share their photos and any feedback from their social media group with the class.

Note: it may take time to get feedback from their local plant health doctor social media groups.

Exercise 7.3: Role play — filling out the Prescription Form

This exercise builds on Exercise 6.6 in Chapter 6.

Trainees should form pairs, where each pair is made up of one experienced plant health doctor and one with less experience (where possible).

Provide each group with a sample or ask the trainees to go outside and collect samples of:

- a pest
- a disease
- an unknown or confused problem
- a nutrient deficiency.

If they cannot find a good sample, trainees can use one of the photos in the manual or one from the Pacific Pests, Pathogens & Weeds app.

Provide each group with a **copy of the Prescription Form** to fill in and a **Farmer Feedback Form** (in appendix) (Exercise 7.5).

Modelling the process

To start with, you or someone who has experience with plant health clinics, should **model the process** of working with a farmer to show the trainees what to do.

You role-play the 'doctor' and choose a trainee to role-play the 'farmer'.

The **'doctor' should interview the 'farmer**' and the other trainees should observe. Clearly model all the steps of being a doctor.

Explain what you are doing as you work through the identification and diagnosis steps carefully (see Chapter 2).

1. Is it A, B or C? (Abiotic, Biotic or Confused).
2. What are the possible and probable causes?
3. Make a diagnosis.
4. Check with the Pacific Pests, Pathogens & Weeds app.
5. Decide on possible recommendations for treatment, both straight away and into the future.
6. Fill in the Prescription Form.

Now **ask your trainees to play the roles** of doctor and farmer.

After this, **swap roles and work through another sample** together. Continue until everyone has had a turn playing both doctor and farmer.

Exercise 7.3: continued...

Emphasise that doctors should not go straight to the Pacific Pests, Pathogens & Weeds app!

When you have finished, **ask trainees to discuss their experience** of the role play.

- How easy or difficult was the process of making the diagnosis?
- What was easy about filling in the form?
- What did they find difficult?
- Were they able to make a diagnosis and give a recommendation? Yes/No.
- If No, why not?

Now ask the person who played the farmer to complete the **Farmer Feedback Form** (see Exercise 7.5).

The **Farmer Feedback Form** will be used at a real clinic. After each interview, the person who played the role of the farmer should give feedback to the plant health doctor on the diagnosis process and their ideas on management.

Remember to tell trainees that handwriting must always be neat on prescription forms so that others can read it. If you know your handwriting is not neat, print carefully or better still use KoboCollect on a phone or tablet.

Exercise 7.4: Using the KoboCollect Prescription Form

KoboToolbox and KoboCollect are apps that can be used on smartphones or tablets instead of the Prescription Form to collect the farmers' data. The advantages have been explained in Chapter 4, but it's worth repeating them here. They are:

- the Prescription Form can be filled in off-line and sent later when there is a Wi-fi connection available
- the results of the interview can be entered straight away
- it is quick to fill in (after some practice)
- typing avoids handwriting by plant health doctors that may be difficult to read
- a single doctor can interview more farmers in a shorter period, when they get used to interviewing and taking notes at the same time
- allows interrogation of the data using specialist software.

Features of KoboToolbox and KoboCollect are:

- it incorporates multimedia – supports video, audio messages, images, GPS, and signature capture
- it creates an Excel spreadsheet automatically
- it has unlimited data storage – uses a secure cloud server
- it supports multiple languages.

Demonstrate to the class how the KoboCollect Prescription Form works.

Trainees should download the KoboCollect app to their smartphones or tablets, then fill in the form using, a sample of a pest or disease that you give them.

Note, farmers will still need a copy of the Prescription Form.

If the KoboCollect app is used at a 'real' PHC, there needs to be two plant health doctors for each farmer, one filling out the KoboCollect app, the other filling in the Prescription Form, so a copy can be given to each farmer.

Exercise 7.5: Filling in the Farmer Feedback Form

The Farmer Feedback Form (also in the appendix) is an important part of PHC improvement, as well as for monitoring and evaluation (M&E) purposes.

- it is used to obtain immediate feedback from farmers after they have seen the plant health doctor at the clinic
- the clinic manager or another person (especially someone who speaks the farmer's language) needs to interview each farmer and complete the form
- the manager needs to make sure that the interviewer understands exactly what information is to be collected, and how it will be used, and by whom.

After the clinic, the manager collects and collates all the feedback forms and presents the information during the reflection session after the clinic (see Exercise 7.7).

Farmer Feedback Form

1. Did the plant health doctor diagnose your problem? (please tick)

   ❑ Yes ❑ No ❑ Not sure

   Why?

2. Do you think you can carry out what the doctor said you should do?

   ❑ Yes ❑ No ❑ Not sure

   Why?

3. Was the clinic useful?

   ❑ Yes ❑ No

   Why?

4. Do you have any suggestions on how to improve the plant health clinic?

5. Would you recommend the clinic to other farmers?

   ❑ Yes ❑ No

   Why?

6. If there is another clinic in your area would you come again?

   ❑ Yes ❑ No ❑ Maybe

Exercise 7.6: Preparing for many farmers attending the clinic with the same problem

It is important that all farmers see a plant health doctor, even if they have the same problem as other farmers.

Often, a number of farmers will bring the same problem to the clinic.

If there is time after the farmers have received their Prescription Form from the doctor, it would be very useful to gather them together and ask one of the doctors to give them a short talk about the problem.

This will give the farmers the opportunity to talk to each other about the problem and what they are doing about it.

Trainees should prepare by making sure they are aware of the major pests and diseases in their area (see Section 2.7 p. 92), although sometimes new problems can spring up quickly, especially when weather conditions change.

Other extension staff and experts should be contacted via the social media groups if necessary, to be told about the new problem, especially if it's likely to spread within the country, and if there are any recommendations on its management.

Trainees:

- either in a group or as a whole class, give your trainees the **names of pests, diseases or nutrient deficiencies that are likely to be a problem** in the area where the clinic is to be held
- if possible, **samples from the field** should be used
- the trainees should research these **using the Pacific Pests, Pathogens & Weeds app** to make sure they understand:
    - the symptoms
    - the diagnosis
    - recommendations for control now and in the future
- **trainees should discuss** how they will approach these problems with the farmers.

7.2 Checklists for running a plant health clinic (PHC)

Throughout Chapters 2-6, your trainees have explored how to identify, diagnose and manage plant pests, diseases or nutrient deficiencies. Now they are ready to apply their knowledge to run a real PHC with their local farmers. To do this properly requires careful planning so that the clinics will run well and be of real benefit to farmers.

An excellent way to make sure a clinic is well planned is to use a checklist for each aspect. This way, nothing is forgotten and the responsibility for planning a clinic can be shared within the plant health doctor team.

Use the checklist in Table 7.1 to check each aspect of planning before, during and after a PHC. Sections 7.2.1 to 7.2.6 provide additional detail for planning for each of the checkpoints in Table 7.1. Also, see the Plant Health Clinic Procedure Check List in Appendix 5.

Table 7.1 **A checklist for before, during and after running a Plant Health Clinic. Tick off each task as they are completed.**

Checklists for Plant Health Clinics	
Tick	**Task**
General preparation for PHCs	
	Clinic timing: ▪ how often should they be held? ▪ make a strategic PHC plan for your country ▪ always plan subsequent clinics in advance, so you can announce the next date at your current clinic
	Samples: ▪ clinics run best when farmers bring samples that are kept for reference — discuss with your team how you are going to collect, label, manage, store and follow up with any samples before planning a PHC
	Staff: ▪ are there enough staff appointed to the PHC team to effectively run clinics in the field and conduct the administration before and after them?
Before the clinic	
	Location — is it: ▪ accessible? ▪ visible? ▪ conveniently timed?
	Phone calls & text messages: ▪ radio ▪ TV ▪ phone calls ▪ emails ▪ encourage whole plant samples to be brought ▪ give farmers plenty of notice
	Budget: ▪ stationery ▪ advertisement ▪ other materials

Table 7.1 Continued…

Tick	Task
Before the clinic continued…	
	Staff: ▪ clinic manager ▪ data entry ▪ plant protection officers (extension, research, biosecurity) ▪ country's plant health doctor social media group on standby
At the clinic	
	Setting up: ▪ table, chairs, tarpaulin ▪ banner and pull-ups advertising the clinic ▪ access to Wi-fi, if possible ▪ a decision on what to do with 'unknowns'
	Plant health doctors — what is needed? ▪ materials for assessing samples, recording data, camera/phone for taking photos, providing prescriptions (see detailed list in Section 7.2.3)
Steps to ensure a successful PHC	
	Farmer registration and direction: ▪ make sure farmer's samples are processed appropriately ▪ ensure the farmers have completed a feedback interview and prescriptions are completed in a timely way and accurately ▪ have the farmers complete a feedback interview? ▪ provide farmers with factsheets, leaflets, other information sheets or resources
What to do with unknowns	
	▪ tell the clinic manager if you have an unknown — he or she should ask other plant health doctors who might be able to identify it ▪ make sure unknowns are assessed by one or more plant health doctors ▪ ask the social media community for help ▪ make sure the clinic manager follows up with SPC, PestNet or other research/biosecurity divisions for identification ▪ do not forget about unknowns — if you tell farmers you will follow up after the clinic to help them, do not forget to get an answer for them — if there is no follow up, farmers will not come to future clinics
Immediately after the clinic	
	▪ enter all the data from the Prescription Form into KoboCollect if you are not using the app to collect data at the clinic ▪ collate Farmer Feedback Forms (the clinic manager usually does this) ▪ follow up on any unknowns that have not been solved
	Review and reflection (Excercise 7.7): ▪ what went well? ▪ what could have been better? ▪ what changes will you make the next time?

7.2.1 General preparation for plant health clinics

How often should clinics be held?

How often you hold a clinic depends on your country's implementation plan, availability of staff, and resources. Ideally, a clinic should be run at least once a month. Always announce at the clinic when you will hold the next one and where it will be held.

Samples

Encourage farmers to bring samples of unhealthy plants, preferably with early symptoms. Farmers should try to bring the whole plant, including the roots.

Each sample should be given a code on a piece of card which is the same as the code in the top right-hand corner of the Prescription Form. If more than one sample is brought in, the letter A, B, etc., should be added to the code on both the card and the form.

After the clinic, the plants should be put into a bag with the correct sample code and be discussed in the reflection time after the clinic. Then they should be disposed of safely to avoid spreading pests and diseases.

Check that the sample has a card with the correct code that matches the Prescription Form when it is put in the bag.

Recording plant clinic data

Clinic data will be entered into Excel spreadsheets (either copied from the prescription forms or entered automatically from KoboCollect using KoboToolbox). The data can supply information on clinic use, such as the ratio of men to women attending, and the number of each pest and disease. It also checks on the quality of advice given by extension staff. Staff who need further training or information can be identified by looking at the data. This is an important element in the M&E part of the plant health system. It means that, over time, a set of data regarding plant health clinics can be built up and used for monitoring and research. If possible, avoid the need to add data manually, and instead use the KoboCollect app which fills an Excel spreadsheet automatically and so avoids mistakes (see Exercise 7.4).

7.2.2 Before the clinic

Location

Clinics should be held in accessible places such as markets and other places that farmers visit regularly, and held at times that are convenient to farmers. Extension offices in agriculture department buildings are not good venues; they are busy places and often too far for farmers to reach easily. The clinic site should be made clearly visible, using banners.

Awareness

Good awareness is essential. Plan awareness and announcements through radio, banners, TV, phone calls, texts, social media, email, word of mouth and other means. Decide when to start, and how many times to repeat the message. Farmers should be reminded to bring samples of unhealthy plants, and also insects that are damaging their crops. They should bring as much plant material as possible including roots. Just bringing part of a small leaf is not useful for a satisfactory diagnosis.

Budget

Check that the estimated budget is sufficient to cover all expenses (stationery, materials, travel etc.) for the clinic.

Staff

Appoint a clinic manager who is in charge of setting up, running, closing the clinic and collating and presenting the farmer feedback data. Where possible there should be at least two plant health doctors to process queries efficiently and share their thoughts on diagnosis and to give advice on management.

Invite staff from other agriculture divisions who directly work in plant protection. They do not need to attend the clinic, but make sure that they are standing by on the day to give advice if needed.

Ensure that the plant doctors are members of their country social media group (Chapter 4). Alert the social media community that there is a clinic taking place and ask them to stand by so they can help in sample identification.

7.2.3 At the clinics — steps to ensure success

Farmer registration and direction[1]

1. At the registration table, greet the farmer.
2. Direct farmers to the waiting area where they can have some refreshments (if provided) and look at useful material, such as:
   - fact sheets
   - posters
   - leaflets
   - newspapers
   - nutrition information
   - video on safe use of pesticides from Papua New Guinea.
3. Take a photo of the farmer's samples.
4. Direct the farmer to the doctor's table when the previous farmer has finished.

[1] The clinic manager may prefer not to have a separate registration desk and let the plant health doctors complete the full form as well as photograph the samples. If so, make sure labelling is carefully done to match: (i) the sample; (ii) photos; and (iii) the Prescription Form

TIP: **The manager or another extension officer could give the farmers a short tour and talk about the information on the posters.**

Giving the farmer advice

1. When the farmer comes to the doctor's table, welcome him or her and ask the questions on the Prescription Form.
2. Fill in the first part of the Prescription Form, if not already completed
3. Examine the sample (if the farmer has brought one), discuss the problem, ask the farmer relevant questions, and try to diagnose it using the diagnosis process you have practised.
4. Suggest recommendations to the farmer, and check if he/she understands them and is able to carry them out.
5. Fill in the rest of the Prescription Form and give the top copy to the farmer.
6. Ask the farmer to go to the person who is doing the farmer feedback interview.
7. Label the farmer's samples and any photos taken of the samples with the same code as that on the Prescription Form.
8. Put the samples in a bag. Make sure this is done and the samples are taken back to the extension office for the reflection after the clinic.

REMEMBER: **If a lot of farmers come with the same problem, let the manager know. He or she can arrange to gather them together and talk to them in a group (Exercise 7.6).**

If needed, trainers should translate the prescription and Farmer Feedback Forms into the national local language but a copy in English is needed for data entry.

7.2.4 What to do with unknowns

Sometimes a plant doctor will find it very difficult to make a diagnosis for the farmer. Before the clinic, the plant health doctors should make sure they know what to do if they have an unknown problem, or if they are confused. Read Chapter 4 again for online help. If a doctor cannot diagnose a sample and cannot make a recommendation, then they need to tell the farmer, not make up an answer. It is worse to give farmers the wrong information than to tell them, "I don't know, but I will find out and get back to you."

Plant health doctors should record the word 'unknown' on the Prescription Form and take the farmer's phone number to follow-up.

What to do if plant doctors have an unknown sample at a clinic:

- tell the clinic manager if there is an unknown — he/she can ask if any of the other doctors can make a diagnosis — it may have already been brought in and diagnosed by another doctor
- if it is still unknown, send a photo via social media to the experts who will be standing by while the clinic is in progress
- the clinic team may need to arrange a visit to the farm
- in the section on the Prescription Form: 'WHAT DO YOU THINK CAUSES THE PROBLEM?', write 'Unknown' and tell the farmer the team will find out what the problem is — do not leave it blank — remember, never write a diagnosis if unsure of the problem — it is always best for a doctor to say if they don't know
- after the clinic, the manager may decide to send the sample to the research/biosecurity division for identification — the process for this is described in Exercise 7.8
- make sure the advice is followed up with the farmer when there is a positive diagnosis. **Never promise you will help the farmer and then do nothing about it!**

IMPORTANT REMINDERS for plant health doctors:

- **fill out the form neatly and clearly, print if necessary, or use the KoboCollect app**
- **tell the clinic manager immediately if there is an unknown**
- **tell the farmer if you don't know, rather than guess**
- **if there is no solution at the clinic, tell the farmer it will be followed up and get back to him or her as soon as possible.**

7.2.5 After the clinic

Data entry

Good quality accurate data allows the plant health team to draw conclusions from the clinics, update a country's information about pests and diseases, and make improvements. The clinic manager or another extension officer is responsible for entering the data from the prescription forms into KoboCollect, if it is not being used at the clinic.

Follow-up with farmers

The clinic manager is responsible for making sure the clinic team follows up on unknowns, i.e., letting the farmers know the results of diagnoses made by experts from biosecurity or elsewhere. The results must be added to the spreadsheet.

In addition, recommendations that were not given to the farmer at the time, but which were identified in discussions during the reflection with other plant health doctors, should be given to farmers over the phone. These, too, should be added to the spreadsheet.

The clinic manager is responsible for making sure that follow-up data are entered into the system to fill in the gaps. For example: If a sample that was sent away for diagnosis comes back from the laboratory, the officer responsible needs to add it to a spreadsheet, as well as communicating with the farmer.

> **NOTE: if the KoboCollect app is used, the information entered can be automatically entered into an Excel spreadsheet which you can access.**

Review and reflection

After the clinic, plant doctors need to come together as well as follow up with the farmers, and collect data that will show how successful the clinic was. This is a very important part of the whole PHC process. It is where the plant health doctors share their experiences of the clinic held that day, think about what went well, what was learned and what needs to be improved or changed next time.

Exercises 7.7-7.12 allow trainees to reflect on what they have learned during their training and their experience at the clinic. It will help identify any areas that require additional training so that they are confident in their ability to run successful PHCs into the future.

It is also very important to make a summary for the clinic. It does not take much time but is necessary for record keeping, and for sending to senior officers, the media and others who are interested in these clinics. To make it easier for you, there is a photosheet[2] summary that can be used as a model (Fig. 7.2). Trainees can practise this in Exercise 7.12.

[2] The photo sheet concept was suggested by Dr Eric Boa, University of Aberdeen.

Fig. 7.2 An example of a plant health clinic photosheet summary to be used as a model for future Plant Health Clinics. *Source: Ministry of Agriculture & Fisheries. Samoa.*

SAMUSU - ALEIPATA, SAMOA

Ministry of Agriculture & Fisheries

4th October 2018

This Plant Health Clinic was held at Samusu – Aleipata, a village towards the far east of Apia, in conjunction with the regional team to test the training manual. I

It started at 10am and concluded at 1pm.

About 18 farmers attended; a third were women. Farmers came from Samusu, Lalomanu, and Salani.

All the farmers brought samples and many brought more than one sample from different crops; there were 40 problems diagnosed.

The problems included bacterial wilt on tomato and capsicum; root-knot nematode on tomato and cabbage; LCM on cabbage; possibly Pythium rot on taro; white flies and sooty-mould on broccoli; root rot (possibly nematodes) on banana; fruit piercing moth on tomato fruits; fruit fly and rot on cucumber.

Plant doctors from MAF were Christian T, Faalelei T, Mu V, Kuini T, Tamoe T, Aleni U, Latatuli L, Tommy T and Leafa G; from the regional team; Ratu Toloi V (Fiji) Tevita T and Emeline A (Tonga), Rosemary A (Solomon Islands), Mani M (Pacific Community) under the supervision of Dr. Grahame Jackson (PestNet) and Dr. Caroline Smith (University of Tasmania). Sailo Pao was the clinic manager.

Prepared and reported by the Ministry of Agriculture and Fisheries.

For more information, contact Sailo Pao, Crops Division, Nu'u Research Station. Mob: 7230442 Email: sailop.pao@maf.gov.ws; Plant Health Clinics are held as part of a sub-regional ICM/IPDM project (HORT/2016/185) - *Responding to emerging pest and disease threats to horticulture in the Pacific islands*, with support from the Australian Centre for International Agricultural Research, Canberra.

Exercise 7.7: Reflection on the clinic process

On butchers paper or brown paper, trainees should discuss:

- what went well and
- what did not go well.

Encourage them to share all their experiences, not just their successes. This is how they will learn.

Trainees should record their discussion using this table and share with the class. An example is provided.

What went well?	What didn't go so well?	What training is still needed?	What improvements will be made at the next clinic
A lot of farmers came	Only a few women came	Diagnosis	Make sure awareness targets women in particular. Check the time was convenient for them. More diagnostic practice before next clinic

Exercise 7.8: Farmer feedback data

The clinic manager will collate all the Farmer Feedback Forms and present the results.

This will let the team know what the farmers thought about the clinic, which will also help to plan for the future.

Discuss the results:

1. What do the results tell your trainees about how well they ran the clinic?
2. What should be done to improve next time?
3. Does the feedback form provide enough information about the farmers' experience at the clinic?
4. Does the form need improving? If so, how?

Exercise 7.9: Reflection on diagnosis and recommendations

This exercise is one of the most important to do after the clinic. In a safe learning environment, your trainees will come together with farmers' samples and copies of the completed Prescription Forms to discuss their descriptions, diagnoses and recommendations.

Trainees should form groups of two or three and go through samples from the clinic. They should discuss:

- **their diagnoses of a pest, a disease or a nutrient deficiency** and a 'confused' sample brought by farmers to the clinic
- **any differences** of opinion
- what they told the farmers to do in
  i) the short term and
  ii) the long term
- any samples that could not be identified ('unknowns')
- how they informed (or will inform) the farmers about the unknowns

Each group should select one sample and report their findings to the class using the template below, either as a PowerPoint or on paper.

The discussion afterwards should **focus on the process of the diagnosis** and the recommendations.

Any changes should be **discussed with reasons**.

<table>
<tr><td colspan="2">Farmer and location:

Crop:

Symptoms:

Diagnosis:</td><td>Insert photo if available</td></tr>
<tr><td>What farmer can do NOW</td><td>e.g. cultural control</td><td>e.g.chemical control</td></tr>
<tr><td>What farmer can do in the future</td><td>e.g. cultural control</td><td>e.g.chemical control</td></tr>
</table>

Exercise 7.10: Sending samples for identification

This exercise shows trainees how to send unknown samples to experts for identification.

If no one is able to identify their sample, it will need to be sent to an expert for examination, either locally or overseas.

Samples of pests and diseases should be placed on three tables labelled 1-3:

1. A fungal or bacterial disease.
2. A pest.
3. A virus.

Trainees can work though the procedure for each type of pest and disease, then move to the next table, so that they have experience preparing samples for different types of pests and diseases.

Details of the methods can also be found on the PestNet website: www.pestnet.org

You will need the following for this exercise:

- ❑ paper for labels
- ❑ pencils
- ❑ plastic bags
- ❑ newspaper
- ❑ sticky tape
- ❑ alcohol (if not ethanol, then isopropyl alcohol)
- ❑ small bottles
- ❑ envelopes
- ❑ camera for taking photographs of samples
- ❑ silica gel and calcium chloride (if available).

Before going to a table, each group should write:

i. a note (a label) to put inside the parcel containing all the information below and
ii. a label with the name and address of the person in research or biosecurity to whom the parcel is to be sent:

- crop/plant name
- code given at the clinic
- doctor's name and address
- code, same as on the Prescription Form
- date and location of the clinic
- farmer's name and phone number
- farmer's village
- a short description of the problem and any other useful information they thought to be useful.

Table 1: Processing damaged or diseased plant samples

1. Collect the samples showing a full range of symptoms.
2. Take a photo of the samples.
3. Make a parcel of the specimens with newspaper.
4. Attach the second label to the front of the parcel. If possible, seal the label with sticky tape to protect it.

Exercise 7.10: continued...

Table 2: Processing insects and mites

1. Take a photo of the samples.
2. For small insects – thrips, aphids, hoppers as well as mites, preserve in alcohol — 70% alcohol is best, but probably not easy to find — so, use isopropyl alcohol which should be available at the local chemist.
3. Place a small amount of alcohol in a bottle.
4. Carefully pick up the insect, or cut out a piece of the plant that contains the insects or mites, and place it in the bottle with alcohol.
5. Add a label (as detailed above) to the bottle. It is important that all labels are written in pencil, as ethanol removes ink.
6. Make sure that the tube/bottle does not leak.
7. Place in plastic bag, and tie the opening.
8. For larger specimens, wrap them carefully in paper envelopes and place them in a secure box so that they are not crushed — use this method for Lepidoptera (butterflies and moths): do not put them in alcohol.

If you are sending a scale insect or mealybug do not attempt to remove it from the leaf or twig on which it is feeding. Do not put butterflies and moths into alcohol as the scales will fall off. Instead, fold in paper envelopes.

Table 3: Processing samples caused by viruses

Trainees are unlikely to process samples infected by viruses as special equipment is needed. However, you might wish to explain how it is done for their interest.

1. Take a photo of the samples.
2. Cut out the area of the leaf that shows symptoms of virus.
3. Place this on a clean wooden board, or a tile or thick paper and cut out strips 10 mm wide, using a clean scalpel or a clean sharp knife (wipe it first with alcohol or bleach).
4. Cut across the leaf pieces, making strips 1 x 10 mm wide
5. Place these, loosely packed, in a screw-capped tube (about 30 ml) half-filled with silica gel (blue) or calcium chloride (if you do not have either, then dry the samples in an air-conditioned room).
6. If the samples are not dry after 24 hours, transfer them to a new tube of drying agent.
7. When dry, fix the second label with clear tape on the outside of the tube.

Note:** **if the silica gel is pink, it needs to be re-dried at 150°C for 3–4 hours until it is blue. Be careful to wait until the silica gel is cool as it retains heat for some time.

Exercise 7.11: Plant health doctor self-evaluation form

Now it is time for your trainees to evaluate themselves as plant health doctors. This is anonymous, but it will help the extension service to monitor how well the program is running and what further training may be needed.

On a sheet of A4 or brown paper, trainees should give their answers to the questions below. In questions 1, 2 and 3, **1 is the lowest level of confidence** and **5 is the highest**. They should **circle the number** that they think best fits their level of confidence.

1. How confident are you in your abilities to make correct disease diagnoses?

   1 2 3 4 5

2. How confident are you in your ability to correctly diagnose pest problems?

   1 2 3 4 5

3. How confident are you in your ability to make correct recommendations?

   1 2 3 4 5

4. Do you feel you need more training?

   ❑ Yes ❑ No

5. If 'Yes' what training is needed? Please specify (e.g. IT, diagnosis, filling out the prescription forms, interviewing farmers, etc.)

Collate and report the results from the class.

Discuss:

- What does this say about your trainees' level of confidence and ability to conduct a plant health clinic?
- How can you and your trainees continue to improve?

Exercise 7.12: Making a plant health clinic photosheet summary

It is very important to make a clinic summary. It does not take much time but is necessary for record keeping, and for sending to senior officers, the media and others who are interested in these clinics. Use the template below.

This can be done in Word or Acrobat Pro. **Following the template**, provide the location and date, the number of farmers, the number of men and women, where they came from, the problems they brought to the clinic, the diagnoses made, and the names of the plant health doctors. **Contact details of the organisation** hosting the clinic should also be added. See the example in Fig. 7.2.

…………………… COUNTRY

…………………… [major administrative area]

…………………… [place of organisation] PLANT CLINIC

…………………… [organisation] | …………………… DATE

Insert Photo 1	Insert Photo 1
Insert Photo 1	Insert Photo 1
Insert Photo 1	Insert Photo 1

This plant clinic was held at ………………… and organised by ………………… .

The ………………… (clinic) is located ….. km N/S/E/W from ………………… town.

[add number] farmers participated at the clinic; there were *[add number]* men and *[add number]* women).

[add number] samples were received.

Some of the key problems presented were ………………… .

The plant doctors were ………………… .

[Other information]: You could add if any specimens were sent for identification.

Prepared and reported by ………………… , Organisation.

For more information contact ………………… (person, phone number, email, etc.).

Photos by ………………… (if a different person).

Plant clinics are held as part of the ACIAR project: *Responding to emerging pest and disease threats to horticulture in the Pacific islands.*

CHAPTER 7 QUIZ: Test your knowledge

Multiple choice. Pick one answer only…

1. Plant health clinics are important parts of:

A. a country's food security
B. a country's plant health system
C. the agricultural extension system
D. all of the above

2. The best place to hold a clinic is:

A. where many farmers gather, e.g. a market
B. at the research station
C. on a farm
D. at the university

3. Important advice for farmers when raising awareness about a forthcoming clinic is:

A. to bring the whole plant, including roots
B. to bring a few leaves
C. to bring a soil sample
D. to bring your phone

4. If you do not know what the problem is, you should:

A. leave that part of the prescription form blank
B. tell the farmer something, even if you are not sure
C. ask if anyone else knows what the problem is
D. send the farmer away

5. Look at the steps below for identifying a disease sample. They are in the wrong order.

1. make a parcel for the specimens with newspaper
2. write a label and put the specimen in a plastic bag with a few drops of water and seal the bag, leave overnight
3. collect samples showing a full range of symptoms

The correct order to do these steps in is:

A. 1, 2, 3
B. 3, 2, 1
C. 2, 1, 3
D. 1, 3, 2

6. Insect samples to be sent away for identification are best preserved in:

A. methanol
B. isopropyl alcohol
C. 70% alcohol
D. beer

7. A plant doctor suspects a farmer's sample has a bacterial wilt. She can test this by:

A. smelling it to see if it smells rotten
B. cutting the stem and dipping the end in water and looking for milky streaming
C. finding the bacteria under a microscope
D. looking for spots on the leaves

CHAPTER 7 QUIZ: Test your knowledge continued...

Multiple choice. Pick one answer only...

8. The most important items to take to a clinic are:

A. chairs
B. kava
C. uniforms
D. Prescription Forms

9. After a clinic, a plant health doctor must always:

A. follow up with a farmer if the farmer has been told that will happen
B. reflect on and review the clinic data and plan to improve next time
C. collect all the samples for looking at later with the other plant health doctors
D. do all of the above

10. A farmer brings yams that have died and gone black. The farmer tells the plant health doctor they have been damaged by lightning. The doctor thinks the problem is anthracnose. The doctor should help the farmer straight away by:

A. agreeing that lightning might be the cause but also offering other ideas of the cause, and suggesting what the farmer could do
B. offering to visit the farm
C. telling the farmer he or she cannot be helped at the clinic
D. asking the farmer to bring in more samples.

7.4 The Big Quiz

Now that your trainees have completed all the plant health clinic training in Chapters 2-7 they can test their knowledge with one final test, The Big Quiz!

You can also make up your own questions.

When they have all finished, go through the answers.

You do not need to ask what marks the trainees got; they will have learned the correct answers by going through the test as a class.

Make sure you discuss any answers they are not sure about.

Then explain that if there is anything they are still not sure about, they should read the manual again and/or ask for help.

THE BIG QUIZ

Multiple choice. Pick one answer only...

1. A plant health system should include:

A. plant health clinics, extension staff, research staff, ministries of agriculture staff
B. biosecurity staff, research staff, hospital staff, quarantine staff
C. plant health doctors, vets, extension staff, research staff
D. media, tourism, agriculture, horticulture

2. Which of the following are all insecticides?

A. Manzate, milk, baking soda, Taratek
B. Sundomil, Attack, Multiguard, Confidor
C. Glyphosate, neem, Blitzem, pyrethrum
D. Confidor, Orthene, Bt, Taratek

3. A sprayer nozzle suitable for fungicide should:

A. be an anvil type and the spray should form a light rain
B. be a flat type and the spray should form a light rain
C. be a hollow cone type and the spray should form a mist
D. be a flat type and the spray should form a cloud

4. A pesticide label says that it should be made up at a concentration of 1 ml pesticide to 10 L water. The concentration of the pesticide is:

A. 10%
B. 1%
C. 0.1%
D. 0.01%

5. A farmer has 10 ha of a crop to be sprayed. The pesticide label tells her that the spray should be 30 ml pesticide per 20 L water and the crop should receive 500 L per ha. How many ml of the pesticide should she use to make up the spray to cover the whole crop properly?

A. 3000 ml
B. 4000 ml
C. 6000 ml
D. 7500 ml

6. Build-up of pesticide resistance in a pest can be prevented by:

A. alternating the spraying between an insecticide and a fungicide
B. spraying early in the morning
C. using the correct type of nozzle for spraying
D. making sure the same type of pesticide is not used all the time

7. Which action should you NOT do if you accidentally spill some pesticide?

A. cover the area with sand
B. make sure you wash yourself and your clothes thoroughly
C. keep children away from the spill
D. leave it to evaporate away

8. Pesticide resistance in insects is caused by:

A. a genetic mutation that is passed on to new generations of the insect
B. using the wrong crop rotation.
C. a herbicide being used by mistake.
D. a virus getting into the insect

THE BIG QUIZ continued...

Multiple choice. Pick one answer only...

9. Which of the following information is NOT usually found on a pesticide label?

A. the type of product
B. which pests are resistant to it
C. what it contains
D. what crops it may be used on

10. A wettable powder:

A. is the same as an emulsifiable concentrate
B. is incompatible with all other pesticides
C. can be mixed with water
D. forms a milky liquid when mixed with water

11. A pesticide withholding period:

A. is the period before it is safe to enter the crop after spraying
B. is the period when animals are not allowed to graze on the crop at any time
C. is the number of days between the last application of a pesticide and crop harvest
D. is the period before a pesticide is allowed into a country from overseas

12. In IPDM, pesticides should be used:

A. always, as a prevention
B. never
C. as a last resort
D. only if the farmer can afford them

13. The adult insect in the picture below is most likely to be:

A. a beetle
B. a wasp
C. a lacewing
D. a fly

14. In order, a companion plant, a biological insecticide and a beneficial organism are:

A. taro, DBM, Trichoderma
B. Chinese cabbage, kocide, ladybird
C. coconut, pyrethrum, trichogramma
D. marigold, metarhizium, spider

15. An example of a good crop rotation would be:

A. lettuce, cabbage, broccoli, bean
B. cucumber, squash, potato, cassava
C. potato, tomato, eggplant, capsicum
D. bean, cabbage, cucumber, cassava

THE BIG QUIZ continued...

Multiple choice. Pick one answer only...

16. A plant health doctor is faced with an unknown pest or disease at the clinic. What should s/he do first?

A. send a picture to social media group
B. make up something; it's better than the farmer thinking they don't know
C. see if anyone else in the clinic knows
D. tell the farmer to go away

17. In IPDM, monitoring involves:

A. deciding whether the problem is caused by a pest or a disease
B. using the best pesticide for the pest
C. checking the level of damage and looking for bugs and eggs
D. identifying the pest or disease

18. The correct sequence for applying IPDM is:

A. monitoring, identification of pest or disease, decide amount of damage acceptable, making a plan
B. evaluation, monitoring, identification of pest or disease, making a plan
C. making a plan, identification of pest or disease, monitoring, evaluation
D. identification of pest or disease, monitor, decide amount of damage acceptable, make a plan and action

19. Which plants are all in the same plant family?

A. cabbage, bok choy, broccoli, chilli
B. potato, cassava, taro, sweet potato
C. bitter gourd, pumpkin, cucumber, pineapple
D. capsicum, chilli, eggplant, potato

20. The best way to control a soil borne bacterial infection is:

A. use a resistant variety if it can be obtained
B. spray with a pesticide
C. use a virus that attacks the bacteria
D. add compost to the soil

21. Which of the following is NOT thought to be associated with companion planting:

A. companion plants can provide food for parasitoids
B. companion plants may have a smell that repels pests
C. companion plants always add large amounts of potassium to the soil
D. companion plants may repel root knot nematodes

22. In order, abiotic and biotic factors that cause damage on plants are:

A. fungi and mites
B. birds and drought
C. potassium deficiency and bacteria
D. phytoplasmas and poor soil

23. Typical symptoms on plants caused by bacteria are:

A. leaf spots, angular or round, with or without haloes
B. wilt and yellowing at the edges of leaves
C. rusty spots and mosaics
D. dieback and the leaves go purple

THE BIG QUIZ continued...

Multiple choice. Pick one answer only...

24. A common disease of tomatoes in the Pacific region is:

A. witches' broom
B. tobacco mosaic
C. early blight
D. ring spot

25. The smallest of these pathogens is:

A. a virus
B. phytoplasma
C. a bacterium
D. a fungal spore

26. A plant doctor finds a plant with symptoms of wilt. The most unlikely cause would be:

A. bacteria in the soil
B. rust fungus
C. nematodes
D. stalk borers

27. Pests with eight legs are not:

A. mites
B. insects
C. scorpions
D. spiders

28. Which of these diseases is caused by a fungus?

A. bunchy top on banana
B. blossom end rot on tomato
C. scale on sweet potato
D. damping off on cabbage seedlings

29. A plant doctor finds a cabbage with a lot of holes in the leaves. Which are not likely causes?

A. diamondback moth
B. large cabbage moth
C. leaf spot
D. snails

30. A virus can be spread by:

A. bacteria
B. fertiliser
C. rhinoceros beetles' larvae
D. aphids

31. Two insects with simple life cycles are:

A. aphids and katydids
B. butterflies and bugs
C. grasshoppers and ants
D. bees and moths

32. Plant health clinics are important parts of:

A. a country's food security
B. a country's plant health system
C. the agricultural extension system
D. all of the above

33. The best place to hold a clinic is:

A. where many farmers gather, e.g. a market
B. at the research station
C. on a farm
D. at the university

THE BIG QUIZ continued...

Multiple choice. Pick one answer only...

34. Important advice for farmers when you are raising awareness about a forthcoming clinic is:

A. to bring a whole sample if possible
B. to bring a few leaves
C. to bring a soil sample
D. to bring your phone

35. If you do not know what the problem is, it is best to:

A. leave that part of the prescription form blank
B. tell the farmer something, even if you are not sure
C. end the farmer away
D. ask if anyone else knows what the problem is

36. Look at the steps below for identifying a disease sample.

1. make a parcel for the specimens with newspaper
2. write a label and put the specimen in a plastic bag with a water and seal the bag
3. collect samples showing a full range of symptoms

The correct order to do these steps in is:

A. 1, 2, 3,
B. 3, 2, 1
C. 2, 1, 3
D. 1, 3, 2

37. Insect samples to be sent away for identification are best preserved in:

A. beer
B. methanol
C. isopropyl alcohol
D. 70% alcohol

38. A plant doctor suspects a farmer's sample has a bacterial wilt. She can test this by:

A. smelling it to see if it smells rotten
B. looking for spots on the leaves
C. placing the end of the stem under water and looking for milky streams
D. finding the bacteria under a microscope

39. The most important items to take to a clinic are:

A. chairs
B. kava
C. uniforms
D. prescription forms

40. After a clinic, a plant health doctor must always:

A. follow up with a farmer if the farmer has been told that will happen
B. reflect on and review the clinic data and plan to improve for the next clinic
C. collect all the samples for looking at later with the other plant health doctors
D. do all of the above

THE BIG QUIZ continued...

Multiple choice. Pick one answer only...

41. A farmer tells the plant health doctor he thinks his crops have been damaged by an evil spirit. The doctor should help the farmer by:

A. agreeing this might be the case and offering other ideas of what the farmer could do
B. sending the farmer to a priest
C. telling the farmer he cannot be helped at a plant health clinic
D. asking the farmer to bring in more samples

42. Which Pacific countries are now thought to have the Guam strain of the rhinoceros beetle?

A. Samoa
B. Guam, Palau, Hawaii, Vanuatu
C. Fiji
D. Guam, Palau, Papua New Guinea, Solomon Islands

43. Good soil is likely to have a pH of around:

A. 1
B. 3
C. 7
D. 9

44. Which of these home-made pesticides is particularly harmful to fish?

A. chilli
B. gliricidia
C. neem
D. derris

45. What are the pests in this photo?

A. rhinoceros beetles on mango
B. green vegetable bugs on tomato
C. black ticks on pumpkin
D. aphids on guava

46. What is the difference between a parasite and a parasitoid?

A. there isn't one: they are the same
B. a parasite does not kill its hosts; a parasitoid does
C. a parasitoid can't be seen with the naked eye; parasites can
D. parasites have complex life cycles whereas those of parasitoids are simple

47. The picture below shows you how:

A. A. to spray low-growing crops
B. B. far apart crops should be
C. C. to use a mist sprayer
D. D. to water your plants in a drought

THE BIG QUIZ continued…

Multiple choice. Pick one answer only…

48. A farmer brings a plant with large irregular spots on the leaves. It is most likely to be:

A. a wilt
B. a deficiency disease
C. a fungal disease
D. something I know nothing about

49. You want to teach your trainees to think about how plant diseases relate to people going hungry. The best teaching strategy is probably:

A. a cause and effects diagram
B. a picture of a hungry child
C. a role play
D. a concept map

50. Which symptoms are often confused?

A. a powdery mildew and a leaf spot
B. a virus and a deficiency disease
C. a bacterial leaf spot and a bacterial wilt
D. overwatering and copper deficiency.

51. Organic matter in soil is found in:

A. the bedrock
B. humus
C. clay
D. water

52. Which of these are NOT ways in which nitrogen can be made available to plants:

A. nitrogen fixing bacteria
B. using leguminous cover crops
C. drawing in nitrogen from the atmosphere
D. applying fertiliser

53. The plant's rhizosphere includes:

A. roots, root exudates and microbes
B. rhizomes
C. flowers and leaves
D. compost

54. 'One Health' refers to:

A. the health of people in the Pacific
B. the idea that the health of all life forms is interconnected
C. how bacteria affect plant roots
D. the health of soil

55. Which of these are NOT normally found in the soil microbiome:

A. archaea
B. bacteria
C. worms
D. fungi

---- End of Quiz ----

Congratulations to the trainer and the trainees in completing the plant health doctor training!

Now – practise, practise, practise!!

Chapter 8

Resources for Trainers

To be an effective trainer, you should ensure you are familiar with the manual content before planning and carrying out PHC training. The resources in Chapter 8 provide some background on being a good trainer, and guide you through the important material in the manual for you to use in your preparation.

8.1 Being a good plant health clinic trainer

Good training of plant health doctors is essential for plant health clinics to be effective. Good trainers are confident about both what to teach and how to teach, and they work to develop a non-threatening and stimulating learning environment.

8.1.1 Become confident about what to teach

Good trainers continually build on their understanding of pests, diseases and nutrient deficiencies, and how to go about diagnosing and controlling them. There is no substitute for practical experience and lifelong learning. You should try to spend a lot of time in gardens and farms with your hand lens and the Pacific Pests, Pathogens & Weeds app on your phone to become familiar with plant pests, diseases and nutrient deficiencies, as they actually appear in the field, as well as talking to farmers and extension staff. This is the best way to develop experience and expertise in diagnosis.

Visits to the field will help you decide whether a problem is caused by a pest or disease or has another cause (poor soil, nutrient deficiencies, dry conditions, water logging, etc.), in other words, whether it is A, B or C, as in Section 2.1 of the manual. Finding out what others think about the problem and what they have done about it is also very helpful and important.

8.1.2 Become confident about how to teach

Even if you have excellent knowledge of plant pests and diseases, to help others learn you need to understand something about how learning takes place. It is not enough to just give a lecture with slides. Some people might learn well that way, but others do not. All human beings naturally enjoy learning to make sense of their world but, unlike children, adult learners already have a lot of knowledge and skills to share with each other, and usually they learn best when they are interested and motivated. Adults expect to be able to learn from each other, as well as the trainer, and respect each other's experience, self-worth and knowledge.

Usually, adults learn best in small groups, so they can discuss ideas together, but there should also be time for people to work alone, or for you to teach the whole class together. The exercises in the manual use a range of teaching strategies designed to help your trainees to become actively engaged in their learning.

8.2 Developing a non-threatening and stimulating learning environment

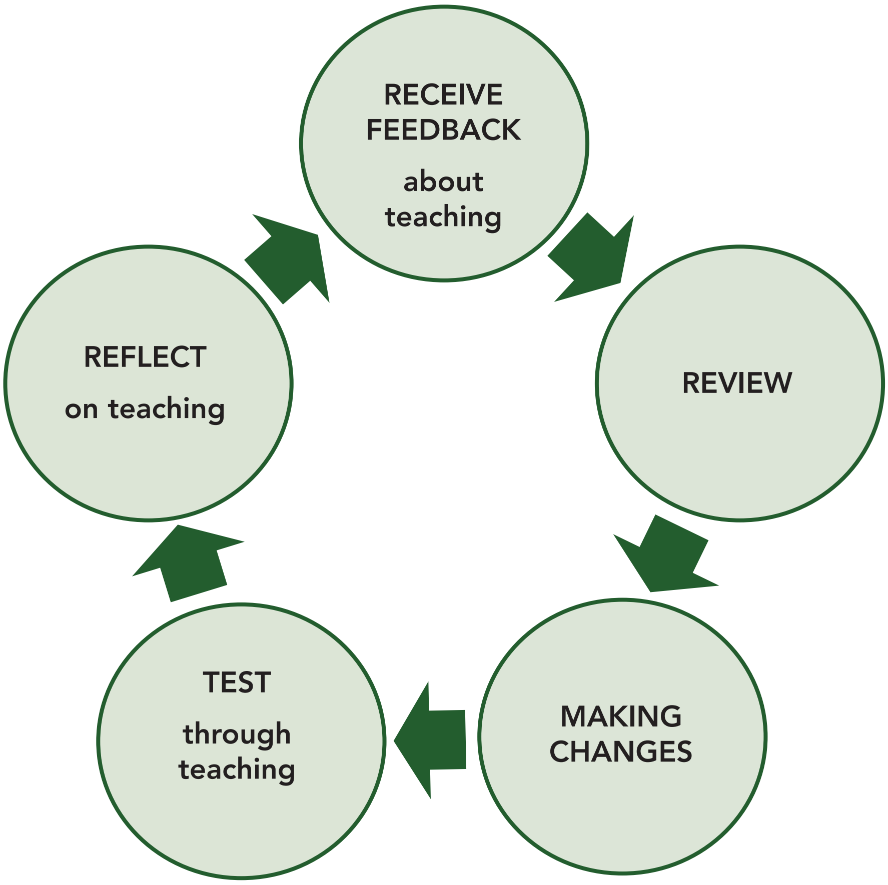
Good trainers work hard to develop strong relationships with their plant health doctor trainees. This has a major impact on your trainees' ability to learn and become confident. Learning takes place best in a safe, non-judgemental and supportive learning environment, where people do not feel foolish if they don't understand something or make mistakes. Rather, they see that making mistakes is an important part of learning, and they should not be afraid to share their mistakes and failures as well as their successes. Neither you nor your trainees should worry about admitting when you don't know or understand something. None of us knows everything, however long we have been working; there is always something new to learn! But you should make an effort to find out what you don't know. Think of yourself as a lifelong learner, always looking for opportunities to learn more.

As you go through the training program, try to become aware of the diversity of the trainees in your class — their backgrounds, gender, age, the languages they speak, their own knowledge and experience, and how they like to learn best.

8.3 Reflecting on your work

Trainers will always improve if they take the time to reflect on their teaching and learning. Feedback from trainees can be in the form of listening to their discussions and answers, and making sure you ask plenty of questions to check their understanding. The learning/teaching process is a cycle that never ends, the aim is to reflect on what has been learned, and to know what to do for continuous improvement (Fig. 8.1).

Fig. 8.1 The reflective learning cycle — it never ends. *Source: authors.*



8.4 What trainers say about the qualities of a good trainer

When they were asked to list the qualities of a good trainer, the regional trainers reviewing and testing the manual came up with the qualities listed below (Table 8.1).

Table 8.1 What plant health clinic trainers say about the qualities of a good trainer.

Qualities of a good trainer	
Know your subject	**Planning**
▪ be well-educated about the topics ▪ have a high level of confidence	▪ plan well ▪ prepare well
Communication	**Personal qualities**
▪ be a good listener ▪ understand the audience ▪ speak the audience's language ▪ communicate well with the audience ▪ ensure training materials match the audience's level of understanding	▪ have empathy ▪ have a positive attitude ▪ be approachable ▪ be friendly and patient ▪ show commitment ▪ be a good role model ▪ be able to build good relationships ▪ be active

8.5 Teaching strategies for effective learning

Research has given us a lot of knowledge about how people learn that can help us develop effective learning across the different cultures in our regional PHC network. Teaching something new so that people understand it well is complex, and no single way of teaching works for all people. We know that learning for deep understanding involves making new nerve pathways in the brain, and this requires effort and practice. Learning is not a spectator sport! We also know that people make sense of the world by integrating new knowledge with what they already know. Sometimes this may lead to misconceptions, such as thinking lightning causes dieback, or that a variegated plant has a viral disease. Trainers should be on the lookout for misconceptions about pests and diseases.

Because people learn in different ways, we need to use a range of teaching approaches. Here are some useful teaching strategies that are used throughout the manual.

- small group discussion
- brainstorming in small or large groups
- drawing and writing
- lectures with PowerPoint
- creating a concept map
- drawing a diagram or a cartoon

- filling in a table
- looking at pictures/photos
- giving instructions to follow
- practical work e.g.
    - farm, garden and market observations
    - collecting and examining samples from the garden or farm
    - carrying out experiments
    - making up home-made pesticides
    - preparing samples to send away for diagnosis
- role play and simulation
    - interviewing farmers and others
    - simulation of a PHC
    - role playing a process, e.g. the life cycle of a pest
- cause and effects diagram
- reflection, planning and retesting
- creating reports and photosheets about a pest or disease
- quizzes.

8.5.1 Small group discussion

In general, discussion with a partner or in a small group is a very good way to help your trainees to develop new understanding. In a small group, people feel free to ask questions that they might not want to ask in front of a large class, and are more likely to share ideas with others. Having an expert and resources available to answer questions further helps their learning, so make sure you visit each group to check how they are going and whether they need any help.

8.5.2 Brainstorming

Brainstorming is a good method for finding out what your trainees understand before you teach a topic. It is also useful for starting to think about the topic. Begin by asking for ideas on a topic, and write down every idea without saying whether they are right or wrong, then discuss the ideas with the class. This allows the trainees to realise they already have some knowledge, and this will help build their confidence.

8.5.3 Drawing and writing

Drawing and writing are useful methods that assist people to learn, as well as helping you as the trainer to assess your trainees' understanding. For example, you might ask your trainees to draw their ideas of a life cycle, write down a definition of pests and diseases, or list methods of control.

8.5.4 Concept/mind mapping

Concept mapping is a powerful tool for both learning about and assessing your trainees' understanding of relationships between important concepts. This is best done in pairs or a small group, and requires real effort, as the trainees have to discuss in depth how they understand these relationships. The concepts are written on small pieces of paper, card or post-it notes and stuck on a large piece of brown paper with blu-tak or sticky tape. The pieces of paper can be moved around till the group is satisfied with the arrangement. Then words describing the relationships between the concepts are written on lines or described orally (Figs 8.2 and 8.3).

You can give your trainees the concepts to explore or ask them to come up with their own. Around eight to ten concepts is a good number, but you can add more or use fewer, depending on the group. It is best to start with a simple map, using everyday examples, e.g. house, mother, garden, chicken, taro, child, so that people understand the process.

Always give your trainees plenty of time to develop their maps, as the time spent in discussion is when the learning takes place.

Fig. 8.2 A concept map linking insect, pest, mite, fungus, pathogen, disease, taro, crop, leafspot, virus, nematode, bacteria (created in Solomon Islands).
Source: authors.

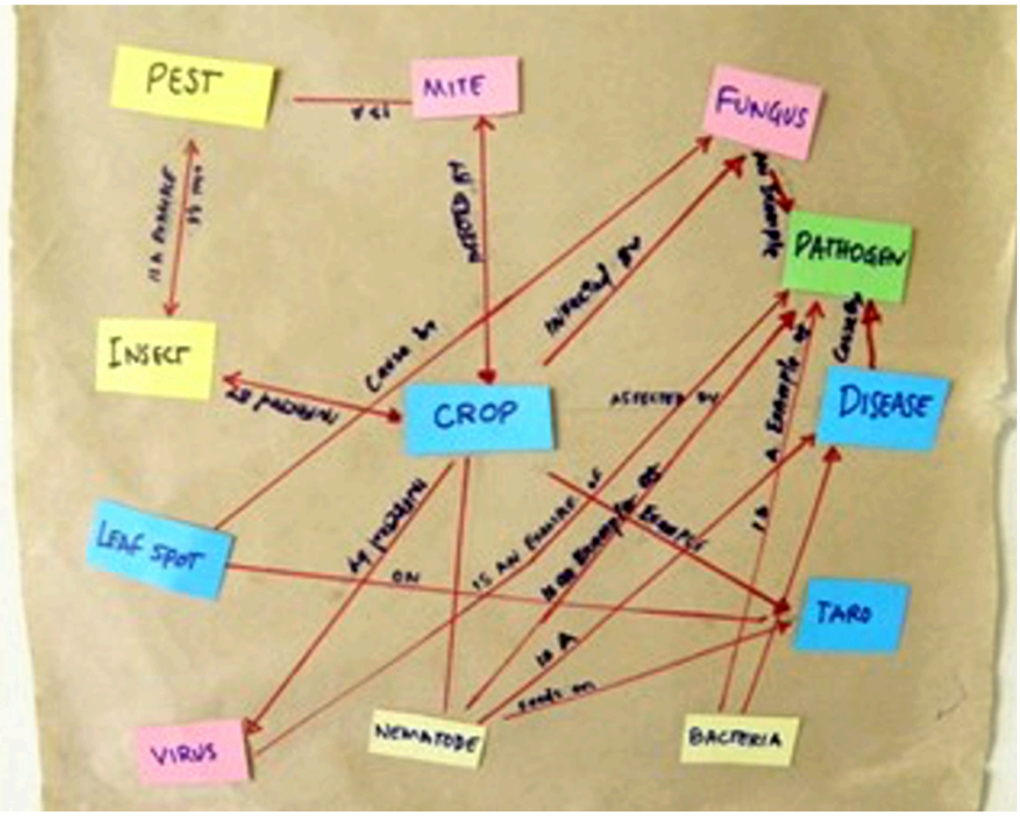
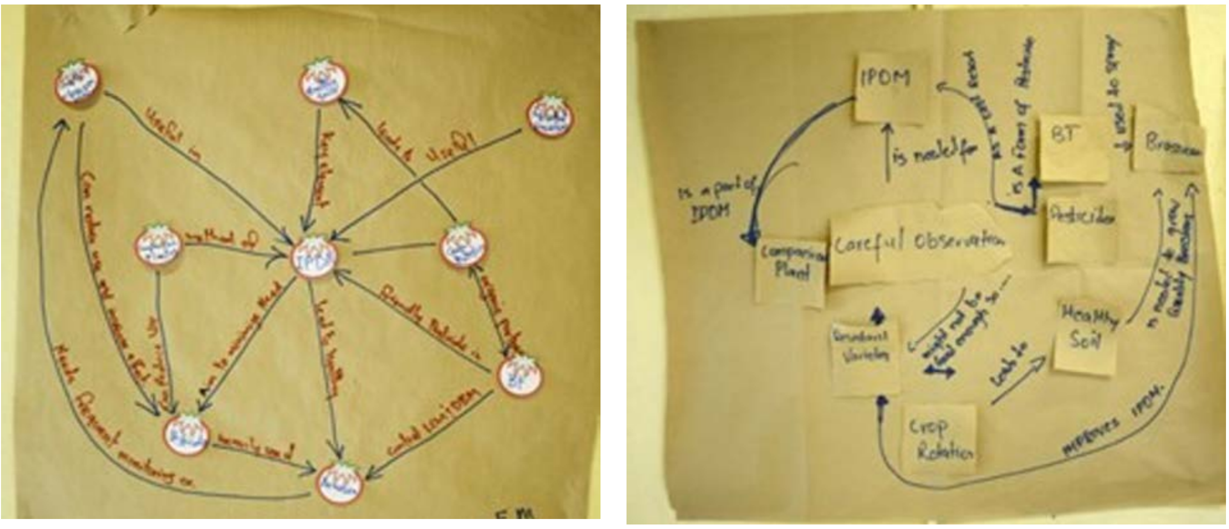


Fig. 8.3 Concept maps linking IPDM, companion plants, pesticides, Bt, resistant varieties, healthy soil, brassicas, crop rotation and careful observation (created in Tonga). *Source: authors.*



8.5.5 Filling in a table

Your plant health doctor trainees can deepen their understanding of any topic by filling in missing words in a table after discussion in pairs or small groups. This method is used widely in the training manual.

8.5.6 Practical work

Hands-on practical experience is extremely important for becoming a good plant health doctor. Your trainees cannot learn just from pictures in training manuals, videos or online apps. Practical work includes observing and examining samples from the field using a hand lens (and a binocular microscope if available), carrying out experiments such as on soil in Chapter 3, and discussing in depth what they might be observing using the A, B, or C and possible/probable diagnostic process. They also need practical experience in preparing samples to send away for identification, making up sprays, using sprayers.

8.5.7 Role-play and simulation

Role-play is a very useful method of learning, where your trainees can work together to explore and develop their understanding of a concept or process through acting. A good role play tries to put in as much detail as possible. People can even dress up! For example, you can role-play the life cycle of an insect.

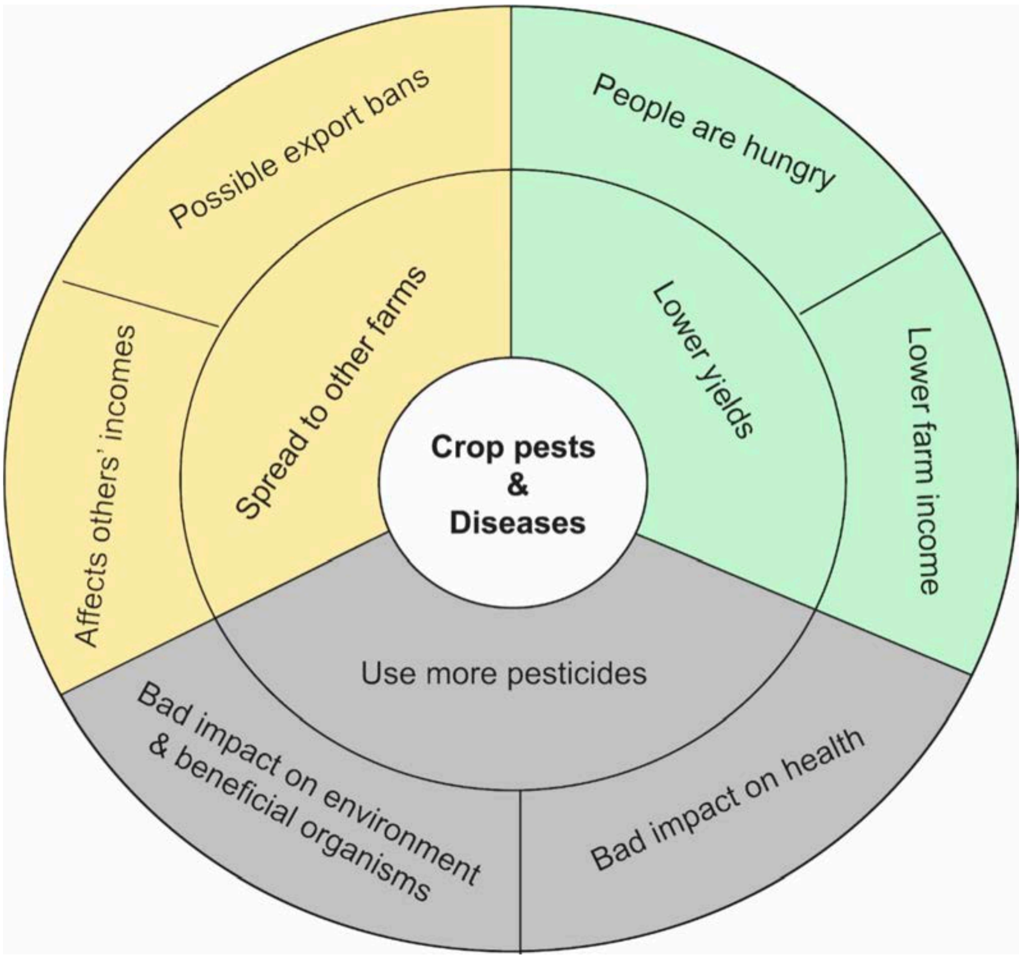
Role-play can also be used to try out or simulate something you want to do in ‘real life’, e.g. working with farmers. Exercises in Chapters 6 and 7 ask your trainees to set up and run a clinic, and play the roles of plant health doctors and farmers. This allows them to experience and reflect on the process of preparing and running a clinic, and to make any changes they need before running a real one.

8.5.8 Cause and effects diagram

By thinking about cause and effect, this method is designed to help trainees to explore the immediate and long-term effects of a concept or problem over time, in order to trace out its overall importance. They need to think about the effect of each item in the diagram, so they can see the overall impact of the concept or problem (i.e., the 'big picture').

Ask your trainees to draw a template with concentric circles as shown in Fig. 8.4. The concept or problem to be explored is written in the centre of the diagram, and the effects of this are explored and written down in the next circle going outwards. These then become the causes for the next circle and so on. More circles can be added if needed.

Fig. 8.4 Cause and effects diagram showing the possible effects of crop pests and diseases. *Source: authors.*



Chapter 9

Guide to Exercises and Answers to Quizzes

9.1 Guide to exercises

This chapter provides a guide to the exercises and answers to exercises and quizzes in the manual. For each exercise in Chapters 2-7 of the manual, you will find information on the purpose of the exercise and some guidance on how to teach it. You will see that in many cases, exercises are often done in pairs or small groups, then the class is brought together for discussion. When checking the answers, make sure you not only KNOW the answers but UNDERSTAND and can EXPLAIN the answers to your trainees.

***NOTE:** You will need to ask your trainees to draw up tables on butchers or brown paper to fill in their answers for some exercises if you are unable to photocopy the templates for them*

If you think some of your trainees prefer to work alone, allow them to do so from time to time. Remember, your job is to facilitate learning in ways that work best for your trainees to build their knowledge and confidence in a non-threatening, supportive learning environment. Also, remember that in your class there are likely to be some very experienced people as well as beginners. It is important that everyone has an opportunity to learn so don't be afraid to call on those with more experience to help others. This will also help their ability to be trainers. You will also be building your own knowledge at the same time – we never stop learning!

REMEMBER

Some of the exercises have definite answers, others do not. This is because:

- ***some answers depend on the examples you as the trainer decide to use***
- ***some answers depend on the samples you or the trainees bring to the class***
- ***some exercises have more than one correct answer.***

9.2 PHC trainer planning and preparation checklist

IMPORTANT

Thoroughly plan and prepare before conducting your training workshop. Before you begin, complete this checklist:

- ❑ read through the manual carefully to become familiar and confident with the contents
- ❑ work through the exercises and know how to facilitate them with your trainees. This will build your confidence as a trainer
- ❑ you do NOT need your trainees to work through EVERY exercise. It will depend on how much time is available and your judgment of how much they know already
- ❑ do not be afraid to give your trainees reading to do for homework if you need to have something finished or to be prepared for the next session
- ❑ make sure you have all the resources you need — a list is provided at the beginning of each chapter
- ❑ arrange to run one or two plant health clinics during the training — a simulated one so that your trainees know the process and how to fill in the Prescription and Farmer Feedback forms, then a full clinic with local farmers.

9.3 Chapter 2 answers

Chapters 2 to 6 are the most difficult and important in the manual. Without good knowledge of identification, diagnosis and management, it is very difficult to be an effective plant health doctor.

In Chapters 2 to 6, you are helping your trainees to develop their identification skills by carefully observing and describing symptoms before they move to a diagnosis. It is worth taking time to go through these chapters very carefully before you teach them, checking your own understanding by completing the exercises yourself.

EXERCISE 2.1: A, B, C?

Crop	Correct answer
Banana	1. BIOTIC: Banana black cross, *Phyllochora musicola*, fungus.
	2. BIOTIC: Banana diamond leaf spot, *Cordana musae*, fungus
	3. ABIOTIC: Natural variation of an ornamental variety
	4. BIOTIC: Cucumber mosaic virus
	5. BIOTIC: Banana burrowing nematode, *Radopholus similis*
	6. BIOTIC: Scab moth, *Nacoleia octasema*
	7. ABIOTIC: Natural colour variation
	8. BIOTIC: Banana bunchy top virus.
Bele	1. CONFUSED: Could be i) feeding of a jassid (leafhopper), ii) hibiscus chlorotic ringspot virus, or the iii) plants are lacking an essential nutrient
	2. BIOTIC: Hibiscus chlorotic ringspot virus
	3. BIOTIC: Shoot borer, *Erias vitella*, moth
	4. BIOTIC: Leafminer, *Acrocercops* species, moth
	5. BIOTIC: Flea beetle, *Nisotra basselae*
	6. BIOTIC: White peach scale, *Pseudaulacaspis pentagona*
	7. BIOTIC: Cotton leaf roller, *Haritalodes derogata*, moth
	8. CONFUSED: Same as 1
Cabbage	1. BIOTIC: Turnip mosaic virus
	2. BIOTIC: Damping-off, fungi
	3. BIOTIC: Chinese cabbage stalk rot, *Erwinia* species, bacteria
	4. BIOTIC: Cabbage centre grub, *Helula undalis*, moth
	5. CONFUSED: Possibly stalk rot (see 3) or Black cutworm, *Agrotis ipsilon*, moth
	6. BIOTIC: Cabbage black rot, *Xanthomonas campestris* pv. *campestris*, bacterium
	7. ABIOTIC: Boron deficiency
	8. CONFUSED: Possible snail damage
Cassava	1. BIOTIC: Cassava green mottle virus
	2. ABIOTIC: Natural variation of an ornamental variety
	3. BIOTIC: Cassava *Amblypelta* dieback, bug
	4. BIOTIC: Spiralling whitefly, *Aleurodicus dispersus*
	5. BIOTIC: White peach scale, *Pseudaulacaspis pentagona*
	6. BIOTIC: Spider mite, *Tetranychus* species
	7. BIOTIC: Bacterial blight, *Xanthomonas axonopodis* pv. *manihotis.*
	8. CONFUSED: Possible mineral deficiency

EXERCISE 2.1: A, B, C? continued...

Crop	Correct answer
Citrus	1. CONFUSED: Caused by scale insects on the underside of the leaf
	2. BIOTIC: Citrus sooty blotch, *Meliola citricola*, fungus
	3. BIOTIC: Greening or Huanglongbing disease of citrus, *Candidatus liberibacter asiaticus*, bacterium
	4. BIOTIC: Citrus tristeza virus
	5. BIOTIC: Greening or Huanglongbing disease of citrus, *Candidatus liberibacter asiaticus*, bacterium
	6. BIOTIC: Citrus scab, *Elsinoe fawcettii*, fungus
	7. ABIOTIC: Zinc deficiency
	8. BIOTIC: Fruit piercing moth, *Eudocrima fullonia*
Coconut	1. BIOTIC: Foliar decay virus
	2. ABIOTIC: Potassium deficiency on fan palm
	3. BIOTIC: Coconut thread blight, *Corticium penicillatum*, fungus
	4. CONFUSED: Coconut Bogia disease or lightning strike
	5. BIOTIC: Coconut termite, *Neotermes rainbowi*
	6. BIOTIC: Coconut leafminer, *Promecotheca* species
	7. CONFUSED: Sooty mould, fungi - but this is not the main cause of the problem
	8. CONFUSED: Feeding lines created by *Promecotheca* species — *Brontispa longissima*, the coconut hispine beetle causes similar symptoms.
Tomato	1. BIOTIC: Tomato black leaf mould, *Pseudocercospora fuligena*, fungus
	2. ABIOTIC: Calcium deficiency, blossom end rot
	3. CONFUSED: One of the many tomato fungal leaf spots
	4. ABIOTIC: Catface. Cause unknown, possibly irregular growth during flowering
	5. CONFUSED: Purple patches on leaves can be caused by phosphorus deficiency, one of a number of viruses, or old age
	6. CONFUSED: Spots on fruit can be caused by fungi or bacteria
	7. BIOTIC: Eriophyid mite, *Polyphagotarsonemus latus*
	ABIOTIC: Tomato fruit splitting caused by irregular temperatures and/or watering
	9. BIOTIC: Bacterial wilt, *Ralstonia solanacearum*
Mixed	1. BIOTIC: Maize mosaic virus
	2. ABIOTIC: Tomato sunscald
	3. CONFUSED: Cocoa cherelle wilt or *Phytophthora palmivora*, oomycete
	4. BIOTIC: Maize boil smut, *Ustilago zeae*, fungus
	5. CONFUSED: Cocoa dieback caused by lack of shade, sunscald or nutrient deficiency
	6. ABIOTIC: Maize zinc deficiency
	7. BIOTIC: Coconut tinangaja viroid
	8. CONFUSED: One of several tomato viruses or herbicide damage

EXERCISE 2.2: Speed dating

This exercise gives more practice on how to describe symptoms on plants carefully and accurately before making a diagnosis.

Ask the trainees to form two lines facing each other so they are standing opposite a partner. Give each trainee a sample of a plant pest or disease or nutrient deficiency, or they could collect their own. One of the pair now carefully describes the symptoms to their partner (their 'date') opposite them, and then both try to decide whether it is caused by abiotic (A) or biotic (B) factors, or it is confused (C).

Give no more than two minutes! When you say 'stop' the other partner has to do the same with their sample. Next, everyone in one line moves to the left so that each has a new partner. Repeat the process of describing the symptoms one more time each (or more if you think trainees need more practice).

Now ask the trainees to place their sample on one of three tables marked A, B or C, depending on whether they think the cause is abiotic, biotic, or it is confused.

Do not give any answers at this stage!

Preparing for Exercise 2.3

Now that you have gone through Exercises 2.1 and 2.2, you have set up your trainees' 'need to know' about pests and diseases. It is time to introduce your PowerPoint presentation on pest and diseases which you will need to prepare from the information in Sections 2.3 to 2.8 in Chapter 2.

Alternatively, if they have access to the manual, you can ask trainees to read these sections for their homework, emphasising how important this information is, and ask if there are any questions. These are long sections with a lot of information, so take your time and give trainees plenty of breaks and time for discussion and questions during the presentation, and check for understanding.

EXERCISE 2.3: Similar symptoms, different groups

Table 2.3 shows that pest symptoms can be confusing as similar symptoms can be caused by very different types of pests. Exercises 2.3 and 2.4 will help your trainees to think about symptoms of pest damage and the range of possible causes. This is a challenging exercise, but the purpose is for your trainees to recognise that similar symptoms can have many causes. It is not necessary for them to learn the names of every pest.

By thinking about and discussing the possible answers in their groups and then with the whole class, your trainees will have a deeper understanding of the complexity of pest diagnosis, so they do not immediately jump to one answer when they see symptoms.

The answers filled in the table below are examples; there will be many other possibilities. Check with Table 2.3 for details.

Symptom	Damage type	Possible causes (pest orders — common names)	Life stage of pest	Confirmed by fact sheet #
Holes (leaf/ fruit)	Chewing	1. Fly 2. Moth/butterfly	Larva (maggot) Larva (caterpillar)	291 23
Speckling (leaf/fruit)	**Sucking**	**1.Thrips 2. True bugs**	**Adult, nymph Adult, nymph**	**49 253**
Mines (leaf)	**Chewing**	**1. Fly 2. Moth/butterfly**	**Larva (maggot) Larva (caterpillar)**	**110 378**
Galls (leaf)	**Sucking**	**1. Psyllid 2. Mite (broad mite)**	**Nymph Adult, nymph**	**366 138**
Holes (seed)	**Chewing**	**1. Beetle/weevil 2. Moth/butterfly**	**Adult, larva (grub) Larva (caterpillar)**	**338 337**
Wilt, dieback (leaves/ branches/ plants)	**Sucking**	**1. True bugs 2. Scale insect**	**Adult, nymph Adult, nymph**	**19 343**
Sooty mould (leaf)	**Sucking**	**1. Leafhopper 2. Scale insect**	**Adult, nymph Adult, nymph**	**263 271**
Distortions (leaf)	**Chewing**	**1. Aphid 2. Mealybug**	**Adult, nymph Adult, nymph**	**38 373**
Scraping (leaf)	**Chewing**	**1.Beetle/weevil 2. Moth/butterfly**	**Adult, larva (grub) Larva (caterpillar)**	**58 31**
Egg-laying strike (fruit)	**Piercing**	**1. Weevil 2. Fly**	**Adult, larva (grub) Adult, larva (maggot)**	**437 425**

EXERCISE 2.4: Understanding chewing, sucking and piercing damage

For this exercise, try to find samples of leaves, fruit or roots that show symptoms of chewing, sucking or piercing, but with no visible pests. This often happens at a plant health clinic.

- give each pair or group of trainees a **different sample of pest damage** (or a photograph if you cannot find field samples)
- your trainees should **examine their sample** carefully with a hand lens and answer the questions in the exercise
- then they should **share their answers** with the whole class and discuss the diagnosis process and any difficulties.

Refer to Tables 2.2 and 2.3 for answers.

EXERCISE 2.5: Using symptoms to make a diagnosis

Once your plant health doctor trainees have received more information about pests and diseases from your PowerPoint presentation and/or worked through the sections in the manual, they should collect their samples from tables A, B or C from Exercise 2.2 and have another look at them, using a hand lens.

Again, ask the trainees to look at the symptoms (signs) on the plant carefully, and try to make a diagnosis. They may want to change their minds or add information. This is good; it means they have learned something new. Being wrong or only partially correct is an important part of learning.

Once they have finished this, discuss what they have learned and ask your trainees to complete Exercise 2.5 and fill in the last column.

The answers to this exercise will depend on the samples you or the trainees have collected. You will need to make sure you are able to identify as many of them as you can before discussing the answers.

EXERCISE 2.6: What have you learned about pests and diseases?

Your trainees should now be able to summarise their learning about insects and pathogens. They should complete the table in pairs or threes.

In the manual, some cells have been filled in as an example (red text). Here is the table completed with some answers, but there are many other possible answers.

	Fungi	Bacteria	Viruses	Nematodes	Insects
Size – can they be seen with the naked eye?	Spores — No. Fruiting bodies and cottony growth (mycelium) — Yes.	**No**	No	No, with a very few exceptions.	Yes, with very few exceptions.
How do they reproduce?	**Spores**	Cells split in half (binary fission).	Use chemicals from host cells to make more virus particles.	There are males and females reproducing via eggs.	Incomplete or complete life cycles. Males and females reproducing via eggs; some give birth to living young without need for males.
How do they spread?	Produce masses of spores, spread in wind and rain; hyphae and mobile spores in soil, on or in planting materials; also via plants and soil associated with horticultural trade. More rarely carried by boring insects.	In wind, rain, movement of water in soil, on or in planting materials; also via plants and soil associated with horticultural trade.	In insects as they chew and suck sap, on tools, on or in planting materials; also via plants associated with horticultural trade. More rarely in fungi and nematodes.	Move though soil, transported in soil water, or in planting materials; also via plants and soil associated with horticultural trade.	Mostly by flying (adults) that lay eggs on plants; also via plants and soil associated with horticultural trade.
How do they survive?	In soil, remains of plants after harvest, on leaf litter, on weeds. Many fungi have special survival spores.	In soil, in plants after harvest, on weeds. Some form resistant spores.	**In living cells**, either in plants or in insects.	In soil, feeding on weeds; as eggs. Some form cysts.	Many survive as eggs between crops, or on alternative hosts, especially weeds, and volunteer plants. In the tropics, survival occurs by moving from harvested to new planted crops.
What are some typical symptoms/ signs on plants?	Spots, blights, rusts, wilts, mildews, rots, root decay.	**Wilts**, spots, rots, blights.	Mosaic (light and dark green patterns on the leaves), yellowing, stunting, distortions.	Wilts, yellowing of leaves, stunting, root galls.	Holes, mines, chewing leaves, wilts due to root damage, silvering of leaves, distortions, rots, galls. Frass sometimes present.

EXERCISE 2.7: Completing a 'stem' table

This exercise helps your trainees to summarise their learning so far about pests and diseases. Trainees should do this on their own or in pairs.

- it is like **completing a sentence** (the 'stem' is the beginning of the sentence).
- **starting with the first column** (Insect pests), they fill in the answers — then they fill in the second column (Nematodes) and so on, until the table is completed — the example in red reads: insects are …a biotic factor
- there will be many correct answers — the prefilled table below provides some possible answers — ask trainees which ones they had difficulty with and discuss.

	Insect pests	Nematodes	Nitrogen deficiency	Viruses	Fungi	Bacteria	Drought
Are:	**a biotic factor**	a small worm-like animal	a lack of an essential element needed by plants	**very small**	a biotic factor guidelines	a single celled organism	Lack of water
Are not:	a mite	**an insect**	a biotic factor	visible to the naked eye	an insect	a virus	a biotic factor
Can:	reproduce quickly	live in soil	cause plants to turn yellow	be spread by insects	form fruiting bodies called a mushroom	spread very quickly	kill crops
Cannot:	**produce spores**	fly	be treated by applying a pesticide	live outside a host cell	photo-synthesise	reproduce sexually	help plants to grow well
May cause:	holes in leaves	wilting	Low yields	mosaics	leaf spots	**wilting**	loss of income for farmer
Does not cause:	mildew	rust	holes in a leaf	nutrient deficiency	**chewing of leaves**	rust symptoms	floods
Can be controlled by:	beneficial insects	marigolds	adding well-decomposted manure to the oil	rogueing	fungicide	copper	irrigation
Cannot be controlled by	herbicide	white oil	**fungicide**	companion planting	insecticide	parasitoids	**fertiliser**

EXERCISE 2.8: What am I?

This guessing game exercise is fun and can be carried out at any point during the training. It is also a useful icebreaker to do at the beginning of a training session. It can be as easy or difficult as you decide to make it, and you can make up any words you like that relate to what you are teaching. It makes sure your trainees really focus on the characteristics of what they are trying to guess.

- write a word on a group of cards, then stick one card to each trainee's back with masking tape — do not allow the trainees to see their card!
- when you are giving out the cards, try to match the words to the trainees, e.g. give the more knowledgeable trainees something more challenging, while you give a simpler word to those who are not as experienced or confident — everyone needs to be able to guess their word, as this builds confidence
- the trainees pair up or move around the class, asking questions of each other — the idea is to find out what the word is, but the questions can ONLY be answered with **'yes', 'no'** or **'sometimes/maybe'** — you may need to demonstrate this with a trainee first
- check in with the trainees while the exercise is in progress, as they may have been given wrong information! ask: "What do you already know so far about your word?" Correct them where necessary. If a trainee is stuck, you may give a clue
- ask trainees to **sit down after** they have found the correct answer
- discuss the exercise afterwards: **Was it easy? Difficult? Why?**

EXERCISES 2.9, 2.10, 2.11: Using the possible and probable approach

By this stage in Chapter 2, your trainees have covered a lot about symptoms and have started to think about diagnosis. In Exercises 2.9, 2.10 and 2.11, they apply their A, B, C learning to use the possible and probable step approach to making a diagnosis. This is something they need to be able to do at the plant health clinic.

First of all, carefully go through the example of eggplant with the class to demonstrate the steps.

Your trainees should then use the same steps to work through the examples in Exercises 2.9, 2.10 and 2.11, working in pairs or threes, or alone if they prefer.

Once they have finished, it is important to ask them why they have decided on a diagnosis, as you may be able to pick up any misconceptions.

Only when they have carried out the steps should they check their answers with the Pacific Plant Pests, Pathogens & Weeds App. They also need to think about what extra information they might need for a diagnosis, and what further questions they would ask if a farmer brought in this problem. If you think that your trainees need more practice, you can make up your own examples.

EXERCISE 2.9: Using the possible and probable approach

EXAMPLE: Cassava with mosaic and distortions

Symptoms:

1. Yellow irregular spots scattered throughout the leaves
2. Leaflets distorted
3. Symptoms mostly and clearest on young leaves

Possible causes	Possible? ✓✗	Probable? ✓✗	Why do you decide this?
BIOTIC			
Insect	✗	✗	Not a symptom of insects; no presence of insects or sign of frass.
Mites	✓	✗	Unlikely, but turn the leaf over to look for mites & webbing to make sure.
Fungi & oomycetes	✗	✗	Not a symptom for fungi.
Bacteria	✗	✗	Not a symptom for bacteria
Virus	✓	✓	Irregular yellow patches & leaf distortions are typical of known viruses of cassava. Viruses of cassava only reported from Solomon Islands.
Phytoplasma	✓	✗	Phytoplasma of cassava do exist in the region, albeit rare (Wallis & Futuna). Symptoms are a yellowing of leaves, stunting.
Nematode	✗	✗	Not a symptom for nematodes.
Weeds	✗	✗	Not a symptom associated with weeds.
Parasitic plants	✗	✗	Not a symptom associated with parasitic plants.
Slugs & snails	✗	✗	None present, and not a symptom associated with slugs & snails.
Mammals	✗	✗	Not a symptom associated with mammals.
Birds	✗	✗	Not a symptom associated with birds.
ABIOTIC			
Nutrient deficiencies	✓	✗	Nutrient deficiencies do cause yellow mottling on leaves, but none known similar to this on cassava.
Sun scald	✗	✗	Not a symptom caused by sun scald.
Water (too much or too little)	✗	✗	Not a known drought symptom of cassava.
Lightning	✗	✗	Not a symptom of lightning strike.
Herbicide	✓	✗	Yellow patterns and leaf deformation could be caused by herbicide damage, but farmer insists no herbicide was used before planting or during growth, or by neighbours.
It's natural	✗	✗	Not at all natural!

EXERCISE 2.10: Using the possible and probable approach

EXAMPLE: Sweet potato with folded and collapsing leaves

Symptoms:

1. Leaves with small holes round, up to 1 cm across
2. Most leaves dying and rotting
3. Some leaves folded with frass inside the fold
4. Only the vines remain alive.

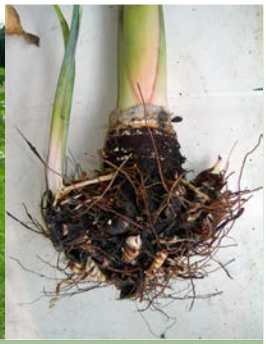
Possible causes	Possible? ✓✗	Probable? ✓✗	Why do you decide this?
BIOTIC			
Insect	✓	✓	Leaves have large numbers of roughly round holes, and some leaves are folded with frass inside the fold.
Mites	✓	✗	Mite damage on this scale not known on sweet potato.
Fungi & oomycetes	✓	✗	Leaves have wilted and collapsed but no spots, blight, or other symptoms present suggesting a bacterial cause.
Bacteria	✓	✗	Leaves are rotting & collapsed but not spots, blight, or other symptoms present suggesting a bacterial cause.
Virus	✗	✗	Not a symptom normally associated with a virus infection, i.e., No mosaic patterns, mottles or deformation.
Phytoplasma	✗	✗	Not a symptom normally associated with phytoplasma infection.
Nematode	✓	✗	Root infection by nematodes leading to leaf collapse is a possibility, but not likely as whole garden has been affected and the problem came rapidly.
Weeds	✗	✗	Not a symptom associated with weeds.
Parasitic plants	✗	✗	Not a symptom associated with parasitic plants.
Slugs & snails	✓	✗	None present, day or night, and no slime trails that might be expected on damage of this severity.
Mammals	✗	✗	Not a symptom associated with mammals.
Birds	✗	✗	Not a symptom associated with birds.
ABIOTIC			
Nutrient deficiencies	✗	✗	Nutrient deficiencies do not result in holes in folding leaves and severe collapse and death of leaves
Sun scald	✗	✗	Not a symptom caused by sun scald.
Water (too much or too little)	✓	✗	It has been dry but not so severe to cause holes to develop in the leaves followed by widespread collapse.
Lightning	✗	✗	Not a symptom of lightning strike.
Herbicide	✓	✗	Some herbicides could kill the plants and result in collapse of the leaves, but farmer insists that none was used before planting & none used by neighbours.
It's natural	✗	✗	Not at all natural!

EXERCISE 2.11: Using the possible and probable approach

EXAMPLE: ***Xanthosoma*** **wilt**

Symptoms:

1. At most, only three leaves on each plant
2. Leaves with marginal necrosis (brown decay)
3. Roots mostly dead.



Possible causes	Possible? ✓✗	Probable? ✓✗	Why do you decide this?
BIOTIC			
Insect	✗	✗	Unlikely, no sign of insect infestation either on leaves or on roots.
Mites	✗	✗	Unlikely, no sign of mites on leaves, no webbing.
Fungi or oomycetes	✓	✓	Plants have fewer leaves than normal, i.e. Some have died early; those remaining show signs of marginal necrosis. Roots show decay. Area was flooded previouly. Oomycetes (*Pythium* sp. known to cause root rot/wilt worldwide). Isolation from roots is required.
Bacteria	✓	✗	The loss of leaves and decay of roots could indicate a bacterial wilt; however, bacterial root rot of *Xanthosoma* is not recorded in Pacific island countries.
Virus	✗	✗	Wilt is not a symptom normally associated with a virus infection.
Phytoplasma	✗	✗	Not a symptom normally associated with phytoplasma infection.
Nematode	✓	✗	Root infection by nematodes leading to leaf collapse is a possibiltiy. Isolations of nematodes from roots required.
Weeds	✗	✗	Not a symptom associated with weeds.
Parasitic plants	✗	✗	Not a symptom associated with mammals.
Slugs & snails	✓	✗	Unlikely that slugs or snails could cause the collapse of large plants of Xanthosoma; root decay by Pythium is a well known problem and more likely to be the cause especially as the area was flooded recently.
Mammals	✗	✗	Not a symptom associated with mammals.
Birds	✗	✗	Not a symptom associated with birds.
ABIOTIC			
Nutrient deficiencies	✗	✗	Marginal scorch of the leaves could indicate K deficiency, but loss of leaves and root rot is not likely to be caused by nutrient deficiency.
Sun scald	✗	✗	Not a symptom caused by sun scald.
Water (too much or too little)	✓	✗	It has not been dry; in fact, the area was flooded recently when the plants were still young, suggesting too much water may have exacerbated the problem but unlikely to be the cause.
Lightning	✗	✗	Not a symptom of lightning strike.
Herbicide	✓	✗	Some herbicides could cause a collapse of the leaves, but the farmer insists that none was used before planting & none used by neighbours.
It's natural	✗	✗	Not at all natural!

CHAPTER 2 QUIZ: Test your knowledge — answers...

The answers are given in **bold**. When they have all finished, go through the answers. You do not need to ask what marks the trainees got; they will have learned the correct answers by going through the test as a class.

Make sure you always discuss with the class any answers they are not sure about.

Explain that if there is anything they are still not sure about, trainees should read the manual again and/or ask for help. You can change or add your own questions.

1. In ORDER, abiotic and biotic factors that cause damage on plants are:

A. a fungus and a mite

B. a bird and drought

C. potassium deficiency and bacteria

D. phytoplasma and poor soil

2. Symptoms on tomatoes and cabbages caused by bacteria are:

A. leaf spots and evenly spread leaf yellowing

B. wilt and V-shaped yellowing at the edges of leaves

C. rust spots and mosaics

D. dieback and with leaves going purple

3. A common disease of tomatoes in the Pacific is:

A. witches' broom

B. tobacco mosaic

C. early blight

D. ring spot

4. The smallest of these pathogens is:

A. virus

B. phytoplasma

C. bacterium

D. fungal spore

5. A plant doctor finds a plant with symptoms of wilt. The most unlikely cause would be:

A. bacteria in the soil

B. powdery mildew

C. nematodes

D. stalk borer

6. Pests with eight legs are:

A. mites

B. insects

C. nematodes

D. millipedes

7. Which of these diseases is caused by a fungus?

A. bunchy top on banana

B. blossom end rot on tomato

C. citrus canker

D. damping-off on cabbage seedlings

8. A plant doctor finds a cabbage with a lot of holes in the leaves. Which <u>are not</u> possible causes?

A. diamondback moth

B. large cabbage moth

C. leaf chewing nematodes

D. snails

CHAPTER 2 QUIZ: answers continued...

Multiple choice. Pick one answer only...

9. A virus cannot usually be spread between plants by:

A. nematodes

B. tools

C. rhinoceros beetles

D. aphids

10. Two insects with complete life cycles are:

A. aphids and beetles

B. butterflies and bugs

C. grasshoppers and ants

D. bees and moths

11. Where do you find the eggs of this spiralling whitefly?

A. inserted into the leaf

B. whiteflies do not lay eggs, they give birth to living young

C. in the waxy spirals

D. underneath the female whiteflies

12. What is the most likely cause for this hibiscus wilt?

A. mites or thrips have attacked the young leaves, and they have wilted

B. it was planted on a slope, and there has been a long drought

C. old age

D. a fungus or an insect is destroying the roots.

9.4 Chapter 3 answers

Exercise 3.1: Practical activity — describing soil

This is a good exercise to start with, as it encourages your trainees' need to use their senses to focus on their soil. Their answers will depend on the soil samples. In general, good soil has a crumbly texture, an earthy smell and is dark brown in colour.

When your trainees have filled in the table, discuss the different soils.

Are they similar? Different? How might they be useful to support good plant growth?

Plan to come back to these answers at the end of the chapter so you can compare what has been learned through the exercises with the trainees' initial ideas.

Exercise 3.2: Traditional knowledge of soil

This exercise builds on Exercise 3.1 as many (but not all) of your trainees will have some experience of working on farms, or with farmers and their soil, and have some idea about how soil relates to farmers' challenges. Again, discuss the trainees' ideas so they can begin to make connections between soil and healthy plant growth.

Exercise 3.3: What is in soil?

As you work through the exercises and activities, adding new learning on wall charts helps keeps the new ideas visible and helps trainees to see that they are building understanding. From time to time, take a moment to add new information to the chart as the workshop progresses.

This will also help you know which exercises and activities to focus on, and which you can omit or move through quickly.

It is essential that the trainees understand the four main components of soil:

Minerals

Mineral particles are inorganic — they do not contain carbon except as carbonates. Mineral particles come from the weathering of rocks, and their components — sand, silt and clay — form the texture of soil. They provide all the nutrients essential for plant health, though some may be missing, which leads to nutrient deficiency symptoms in plants.

Exercise 3.3: continued...

Organic matter

Organic matter (carbon containing compounds) in soil comes from the decay of living organisms — plants and animals — which break down into humus. Humus gives the soil its dark colour. Organic compounds are important for holding the soil particles together and giving soil its structure.

Air and water

Air and water are essential for plant growth. They are held in the soil in the pores and spaces between the soil particles.

Minerals, organic matter, air and water make up the non-biological components of soil and contribute to its structure.

Living organisms

The biological components of soils are the living organisms — macroorganisms (those we can see with the naked eye or a binocular microscope) and microorganisms (those we can only see with a more powerful microscope). Together, they make up the soil microbiome. The living organisms are important for making nutrients available to plants and performing many other important functions to keep plants healthy.

Exercise 3.4: Practical activity — composition or texture of soil, the ribbon test

Exercise 3.5: Practical activity — sedimentation test

These two (Exercises 3.4 and 3.5) give your trainees a good idea about the various composition of soils. When they have finished, trainees should share their results. Encourage them to use technical language that describes their soil in terms of its sand, silt and clay components, as well as any unbroken organic matter. These results are used in Exercise 3.11 to describe the type of soil structure.

Exercise 3.6: Interpreting the soil composition triangle diagram

The USDA soil triangle is commonly used as a simple way of working out the composition of soil.

The composition creates the soil texture.

Work through steps in the example with the trainees; you can make up some of your own results as well if you think your trainees need more practice. They should understand the process, so they are able to work out the composition of their own soil when they have some results from their experiments.

Exercise 3.7: Practical activity — organic soil carbon content

You may be able to find potassium permanganate in a pharmacy, or from your agriculture department laboratory. You will need to prepare the solution beforehand, a concentration of about 3 g/L.

The lighter the colour the purple potassium permanganate solution becomes, the more organic matter is in the soil, and the healthier the soil. Compare the colour with the original solution and ask trainees to line their samples in order from darker and more purple to lighter and less purple. The order can be compared with the soil type.

In general, a soil with a high level of organic matter will turn the permanganate lighter and is an indication of the health of the soil.

Exercise 3.8: Practical activity — growing soil microorganisms

Seeing soil organisms which are usually invisible growing on agar plates is exciting for your trainees. The agar plates need to be prepared before the practical activity, unless you want the trainees to make them themselves. The plates need time to cool down and the agar to set before they are used. Keep the plates in the dark for a few days to allow the bacteria and fungi to grow.

Keep the plates covered as far as possible and make sure your trainees do not breath in any spores from the plates.

Compare the plates from the different soil samples. Fungi usually look furry while bacteria tend to be shiny. If you have access to binocular microscopes, trainees may be able to see spores. Even a hand lens will show some of the structures.

Exercise 3.9: Practical activity — examining soil for earthworms

You can also usually find earthworms under compost heaps. Keep them in a bottle with food scraps and keep moist. Exercise 3.21 shows you how to do this.

Earthworms are fascinating creatures, and it is interesting for your trainees to see them under a binocular microscope or even a hand lens. It is best to have some earthworms available before the exercise as earthworm populations are very patchily distributed and variable, so your trainees may not find any.

Put the earthworms back into the soil after the exercise, do not allow them to dehydrate as this will kill them.

Exercise 3.10: The carbon food web role play

This exercise helps trainees to understand the way carbon cycles in the soil food chain/web, and that everything is connected to form an integrated system.

Once the exercise has finished, the strings will look like a complicated spider's web. This is good as it gives a visual picture of the complexity of the carbon food web. Ask trainees to explain their connections. For example, if someone with a carbon dioxide card has connected with someone with a photosynthesis card, they should explain why they are connected — see Figure 3.10.

Also, discuss how energy moves through the web, from sunlight via photosynthesis to being stored in sugars, then used as food by animals/humans, and then by soil organisms when the plants or animals die.

Exercise 3.11: Practical activity — soil infiltration rate

This is probably best done as a demonstration unless you have enough equipment. If you do have the equipment, your trainees can test different soils in their groups.

The longer the soil takes to infiltrate, the more compacted it is and/or the higher the clay content. For a healthy light or medium soil, the water should drain away within 2 to 5 minutes. A compacted or heavy clay soil with poor structure could take 20 minutes or longer.

Once your trainees have completed their measurements, discuss the results and what they have learned about soil compaction.

By this stage, your trainees should have a good understanding of the components of soil. They should also be able to see differences between their soil samples.

Exercise 3.12: Practical activity — measuring the water holding capacity of soil

This exercise is a simple one, but needs to be carried out very carefully to get the most accurate results. Generally, a good soil will have an adequate water holding capacity, but still allows water to filter through.

Once you have everyone's results, look back at the answers to Exercises 3.4 and 3.5 and discuss any relationship between soil holding capacity and type of soil. Also, come back to think about these results again once you have carried out Exercise 3.11.

In general, sandy soils have a low water holding capacity, clay a high one.

Exercise 3.13: Practical activity — soil horizons (layers), digging a soil pit

Trainees may not be aware that there are different layers in soil (soil horizons). It is important to find soil that is relatively easy to dig down into, as you need to dig to a depth of about 1 m to see the layers clearly.

Make sure samples of the different layers are kept for testing. If time, you can test each layer using the tests in Exercises 3.4, 3.5, 3.6, 3.12, 3.15 & 3.16.

Exercise 3.14: Practical activity — measuring soil pH

This is a simple activity, but it is very important to be as accurate as possible, as pH has such an important impact on soil health.

If you have access to a pH meter this will give you a more accurate measure of pH.

Your discussion should focus on the trainees' answers, and what soil pH means for plant health. They should also discuss whether there is any relationship between pH and soil texture. It relates closely to the next section which shows how important pH is for plants to take up soil nutrients.

Exercise 3.15: pH and nutrient availability

This activity applies the idea of soil pH to the availability of nutrients to plants. Trainees should use the diagram in Fig. 3.19 to work out which elements are available and unavailable to plants.

They should also think about which nutrients might not be available in their own soil samples.

Exercise 3.16: Deciding on nutrient deficiencies

Nutrient deficiencies are extremely difficult to diagnose and may look different on different plants. Also, some are very hard to tell apart from disease symptoms cause by fungi, viruses or bacteria. It is important that you collect as many examples of known deficiencies as you can, to provide your trainees with as much experience as possible.

Trainees should describe the symptoms as clearly as possible, such as the colour of the veins and the rest of the leaf and/or fruit.

You should also look at Section 2.9.1 Exercises 2.9, 2.10 & 2.11 in Chapter 2 — diagnosis through the process of Possible/Probable, as nutrient deficiency symptoms can be confused with disease symptoms.

Use Figures 3.20 to 3.30 in the manual in Section 3.9.2, but also any from the field that you are aware of. If you can, ask your agriculture department or local farmers to indicate any nutrient deficiency examples that are found in your area that you can collect and show to the trainees.

Exercise 3.17: Data from soils from three Pacific countries — Fiji, Samoa and Tonga

These data come from the Pacific Soil Portal and show your trainees how different soils can be across the region. Once they have analysed the data, discuss the differences with the trainees and what problems farmers may have when working with these soils and what will grow well and what will not.

Soil location	Source of soil (parent material)	Texture	Soil pH	Fertility	Minerals lacking	Drainage/ flooding	Soil quality — good for growing crops?	Soil amend -ments necessary
Fiji	River alluvium	One or more of 0-25 cm clay loam 25-35 cm silt loam	< 7	Low organic carbon (C) values. Low potassium (K) values in subsoils	Impossible to say. All available at this pH.	Minor risk	Good	Organic matter
Samoa	Basalt	10 cm stony clay loam 20cm very stony clay Base very rocky clay	5.1	Moderate fertility Potassium (K) very high, low in subsoil	Mg, Ca, Mo	Good, no risk	Moderate	Mg, Ca, Mo
Tonga	Not given	0-17 cm black coarse sand; 17-50 cm sand on coral limestone	> 7	High organic carbon (C), nitrogen (N) in A horizon; phosphor us (P) high to very high	Possibly Fe	Good, no risk	Moderate	Possibly Fe, need to test

Exercise 3.18: Review — what have trainees learned so far about their soils?

At this point in the workshop your trainees will be able to bring their learning together so they can begin to understand how complex soil is, and that soil health is so important for plant health. It is also a good time to add any new information to the charts on the wall.

Exercise 3.19: Analysing CO_2 burst test results

Now that your trainees have developed an understanding of what is in soil, in the following sections, your trainees learn about how to keep soil healthy and what degrades it.

The CO_2 burst data gives an idea of which treatments are best for soil – the higher the CO_2 burst, the healthier the soil. Trainees should be able to look at the figures and work out which soil treatments work best. These are the results from the CO_2 burst test placed in order from best to worst treatment.

Crop / treatment	CO_2 burst (ppm)
Topsoil, cover crops for 20 years	230
Multispecies cover crop	137
Virgin grassland	137
Maize, no till	115
Rye cover crop	107
Vegetables, truck soil	69
Subsoil (below topsoil) no till	71
Tobacco, tilled	57

Clearly, the soil that had a cover crop for 20 years is the best in this list. It is important for trainees to see that a cover crop is really important, and that tilling the soil is damaging.

Discuss these results and ask trainees whether they could be applied to the farmers they work with. Why or why not?

Exercise 3.20: Practical activity — making hot compost

A compost heap needs 3-4 days to heat up. You can start the heap with your trainees at the beginning of the workshop, alternatively start it yourself beforehand. Check the heap daily. Point out to the trainees how it is heating and that it needs turning regularly to add oxygen, and water if it dries out.

Exercise 3.21: Practical activity — building a mini worm farm in a bottle

Seeing worm activity in this way is interesting to your trainees. You can use the activity to emphasise how important worms are and how they need healthy soil to thrive.

Exercise 3.22: Practical activity — what is in a fertiliser?

For this activity you will need to obtain bags of fertilisers that are used locally. It is important that your trainees are able to read the information on any fertiliser a farmer is using and think about whether it is the best fertiliser for the soil.

This is similar to the exercises on reading a pesticide label in Chapter 6.

Trainees should discuss what fertiliser (if any) needs to be added to their own soil sample and why, and which type/trade name would be the best to apply. This also relates to Exercise 3.18.

Exercise 3.23: Crop rotation

Direct trainees to read Section 5.4 — Crop rotation, in the manual Chapter 5. They should carry out Exercise 5.3 in Chapter 5 and discuss their answers with the class.

Exercise: 3.24: Thinking about all the components of healthy soil

The idea that healthy soil is complex cannot be stressed enough. This exercise helps your trainees recall all the components of soil that they have learned about.

Once the trainees have filled in as much as they can, pin the sheets to the wall and use them to draw attention to the complexity of soil.

Some answers:

- minerals
  - sand
  - silt
  - clay
- other components
  - water
  - air
- organic components
  - carbon containing compounds
  - humus
  - worm castings
- microoganisms
  - bacteria
  - fungi
  - mycorrhizae
  - archaea
  - viruses
    protozoa
  - nematodes
- macroorganisms
  - worms
  - spiders
  - beetles
  - other arthropods — millipedes, centipedes
- nutrients
  - nitrogen
  - phosphorus
  - potassium (and other elements present in the soil)
- texture
  - sandy
  - clay
  - loam
- pH.

Exercise 3.25: Comparing landscapes

The main idea here is that healthy soils have a high level of carbon, and healthy agricultural systems are as biodiverse as possible. High levels of biodiversity support the soil microbiome, as well as help reduce the level of pests and diseases in crops.

1. The first figure shows a small farm with a high level of biodiversity and with a lot of cover over the soil. It is likely to have healthy soil and low levels of pests and diseases.
2. The second figure shows a landscape that has been overgrazed by animals (sheep, cattle) so the soil is depleted and has very little vegetation cover. The hoofs of the animals destroy the fragile topsoil. It also shows a lot of soil erosion along a creek bed which has not been fenced off from grazing. There is some tree planting taking place to restore the soil and environment. It is likely that the soil is depleted, particularly regarding organic matter and its pH is likely to be low.
3. The third figure shows a small food garden in Solomon Islands. This also shows a high level of biodiversity, what appears to be raised beds for planting, with good soil. It is likely to have healthy soil and few pests and diseases.
4. The fourth figure shows a landscape heavily overgrazed by sheep, possibly in time of drought. The vegetation has been eaten down to the soil and the top soil is being eroded away. The soil is likely to have a very poor structure.

Exercise 3.26: Creating a concept map

See Chapter 8, Section 8.5.3 for details on concept mapping.

This and Exercises 3.27 and 3.28 help your trainees to check your understanding at the end of this chapter. You can choose as many concepts as necessary. These types of exercises can be made as easy or as difficult as you decide and can be carried out at any point during the training to strengthen learning.

Concept mapping is very useful for both learning about and assessing your trainees' understanding of relationships between important concepts. Ask your trainees to write the concepts on small pieces of paper, card or post-it notes and stick them on a large piece of brown paper with blu-tak or sticky tape. The pieces of paper can be moved around till the group is satisfied with the arrangement. The words describing the relationships between the concepts are written on lines or described orally (see Figures 8.2 & 8.3).

Soil	Carbon	Bacteria	Earthworms	pH
Texture	Mycorrhiza	Molybdenum	Fertility	One Health

Exercise 3.27: What am I?

This guessing game exercise is described in the answers to Exercise 2.8 in Chapter 2. Using relevant words, it can be carried out at any point during the training.

Exercise 3.28: Match the term to the definition

Answers:

Term	Definition
1. Mycorrhiza	D. Network of fungal hyphae
2. Endophyte	A. Fungus that lives inside a plant cell
3. Agro-ecology	I. The application of ecological principles to make agricultural systems more sustainable
4. Cover crop	Q. Crop planted to be ploughed into soil as a fertiliser
5. Manganese	M. A necessary micronutrient for plant health
6. One Health	L. Idea that all life forms are interconnected and affect each other
7. Water holding capacity	B. Amount of water that a soil can hold measured in grams of water/ gram of soil
8. Weathering	H. Breaking down of rocks into small particles
9. Soil horizon	S. Layers of soil from surface downwards
10. Humus	F. Decomposed organic matter in soil
11. Vermicompost	C. Fertiliser produced by worms
12. Crop rotation	T. Sequence of crops grown that keep soil healthy, prevent pests and diseases and provide nutrients
13. Microbiome	J. All the microorganisms present in soil
14. Carbon sequestration	P. Carbon held in soil
15. Loam	K. A soil that is a good mixture of sand, silt and clay
16. pH	O. The level of acidity
17. Aggregate	G. Small clumps of soil
18. Archaea	N. A type of microorganism, part of the soil microbiome
19. Biochar	E. Carbon formed by the anaerobic combustion of plant material
20. Hartig net	R. Network of hyphae between epidermis and the cortex in a plant root

Exercise 3.29: Applying learning about soils — giving a farmer advice

This exercise challenges your trainees to bring together their learning about soil to give advice to a farmer, something they may need to do at a PHC.

You can combine this exercise with Exercise 7.9 in Chapter 7.

SCENARIO 1: Watermelon on the Guadalcanal plains, Solomon Islands

Possible diagnosis with reasons

Yellowing of the leaves suggests nitrogen deficiency. The farmer has used a crop rotation over the years that has depleted the soil of nitrogen and, perhaps, also sulphur due to burning the grassland.

What can the farmer do now?

Add some inorganic nitrogen fertiliser (NPK) if the crop is still growing.

What can the farmer do in the longer term?

- plant a legume crop next time to fix nitrogen into the soil
- or plant a cover crop and plough it into the soil before flowering.

SCENARIO 2: Tomatoes in Fiji

Possible diagnosis with reasons

Blossom end rot, a calcium deficiency in the plant. This may be caused by uneven watering of the crop which means it was unable to transport calcium to the developing fruit, as well as low levels of calcium in the soil. Also, overuse of nitrogen can cause calcium to be unavailable. Note, calcium does not move from old to young parts of the plant.

What can the farmer do now?

Nothing at this stage, unless the fruits are still producing fruit; in which case ensure there is regular watering.

What can the farmer do in the longer term?

- make sure the soil has a good supply of calcium through a top dressing of lime or dolomite. If possible, test calcium levels in the soil
- do not add too much nitrogen, especially when fruiting is starting
- it is not possible to control rainfall, but do not allow the crop to dry out during the growth stage.

Exercise 3.29: continued...

Scenario 3: Banana in Kiribati

Possible diagnosis with reasons

Interveinal chlorosis on the young emerging leaves, with veins remaining green at first, suggesting iron deficiency. In severe cases, the leaves are undersize and, on atolls, may become pale white, including the veins. Results in fruits of poor quality. Occurs in soils where pH is above 6.5.

What can the farmer do now?

Iron is not a mobile element, and does not move from old to young leaves, so if immediate action is required, a foliar spray is necessary: apply iron sulphate or iron chelate (Fe EDTA).

What can the farmer do in the longer term?

Best to replant the sucker in a pit with plenty of compost or manure and/or soil taken from local trees. Alternatively, use ammonium sulphate as the source of nitrogen as this may lower the pH of the soil. Probably, the best solution is to add rusty tin cans to the pits together with the compost/manure/soil mixture. Also, seek local knowledge on varieties; some varieties of bananas or plantains may be more tolerant of iron deficiency than others.

Now re-visit Exercise 3.1 and discuss whether your trainees' ideas about soil have changed after working though this chapter.

CHAPTER 3 QUIZ: Test your knowledge

Answer are in bold...

1. Sand particles are:

A. the largest particles in soil and float on the top of water

B. the smallest particles in soil and float on top of water

C. the largest particles in soil and sink in water

D. the smallest particles in soil and sink in water

2. Organic matter in soil is found in:

A. the bedrock

B. humus

C. clay

D. water

3. Which of these are NOT normally found in the soil microbiome:

A. archaea

B. bacteria

C. worms

D. fungi

4. Fungi that live inside the cells of plants are called:

A. endophytes

B. mycorrhizae

C. spores

D. microbiome

5. Soils with plenty of organic matter are likely to be rich in:

A. carbon

B. magnesium

C. potassium

D. iron

6. Which of these are NOT ways in which nitrogen can be made available to plants:

A. nitrogen fixing bacteria

B. using leguminous cover crops

C. drawing in nitrogen from the atmosphere

D. applying fertiliser

7. 'One Health' refers to:

A. the health of people in the Pacific

B. the idea that the health of all life forms is interconnected

C. how bacteria affect plant roots

D. the health of soil

8. The term 'aggregate' refers to:

A. soil particles bound together in clumps by organic matter and microbes

B. all the layers in a soil horizon

C. compost

D. the total of minerals in a particular soil

9. A soil has a pH of 8. Which three minerals are likely to be less available to plants?

A. K, S, Fe

B. Mn, Cu, Zn

C. Ca, Mg, Mo

D. N, Ca, Mn

10. A soil contains 30% clay, 30% silt and 40% sand. It is best described as:

A. silty loam

B. compost

C. clay loam

D. sandy clay

11. The symptoms on this yam leaf (right) suggest:

A. nitrogen deficiency

B. boron deficiency

C. it is the normal colour of the leaf

D. iron deficiency

12. Practices that contribute to soil health are:

A. cover crops

B. flooding

C. use of pesticides

D. raising soil pH to above 8

13. Physical weathering of soil refers to:

A. minerals within rocks reacting with water, air or other chemicals.

B. splitting of rocks through temperature changes and collisions of rocks with each other

C. breakdown of rocks by living organisms

D. ploughing the soil

14. Which of these is not true:

A. *Mucuna pruriens* can be used as a cover crop

B. a plant under stress is less resistant to disease

C. a soil with a pH of 7.5 is slightly alkaline

D. compost requires a carbon to nitrogen ratio of about 1:25

15. the plant's rhizosphere includes:

A. roots, root exudates and microbes

B. rhizomes

C. flowers and leaves

D. compost

9.5 Chapter 4 answers

There are no exercises for Chapter 4. Just work through the chapter to ensure your trainees have joined their country social media groups for plant health doctors and know how to use KoboToolbox (if available), the Pacific Pests, Pathogens & Weeds app, and are familiar with PestNet.

9.6 Chapter 5 answers

In Chapter 2, your plant health doctor trainees learned to identify and diagnose pest and disease symptoms on plants, and Chapter 4 introduced digital resources to help diagnose unknowns. Chapters 5 and 6 help your trainees to understand ways of managing pests and diseases. Chapter 5 covers IPDM options using cultural and biological control methods, which should always be the first option. Chapter 6 covers pesticides.

EXERCISE 5.1: What do you already know about IPDM cultural control methods for specific pests and diseases?

Your trainees will already have a lot of knowledge about cultural methods of control. In groups, they should write down and discuss any IPDM pest and disease control methods they know about for two pests and two diseases from their region, for both large and small scale cropping, and how the methods work. They should fill in the table below, then share and discuss their answers with the rest of the class. Answers will depend on the examples chosen.

An example is given for an insect and an example of a disease.

	Crop	What IPDM cultural control methods are possible?			
		For large scale	How it works	For small scale	How it works
Insect/mite pest					
Example: Diamondback moth (DBM)	Brassicas	Remove weeds in the Brassica family	Reduces DBM populations that maintain populations between crops	Hand pick caterpillars	Removes pests
1					
2					
Diseases					
Example: Citrus scab (*Elsinoe fawsetti*)	Citrus	Isolate nurseries from orchards	▪ prevents spread of fungus ▪ prune to keep canopy open	▪ isolate nurseries from orchards ▪ prune to keep canopy open	Prevents spread of fungus
1					
2					

EXERCISE 5.1: answers...

EXERCISE 5.2: Using IPDM — working out the steps

For IPDM to work properly, several important steps need to be taken.

These steps are what the plant health doctors need to tell farmers at the PHC.

This exercise helps your trainees work through the correct steps for applying IPDM. When they have had time to think about their answers, ask each group to share their ideas with the class. If they have anything in the wrong order, discuss this.

CORRECT ORDER

A. E: Knowledge — identify the pest or disease and know its life cycle.

B. A: Go to the garden regularly. Look for damage.

C. D: Decide how much damage is acceptable.

D. C: Make a plan of action for the present crop and the next crop: A) before planting (next crop); B) during growth of present crop; and C) after harvest of present crop. If it is a pest, count the pests (can you see natural enemies?). Is the problem getting worse or not? KEEP NOTES.

E. B: Was your plan successful or not? Are any changes needed? Is it a problem likely to be caused by a pest or a disease? Use the possible/probable approach in Chapter 2.

EXERCISE 5.3: Applying crop rotation

It is important that your trainees are familiar with the principles of crop rotation and are able to explain it.

The example shows possible crops to plant in a rotation based on Fig. 5.4. Each column represents a separate plot and has four cycles.

Note that as long as the crops are in the correct families and follow the current sequence, the actual crop that the trainees suggest does not matter. There is more than one correct answer, but there are also incorrect answers.

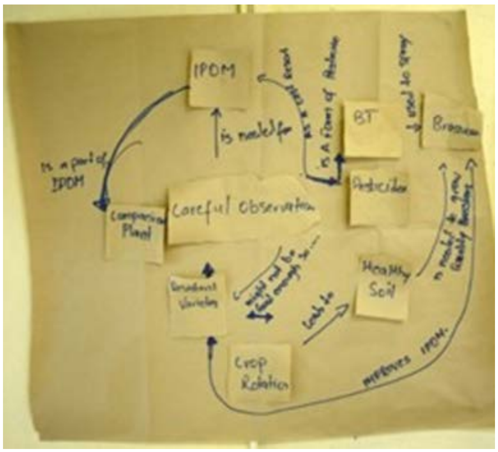
Cycle	Plot 1	Plot 2	Plot 3	Plot 4
1	Leafy crop e.g. *bele*	Legume crop e.g. Mucuna	Root crop e.g. taro	Legume crop e.g. Mucuna
Reason why you chose this crop rotation:				
2	Solanaceae crop e.g. capsicum	Curcubit crop e.g. cucumber	Brassica crop e.g. bok choy	Leafy crop e.g. lettuce
Reason why you chose this crop rotation:				
3	Root crop e.g. cassava	Root crop e.g. carrot	Legume crop e.g. bean	Solanaceae crop e.g. chilli
Reason why you chose this crop rotation:				
4	Legume crop e.g. peanut	Brassica crop e.g. cabbage	Cereal crop e.g. maize	Cucurbit crop e.g. watermelon
Reason why you chose this crop rotation:				

EXERCISE 5.4: Concept mapping of IPDM — answers

Creating a concept map is a very useful exercise to help your trainees make connections between concepts in any topic. It is best done in pairs or small groups. The concepts are written on a sticky note or piece of paper with blu-tak or sellotape on the back, then moved around on brown paper or butchers paper until the group agrees where they fit. The process of discussing and making decisions is an important part of the learning process.

You might want to start with a simple map of concepts that all trainees are familiar with, e.g. **house, mother, garden, chicken, taro, child,** so that they understand the process. They should write on the connecting lines how the concepts are linked.

You can decide to leave out or add other terms or change them if you think others might be better. About eight terms work well, but you can add more if your trainees need more challenges. Alternatively, you can ask the trainees to give you the terms to work with.



There is no one correct answer, but some answers could be incorrect. Some trainees will decide to create a flow diagram — 'this' leads to 'that' — while others will link the concepts. It does not matter how people relate the concepts, but trainees must write how they are related on the linking lines, as in the example here.

See Figs. 8.2-8.3 in Section 8.5.3 for other examples.

When they have finished, ask the trainees to put their map on the wall, and explain it to the rest of the class.

You can use concept mapping at any time during the training to help your trainees deepen their learning and make connections between content.

EXERCISE 5.5: Summary of cultural practices for IPDM control of some common pests and diseases

Exercise 17 is designed to help your plant health doctor trainees bring all their knowledge about cultural control for IPDM together. They should discuss the answers in their small groups, using their own knowledge as well as the resources and information you have covered in this chapter, to complete the table. Or you could set it as a homework exercise. When they have finished, discuss the answers with the whole class. Not everyone will be aware of all these cultural controls, so spend some time on the discussion.

The answers will depend on the examples the trainees use. You can provide them with examples, or they can come up with their own. Some examples are provided here.

Cause	Example	Crop & part affected	CR	GH	F	GD	CP	V	HPM	HP	TC	BC
Pests (insects & mites)	Tomato fruit borer	Tomato fruit	✓	✓	✗	✗	✗	✗	✗	✓	✓	✓
Pathogen (Nematodes)	Dry rot *(Pratylenchus)* nematode	Yam, roots, tubers	✓	✓	✓	✗	✗	✗	✓	✗	✗	✓
Pathogens (fungi, bacteria & viruses	Bacterial wilt	Tomato, whole plant	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗

Key

CR: Crop rotation

GH: Good hygiene

F: Fertiliser/compost/organic matter

GD: Good drainage

CP: Companion planting

V: Resistant variety

HPM: Healthy planting material

HP: Hand picking

TC: Trap crops

BC: Biological control

CHAPTER 5 QUIZ: Test your knowledge

The answers are given in **bold**. When they have all finished, go through the answers. You do not need to ask what marks the trainees got, they will have learned the correct answers by going through the test as a class.

Make sure you always discuss with the class any answers they are not sure about. Then explain that if there is anything they are still not sure about they should read the manual again and/or ask for help.

1. In IPDM, pesticides should be used:

A. always
B. never
C. as a last resort
D. only if the farmer can afford them.

2. The adult in the picture below is most likely to be:

A. a beetle
B. a wasp
C. a lacewing
D. a fly.

3. In order, a companion plant, a bio-insecticide and a beneficial organism are:

A. taro, DBM, Trichoderma
B. Chinese cabbage, kocide, ladybird
C. coconut, pyrethrum, Trichogramma
D. marigold, Metarhizium, spider.

4. An example of good crop rotation would be:

A. lettuce, cabbage, broccoli, bean
B. cucumber, squash, potato, cassava
C. potato, tomato, eggplant, capsicum
D. bean, cabbage, cassava, cucumber.

5. Rogueing means:

A. using bio-insecticides
B. destroying infected plants
C. using companion plants
D. planting resistant varieties.

6. In IPDM, monitoring involves:

A. deciding whether the problem is caused by a pest or a disease
B. using the best pesticide for the pest
C. checking the level of damage and looking for bugs and eggs
D. identifying the pest or disease

7. The correct sequence for applying IPDM is:

A. monitoring, evaluation, making a plan, identification of pest or disease
B. evaluation, monitoring, identification of pest or disease, making a plan
C. making a plan, identification of pest or disease, monitoring, evaluation
D. identification of pest or disease, monitoring, decide amount of damage acceptable, making a plan

8. Which plants are all in the same plant family?

A. cabbage, bok choy, broccoli, chilli
B. potato, cassava, taro, sweet potato
C. bitter gourd, pumpkin, cucumber, squash
D. capsicum, chilli, eggplant, bean

9. The best way to control a soil-borne bacterial infection is:

A. to use a resistant variety if it can be obtained
B. to spray with a pesticide
C. to find a virus that attacks the bacteria
D. to add compost to the soil.

10. Which of the following is NOT thought to be a characteristic associated with companion planting?

A. companion plants can provide food for parasitoids
B. companion plants may have a smell that repels pests
C. companion plants put copper into the soil
D. companion plants may repel root knot nematodes

9.6 Chapter 6 answers

In Chapter 5, your plant health doctor trainees learned about some of the cultural controls that can be applied to IPDM. Chapter 6 introduces them to pesticides. Remember to stress that these should be used only as a last resort, given the damage they cause to humans, natural enemies and the environment, as well as the problem of build-up of resistance in pest populations.

Chapter 6 reviews many aspects of pesticides and their uses, and Exercises 6.1-6.8 will test your trainees' knowledge on this topic.

EXERCISE 6.1: What do you already know about commercial pesticides?

This exercise helps you find out what your trainees already know about some commonly used (commercial) pesticides. They can check their own answers in Table 6.2. If any answers are incorrect, discuss. Add any others not on the list. This exercise also draws your trainees' attention to the fact that some pesticides may contain the same active ingredients but are sold under different trade names. It is important that they know this to be able to advise farmers properly.

Trainees should carry out this exercise in pairs or small groups. Discuss with the class and add any they do not know. Pesticides with different trade names, but the same active ingredients, are grouped and highlighted below.

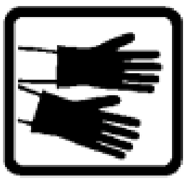
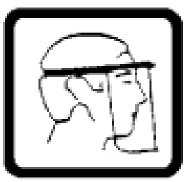
Pesticide name	Purpose	Type of pesticide	Active ingredient
Attack	Caterpillar, aphids.	I	Pirimiphosmethyl/ permethrin
Sundomil	Broad-spectrum.	F	Mancozeb
Glyphosate	Perennials, woody weeds.	H	Glyphosate
Kocide	Broad-spectrum.	F (and a bacteriocide)	Copper hydroxide
Confidor	Sucking insects — aphids, leafhoppers, thrips, whitefly, mealybugs, scale insects and taro beetle.	I	Imidacloprid
Orthene	Chewing and sucking insects — caterpillars, aphids, thrips, leafminers, leafhoppers, planthoppers, cutworm — on vegetables and fruits.	I	Acephate
Agazone	Annual and grass weeds.	H	Paraquat
Suncloprid	Sucking insects — aphids, leafhoppers, thrips, whitefly, mealybugs, scale insects and taro beetle.		Imidacloprid
Talendo	Broad-spectrum.	F	Chlorothalonil/ Thiophanate
Blitzem	Snails and slugs.	M	Metaldehyde
Steward	Caterpillars, pod borer, armyworm, centre grubs, cutworm, leafroller, leafminers.	I	Indoxacarb
Prevathon	Caterpillars, pod borer, armyworm, centre grubs, cutworm, leafroller, leafminers.	I	Rynaxypyr or chlorantraniliprole
Others:			
Farmers' imidacloprid	Sucking insects — aphids, leafhoppers, planthoppers, thrips,whitefly, mealybugs, scale insects and taro beetle.	I	Imidacloprid
Manzate	Broad-spectrum.	F	Mancozeb
Kotek	Broad-spectrum.	F	Mancozeb

EXERCISE 6.2: Understanding the pesticide label

Understanding a pesticide label is critically important for the correct and safe use of pesticides. This exercise focuses your trainees on how to understand the label. Make sure each group has a different label to work with. They should write their answers on brown paper or butchers paper. When finished, each group should hold their paper up and read out their answers to the class and discuss.

What is the pesticide used for?	Depends on label allocated to trainees
What is the common name of the pesticide?	Depends on label allocated to trainees
What is the trade name of the pesticide?	Depends on label allocated to trainees
Is the label divided into separate panels? If so, what information does each of these panels give you? Centre panel? Left panel? Right panel?	Depends on label allocated to trainees
What is an emulsifiable concentrate (EC)?	This will form a milky liquid when mixed with water
What is a sticker?	A substance that is put into a pesticide to make it stick to crop plants
What is a spreader?	A substance that helps spread the pesticide across the leaf surface
What is meant by 'compatibility'?	Pesticides that can be used together
What should you avoid doing when spraying, but do immediately after spraying?	Avoid contact with undiluted pesticide during preparation. Avoid getting spray on people, animals or into waterways. Clean the tank immediately after spraying so that the chemical does not dry on the inside: ▪ to do this, open the tank, remove the strainer, fill the tank with 1.5 L of water, replace the cap and shake ▪ pour the water out onto area that has been sprayed, or the ground nearby ▪ add another 1.5 L of water and spray to clean the hose, lance and nozzle
What clothing is recommended when preparing the spray and spraying?	Masks (including respirators) and goggles to protect the mouth and eyes, gloves, boots, hat and overalls. As a minimum, wear a long sleeved shirt, long trousers, rubber boots and a hat
What is the recommended way to store the pesticide?	Store the product in its original container, tightly closed, and away from heat and food, and out of reach of children, preferably in a locked cupboard
What does 'run-off' mean?	Pesticide that has left the crop and run off into the soil, drains, waterways, etc.
Is there a hazard number on the label? What is it and what does it mean?	1a — extremely hazardous 1b — highly hazardous II — moderately hazardous III — slightly hazardous U — unlikely to present acute hazard

EXERCISE 6.2: continued...

What should you do after spraying and before eating, drinking or smoking?	Remove your clothes and shower. Wash the clothes separately from other clothing. Do not eat or drink after spraying until you have washed
Can you wash the sprayer or empty container in the river? If not, why not?	No. It may contaminate the water to make it undrinkable, as well as kill fish and other aquatic creatures that live there
Where are the best places to put the container when it is empty?	Bury it or send it to a landfill. Do not re-use the container or leave it in the field
Is it recommended that you induce vomiting if a person has drunk the pesticide?	Depending on the pesticide, the label will tell you whether vomiting should be induced or not
If you spill the pesticide, what should you do?	Wear protective clothing Cordon off the area Prevent the chemical from entering drains Absorb it with inert material (soil, sand or sawdust) Place it in bins for disposal in a landfill Wash the contaminated area with water
Can you give livestock feed that has been sprayed with the pesticide?	Depends on the pesticide. There may be a withholding period till the animals can be slaughtered when they have grazed on sprayed crops. The pesticide label should tell you this
What is meant by the pre-harvest interval (also known as the withholding period)?	How long before the crop can be marketed after spraying to be considered safe to eat
What do these pictograms mean?	
a) 	a) Wear protective clothing
b) 	b) Always wash after applying pesticide
c) 	c) Wear gloves
d) 	d) Wear a mask or face guard

EXERCISE 6.3: Making up a pesticide for spraying

This exercise asks trainees to calculate the quantities needed to make up pesticide concentrations correctly for spraying. It is very important that they are confident with this sort of calculation. Go through it step by step if anyone is having difficulties.

- the pesticide label (Eko) tells you that you should apply Eko in 400 L of water per ha
- Eko is made up at 34 ml per 20 L sprayer (see Fig. 6.6)
- the farmer has a 5 square chain tomato field.
- area: 5 square chains is equivalent to 0.2 ha (25 sq chains = 1 ha, 5/25)
- spacing: 0.5 m x 1 m
- the farmer has a 15 L knapsack.

1. How many knapsack sprayers are needed to spray 1 ha of tomato?
   Answer: 26.7 knapsacks if using a 15 L sprayer (40 if a 10 L sprayer; 20 if a 20 L sprayer).
2. How much (Eko) chemical will you need to spray 1 ha of tomato?
   Answer: 680 ml of Eko chemical.
3. What advice would you give the farmer about the amount of chemical (Eko) … that he/she will use?
   Answer: 136 ml of Eko chemical.

Trainees should check their answer with a partner and then discuss with the whole class.

EXERCISE 6.4: Important factors in spraying

In pairs or small groups, trainees should write down at least four important things that they need to know before, during and after spraying. Discuss answers with the class.

Spraying	Important things you need to know
Before spraying	▪ do not spray on windy days ▪ have another person with you ▪ check that your knapsack is not leaking and was cleaned properly after its last use ▪ check you have the correct nozzle for the pesticide you are using ▪ check you have the correct concentration of pesticide (consult label) ▪ wear proper protective clothing
During spraying	▪ spray either early in the morning or late in the afternoon, when wind is less strong ▪ spray down wind ▪ use a spray shield to prevent chemical drift ▪ if accidents happen, refer to the label ▪ in case of a spill, cover with sand, sawdust or soil, and bury away from the house at the edge of the garden or field, or take to land fill
After spraying	▪ clean the tank immediately after use so that the chemical does not dry on the inside ▪ open the tank, remove the strainer, fill the tank with 1.5 L water, replace the cap and shake ▪ pour the water out onto the area that has been sprayed, or the ground nearby ▪ add another 1.5 L water and spray to clean the hose, lance and nozzle ▪ after spraying, remove your clothes and shower ▪ wash these clothes separately from other clothing ▪ do not eat or drink after spraying until you have washed

EXERCISE 6.5: Advantages and disadvantages of using pesticides

Your trainees have now covered Chapters 5 and 6 on IPDM methods of management of pests and diseases. They should now be able to discuss what they have learned about the advantages and disadvantages of using pesticides compared with other methods included in IPDM.

Some possible answers are given here:

Advantages of using pesticides	Disadvantages of using pesticides	Safer alternatives
▪ they are cheap ▪ farmers see their effects immediately ▪ they can be applied quickly over large areas	▪ they are toxic to human beings and the environment ▪ they destroy beneficial insects ▪ pests become resistant to them. ▪ for many people, they are difficult to choose and use at the correct rate	▪ cultural control strategies for example: ▪ crop rotation ▪ destruction of crop debris at harvest ▪ resistant varieties ▪ biological pesticides

EXERCISE 6.6: Using trainees' knowledge to identify and develop a management strategy for a farmer

Your trainees have studied the identification, diagnosis and management of pests and diseases, now they need to put their knowledge into practice. Practice and experience are essential; becoming a competent plant health doctor is complicated and takes work!

This is an important exercise, as it prepares your trainees for plant health clinics and is a good introduction to Chapter 7: Running a plant health clinic. It also gives them practice in filling out the Prescription Forms that are used at clinics, and asks them to reflect on their advice and to think about what they could do better.

This exercise is in five parts:

1. Identify and diagnose the problem.
2. Ask the farmer questions about the problem.
3. Manage the problem — make a plan.
4. Completing the Prescription Form.
5. Discuss and reflect.

EXERCISE 6.6: Using trainees' knowledge to identify and develop a management strategy for a farmer

Part 1: Identifying and diagnosing the problem

Trainees should now work through the process of identification and diagnosis of the problem in their photos. They should use all the information from the manual, Fact Sheets in the Pacific Pests, Pathogens & Weeds app, as well as their own experience.

Remind trainees to use the identification and diagnosing process in Chapter 2:

1. Is it A, B, or C? (abiotic, biotic or confused).
2. Possible and probable?
3. They should check with the fact sheets in the Pacific Pests, Pathogens & Weeds app only after they have done steps 1 and 2.

Part 2: Identifying and diagnosing the problem

As well as examining the sample, at a clinic, plant doctors will need to ask the farmer questions to provide more information about the pest or disease.

Trainees should make a list of questions they would ask the farmer. These questions could include:

1. How widespread is the problem? (e.g. a whole field, a few plants only)
2. Have other farmers in the area got the same problem?
3. Has the farmer seen the problem before?
4. Is it a new problem or does it occur every year?
5. How serious is the problem? (e.g. only a few leaves affected, the whole plant is affected)
6. How has the farmer tried to manage the problem? Was he or she successful?
7. What has the weather been like? (e.g. rain, drought, cyclone, frost, etc.)
8. Other questions?

Each pair should show the class their photos, discuss their diagnosis and read out their questions.

For unknowns, refer your trainees to the online tools in Chapter 4.

EXERCISE 6.6: Using trainees' knowledge to identify and develop a management strategy for a farmer

Part 3: Managing the problem — making a plan

Once you are satisfied that the trainees have the correct diagnosis, next ask them to discuss and write down all the different ways the problem could be managed, both now and into the future.

- biological control
  - are there any natural enemies that are important to preserve which might be killed with some pesticides?
- cultural control – what can be done?
  - before planting
  - during growth
  - after harvest
- resistant varieties
  - these can only be recommended if they are known to be available in the country
- chemical control
  - homemade pesticides
  - commercial pesticides.

Part 4: Completing the Prescription Form

Once they think the problem has been diagnosed and they have thought about a management plan, trainees should now practise completing the plant health clinic Prescription Form. This is the form they will use at the clinics, so it is very important they are familiar with it. Stress that they should fill in ALL parts, using clear handwriting. (They can make up the farmer's details.)

Stress to your trainees that plant doctors should NEVER give advice if they are uncertain. If using a language other than English, an English copy will be needed for record keeping, or use the KoboToolbox app on a smartphone or a tablet.

Make it very clear that the Pacific Pests, Pathogens & Weeds app should be used to check a diagnosis and to guide management strategies ONLY after this process is complete. Suggest to your trainees that they use the mini fact sheets in preference to full fact sheets as they present a summary of problems.

Part 5: Discussion and reflection

Reflection is also a very important part of the process. Discuss the exercise as a whole class, encouraging your trainees to discuss not only what they were able to diagnose easily, but also the unknowns and other difficulties. Ask them what they need to do to give a farmer better advice? What further study do they need to do?

If time, this exercise should be repeated using a sample from a garden or field. Your trainees can never have enough practice!

CHAPTER 6 QUIZ: Test your knowledge

The answers are given in **bold**…

1. Which of the following are all fungicides?

A. Manzate, milk, baking soda, malathion
B. Sundomil, Kotek, Kocide, Talendo
C. Glyphosate, neem, Blitzem, pyrethrum
D. Confidor, Orthene, Bt, Manzate

2. A sprayer nozzle suitable for fungicides should:

A. be an anvil type and the spray should form a light rain
B. be a flat type and the spray should form a mist
C. be a hollow cone type and the spray should form a mist
D. be a flat type and the spray should form a cloud

3. A pesticide label says that it should be made up at a concentration of 10 ml pesticide to 10 L water. The concentration of the pesticide is:

A. 10%
B. 1%
C. 0.1%
D. 0.01%

4. A farmer has 10 ha of a crop to be sprayed. The pesticide label tells her that the spray should be 30 ml pesticide per 20 L water and the crop should receive 400 L per ha. How many ml of the pesticide should she use to make up the spray to spray the whole crop properly?

A. 4000 ml
B. 600 ml
C. 6000 ml
D. 2400 ml

5. Buildup of insecticide resistance in a pest can be prevented by:

A. alternating the spraying between an insecticide and a fungicide
B. spraying early in the morning
C. using the correct type of nozzle for spraying
D. making sure the same type of insecticide is not used all the time

6. Which of these pesticides are not allowed in organic farming?

A. copper fungicides
B. tobacco
C. castor oil
D. Glyphosate

7. Which action should you NOT do if you accidentally spill some pesticide?

A. cover the area with sand
B. make sure you wash yourself and your clothes thoroughly
C. get the dog to lick it up
D. keep children away from the spill

8. Pesticide resistance in insects is caused by:

A. a genetic mutation that is passed on to new generations of the insect
B. a fungicide being used by mistake
C. a virus getting into the insect
D. using the wrong crop rotation

CHAPTER 6 QUIZ: continued...

9. Which of the following information is NOT usually found on a pesticide label?

A. the type of product
B. which pests are resistant to it
C. what it contains
D. what crops it may be used on

10. An emulsifiable concentrate:

A. is the same as a wettable powder
B. is incompatible with all other pesticides
C. cannot be mixed with water
D. forms a milky liquid when mixed with water

11. A pesticide withholding period means:

A. how long before it is safe to enter the crop after spraying
B. the period during which animals are not allowed to graze on the crop at any time
C. the number of days between the last application of a pesticide and crop harvest
D. how long before a pesticide is allowed into a country

12. Copper can be used to control:

A. phytoplasmas and viruses
B. nematodes and mites
C. snails and insects
D. bacteria and fungi

13. Pests in a small farm or garden are best controlled by:

A. ignoring them
B. using pesticides as soon as they are seen
C. encouraging beneficial insects and spiders
D. using insecticides and fungicides weekly

14. Pesticides allowed in organic farming:

A. come only from plants
B. are the same as commercial pesticides only weaker
C. are controlled under organic standards
D. are always safe

9.7 Chapter 7 answers

Chapter 7 brings together everything your trainees have learned in the previous chapters to plan, run and reflect on a PHC, first as a simulation and then a real one for farmers.

EXERCISE 7.1: What do we need to run a successful PHC?

Give your trainees time to think about everything they need to run a PHC successfully. By talking it through from beginning to end and sharing their ideas, they will develop a good understanding of the overall process, and feel more confident as plant health doctors.

Some answers are given below, but check Section 7.2 and Appendix 5 for a full list.

What do we need?		
Before the clinic	**During the clinic**	**After the clinic**
▪ good location for farmers ▪ awareness of the clinic before it is held ▪ tables/chairs ▪ banner ▪ join country social media group for plant health doctors	▪ Pacific Pests, Pathogens & Weeds app ▪ KoboToolbox app ▪ Prescription Forms ▪ pen or pencil ▪ knives ▪ hand lens ▪ camera	▪ samples brought by farmers ▪ Farmers' Feedback Forms ▪ Prescription Forms (copies) ▪ photosheet summary template

Exercise 7.2: WhatsApp — how to use it

The country social groups were discussed in Chapter 4. Here, your trainees learn to send pictures of unknowns or confusing samples to the social media group as part of running a clinic. Trainees should send their phone numbers to the person in charge of the social media groups before the clinic.

You should ask members of the country and other social groups if they can be available when you run this exercise.

Exercise 7.3: Role play — filling out the Prescription Form

This exercise builds on Exercise 6.6 in Chapter 6.
Ask the trainees to go outside and collect a sample of:

- a pest
- a disease
- an unknown problem.

If this is not possible, you need to provide the samples yourself, or use one of the photos in the manual or from the Pacific Pests, Pathogens & Weeds app.

You should carefully model the process of the clinic first, acting as the plant doctor while one of your trainees plays the role of the farmer. Go through the farmer interview process step by step, explaining clearly what you are doing at each step while the trainees observe.

After you have done this and discussed any issues or questions, ask trainees to form pairs. Provide each pair with a Prescription Form to fill in.

Remind the trainees to go through the A,B,C and possible/probable identification and diagnosis steps carefully (see Chapter 2). They should not go straight to the Pacific Pests, Pathogens & Weeds app. When doctors do this at clinics, they often make the wrong diagnosis, something similar to humans self-diagnosing a disease using Google!

The 'doctor' should interview the 'farmer' and fill in the Prescription Form carefully and clearly. The data can also be added to the KoboToolbox app to practise using it.

Sometimes doctors give a farmer incorrect information because they do not want the farmer to think they do not know something. Stress to your trainees that they should not fill in answers if they do not know what the problem is. It is much better to tell a farmer they do not know and they will find out, than give incorrect advice. In this case, they should write on the Prescription Form 'unknown'.

When they have finished, discuss the exercise with the class. It is really important that proper reflection is done at this stage to uncover problems the trainees may have encountered.

Exercise 7.4: Using the KoboToolbox Prescription Form

Demonstrate to the class how the KoboCollect form works. Have the trainees download the KoboCollect app to their smartphone or tablet and open the plant health clinic Prescription Form. Now take any pest or disease sample and fill in the form (offline), as has been done for the hard copy.

Even if we find a way to print out the form, there may still be a need to have the completed form translated into local languages first.

This issue needs to be discussed and resolved by the plant health team in each country.

Exercise 7.5: Fill in the Farmer Feedback Form

The Farmer Feedback Form is an important document to be used after the farmer has seen the plant health doctor at the clinic. The clinic manager or another designated person (especially someone who speaks the farmer's language) interviews each farmer about his/her experience of the clinic and completes the feedback form. The team in each country should ensure translations into their local languages are made available, as well as English.

The manager collects and collates all the feedback forms to present and discuss during the reflection after the clinic. This is an important part of reflection, as well as monitoring and evaluation.

The manager should use the Farmer Feedback Form to provide feedback to plant health doctors at the reflection on processes of diagnosis and make suggestions on improvements, if necessary.

Exercise 7.6: Preparing for many farmers attending the clinic with the same problem

Often, a number of farmers bring the same problems to the clinic if there is an outbreak of an insect pest or disease in the area. If the clinic manager notices this, and if there is time after they have received their prescription from the doctor, it would be very useful to gather the farmers together and ask one of the doctors to give them a short talk about the problem. This will give the farmers the opportunity to talk to each other about the problem and what they are trying to do about it.

Note that it is important that all farmers see the doctor first.

It is very important that you prepare your trainees for the possibility that many farmers will bring the same problem; you can do this by helping them become familiar with plant pests or diseases that they are likely to see at the clinic. Extension staff should already be aware of the major pests and diseases in their area, though sometimes new problems spring up quickly, especially when weather conditions change.

Make sure that trainees have consulted the section of the Pacific Pests, Pathogens & Weeds app where each country has selected 20 mini fact sheets of the most common pests and pathogens in their respective countries. These mini fact sheets have been translated into local languages

For this exercise, give your trainees an example of a pest or disease which is likely to be a problem in the area where the clinic is to be held. If you cannot find a live sample, use a picture or an example from the Pacific Pests, Pathogens & Weeds app. The trainees should prepare a short presentation about the problem for the class covering:

- the symptoms
- the diagnosis
- recommendations for control now and in the future.

Ensure each group presents on a different pest or disease.

Exercise 7.7: Reflection on the clinic process

Exercise 7.8: Farmer feedback data

Exercise 7.9: Reflection on diagnosis and recommendations

These three exercises are critically important for learning and improving the clinics, and should be gone through carefully. Emphasise that being wrong is nothing to be ashamed of, rather it is a vital part of the learning process, and that everyone gains from it, however experienced we may be. It is something we can all share in.

Exercise 7.10: Sending samples for identification

This is an exercise in sending a sample to an expert for examination, locally or overseas, so that an identification can be made. Make sure that you have the equipment needed before starting this exercise.

Set up three tables, with examples of either:

1. A fungal or bacterial disease.
2. A pest.
3. A virus.

Write the instructions for sending away each type of problem and place on the table.

To start, each group should write a label to put inside the parcel containing:

- crop/plant name
- code given at the clinic
- doctor's names and address
- code, same as on the prescription form
- date and location of the clinic
- farmer's name and phone number
- farmer's village
- a short description of the problem and any other useful information they think will be useful.

Trainees should follow the instructions for their pest or disease, and when they have finished, they should unwrap or dismantle the sample for the next group and move to the next table.

Exercise 7.11: Plant health doctor self-evaluation form

Now it is time for your trainees to evaluate themselves as plant health doctors. This is anonymous, but it will help the extension service to monitor how well the program is running and what further training may be needed.

Collate and report the overall results from the class. Discuss what this says about your trainees' confidence and ability to conduct a clinic. Ask:

- What do they think needs to be done to improve?
- How should this take place?

Exercise 7.12: Making a plant health clinic photosheet summary

It is very important to make a summary for the clinic to record the main points and to send it to senior officers, the media and others who are interested in the clinic program. This should be done on the day of the clinic if possible, usually by the clinic manager. The template for this is in Appendix 3.

CHAPTER 7 QUIZ: Test your knowledge

The answers are given in **bold**...

1. Plant health clinics are important parts of:

A. a country's food security
B. a country's plant health system
C. the agricultural extension system
D. all of the above

2. The best place to hold a clinic is:

A. where many farmers gather, e.g. a market
B. at the research station
C. on a farm
D. at the university

3. Important advice for farmers when raising awareness about a forthcoming clinic is:

A. to bring the whole plant, including roots
B. to bring a few leaves
C. to bring a soil sample
D. to bring your phone

4. If you do not know what the problem is, you should:

A. leave that part of the prescription form blank
B. tell the farmer something, even if you are not sure
C. ask if anyone else knows what the problem is
D. send the farmer away

5. Look at the steps below for identifying a disease sample. They are in the wrong order.

1. make a parcel for the specimens with newspaper
2. write a label and put the specimen in a plastic bag with a few drops of water and seal the bag, leav overnight
3. collect samples showing a full range of symptoms

The correct order to do these steps in is:

A. 1, 2, 3
B. 3, 2, 1
C. 2, 1, 3
D. 1, 3, 2

6. Insect samples to be sent away for identification are best preserved in:

A. methanol
B. isopropyl alcohol
C. 70% alcohol
D. beer

7. A plant doctor suspects a farmer's sample has a bacterial wilt. She can test this by:

A. smelling it to see if it smells rotten
B. cutting the stem and dipping the end in water and looking for milky streaming
C. finding the bacteria under a microscope
D. looking for spots on the leaves

CHAPTER 7 QUIZ: continued...

8. The most important items to take to a clinic are:

A. chairs

B. kava

C. uniforms

D. prescription forms

9. After a clinic, a plant health doctor must always:

A. follow up with a farmer if the farmer has been told that will happen

B. reflect on and review the clinic data and plan to improve next time

C. collect all the samples for looking at later with the other plant health doctors

D. do all of the above

10. A farmer brings yams that have died and gone black. The farmer tells the plant health doctor they have been damaged by lightning. The doctor thinks the problem is anthracnose. The doctor should help the farmer straight away by:

A. agreeing that lightning might be the cause but also offering other ideas of the cause, and suggesting what the farmer could do

B. offering to visit the farm

C. telling the farmer he or she cannot be helped at the clinic

D. asking the farmer to bring in more samples.

THE BIG QUIZ

This should be done at the end of training as a revision exercise, and afterwards, celebrate the end of training! The answers are given in **bold…**

1. A plant health system should include:

A. plant health clinics, extension staff, research staff, ministries of agriculture staff

B. biosecurity staff, research staff, hospital staff, quarantine staff

C. plant health doctors, vets, extension staff, research staff

D. media, tourism, agriculture, horticulture

2. Which of the following are all insecticides?

A. Manzate, milk, baking soda, Taratek

B. Sundomil, Attack, Multiguard, Confidor

C. Glyphosate, neem, Blitzem, pyrethrum

D. Confidor, Orthene, Bt, Taratek

3. A sprayer nozzle suitable for fungicide should:

A. be an anvil type and the spray should form a light rain

B. be a flat type and the spray should form a light rain

C. be a hollow cone type and the spray should form a mist

D. be a flat type and the spray should form a cloud

4. A pesticide label says that it should be made up at a concentration of 1 ml pesticide to 10 L water. The concentration of the pesticide is:

A. 10%

B. 1%

C. 0.1%

D. 0.01%

5. A farmer has 10 ha of a crop to be sprayed. The pesticide label tells her that the spray should be 30 ml pesticide per 20 L water and the crop should receive 500 L per ha. How many ml of the pesticide should she use to make up the spray to cover the whole crop properly?

A. 3000 ml

B. 4000 ml

C. 6000 ml

D. 7500 ml

6. Build-up of pesticide resistance in a pest can be prevented by:

A. alternating the spraying between an insecticide and a fungicide

B. spraying early in the morning

C. using the correct type of nozzle for spraying

D. making sure the same type of pesticide is not used all the time

7. Which action should you NOT do if you accidentally spill some pesticide?

A. cover the area with sand

B. make sure you wash yourself and your clothes thoroughly

C. keep children away from the spill

D. leave it to evaporate away

8. Pesticide resistance in insects is caused by:

A. a genetic mutation that is passed on to new generations of the insect

B. using the wrong crop rotation.

C. a herbicide being used by mistake.

D. a virus getting into the insect

THE BIG QUIZ continued...

9. Which of the following information is NOT usually found on a pesticide label?

A. the type of product
B. which pests are resistant to it
C. what it contains
D. what crops it may be used on

10. A wettable powder:

A. is the same as an emulsifiable concentrate
B. is incompatible with all other pesticides
C. can be mixed with water
D. forms a milky liquid when mixed with water

11. A pesticide withholding period:

A. is the period before it is safe to enter the crop after spraying
B. is the period when animals are not allowed to graze on the crop at any time
C. is the number of days between the last application of a pesticide and crop harvest
D. is the period before a pesticide is allowed into a country from overseas

12. In IPDM, pesticides should be used:

A. always, as a prevention
B. never
C. as a last resort
D. only if the farmer can afford them

13. The adult insect in the picture below is most likely to be:

A. a beetle
B. a wasp
C. a lacewing
D. a fly

14. In order, a companion plant, a biological insecticide and a beneficial organism are:

A. taro, DBM, Trichoderma
B. Chinese cabbage, kocide, ladybird
C. coconut, pyrethrum, trichogramma
D. marigold, metarhizium, spider

15. An example of a good crop rotation would be:

A. lettuce, cabbage, broccoli, bean
B. cucumber, squash, potato, cassava
C. potato, tomato, eggplant, capsicum
D. bean, cabbage, cucumber, cassava

THE BIG QUIZ continued...

16. A plant health doctor is faced with an unknown pest or disease at the clinic. What should s/he do first?

A. send a picture to social media group
B. make up something; it's better than the farmer thinking they don't know
C. see if anyone else in the clinic knows
D. tell the farmer to go away

17. In IPDM, monitoring involves:

A. deciding whether the problem is caused by a pest or a disease
B. using the best pesticide for the pest
C. checking the level of damage and looking for bugs and eggs
D. identifying the pest or disease

18. The correct sequence for applying IPDM is:

A. monitoring, identification of pest or disease, decide amount of damage acceptable, making a plan
B. evaluation, monitoring, identification of pest or disease, making a plan
C. making a plan, identification of pest or disease, monitoring, evaluation
D. identification of pest or disease, monitor, decide amount of damage acceptable, make a plan and action

19. Which plants are all in the same plant family?

A. cabbage, bok choy, broccoli, chilli
B. potato, cassava, taro, sweet potato
C. bitter gourd, pumpkin, cucumber, pineapple
D. capsicum, chilli, eggplant, potato

20. The best way to control a soil borne bacterial infection is:

A. use a resistant variety if it can be obtained
B. spray with a pesticide
C. use a virus that attacks the bacteria
D. add compost to the soil

21. Which of the following is NOT thought to be associated with companion planting:

A. companion plants can provide food for parasitoids
B. companion plants may have a smell that repels pests
C. companion plants always add large amounts of potassium to the soil
D. companion plants may repel root knot nematodes

22. In order, abiotic and biotic factors that cause damage on plants are:

A. fungi and mites
B. birds and drought
C. potassium deficiency and bacteria
D. phytoplasmas and poor soil

23. Typical symptoms on plants caused by bacteria are:

A. leaf spots, angular or round, with or without haloes
B. wilt and yellowing at the edges of leaves
C. rusty spots and mosaics
D. dieback and the leaves go purple

THE BIG QUIZ continued...

24. A common disease of tomatoes in the Pacific region is:

A. witches' broom
B. tobacco mosaic
C. early blight
D. ring spot

25. The smallest of these pathogens is:

A. a virus
B. phytoplasma
C. a bacterium
D. a fungal spore

26. A plant doctor finds a plant with symptoms of wilt. The most unlikely cause would be:

A. bacteria in the soil
B. rust fungus
C. nematodes
D. stalk borers

27. Pests with eight legs are not:

A. mites
B. insects
C. scorpions
D. spiders

28. Which of these diseases is caused by a fungus?

A. bunchy top on banana
B. blossom end rot on tomato
C. scale on sweet potato
D. damping off on cabbage seedlings

29. A plant doctor finds a cabbage with a lot of holes in the leaves. Which are not likely causes?

A. diamondback moth
B. large cabbage moth
C. leaf spot
D. snails

30. A virus can be spread by:

A. bacteria
B. fertiliser
C. rhinoceros beetles' larvae
D. aphids

31. Two insects with simple life cycles are:

A. aphids and katydids
B. butterflies and bugs
C. grasshoppers and ants
D. bees and moths

32. Plant health clinics are important parts of:

A. a country's food security
B. a country's plant health system
C. the agricultural extension system
D. all of the above

33. The best place to hold a clinic is:

A. where many farmers gather e.g. a market
B. at the research station
C. on a farm
D. at the university

THE BIG QUIZ continued...

34. Important advice for farmers when you are raising awareness about a forthcoming clinic is:

A. to bring a whole sample if possible
B. to bring a few leaves
C. to bring a soil sample
D. to bring your phone

35. If you do not know what the problem is, it is best to:

A. leave that part of the prescription form blank
B. tell the farmer something, even if you are not sure
C. end the farmer away
D. ask if anyone else knows what the problem is

36. Look at the steps below for identifying a disease sample.

1. make a parcel for the specimens with newspaper
2. write a label and put the specimen in a plastic bag with a water and seal the bag
3. collect samples showing a full range of symptoms

The correct order to do these steps in is:

A. 1, 2, 3,
B. 3, 2, 1
C. 2, 1, 3
D. 1, 3, 2

37. Insect samples to be sent away for identification are best preserved in:

A. beer
B. methanol
C. isopropyl alcohol
D. 70% alcohol

38. A plant doctor suspects a farmer's sample has a bacterial wilt. She can test this by:

A. smelling it to see if it smells rotten
B. looking for spots on the leaves
C. placing the end of the stem under water and looking for milky streams
D. finding the bacteria under a microscope

39. The most important items to take to a clinic are:

A. chairs
B. kava
C. uniforms
D. prescription forms

40. After a clinic, a plant health doctor must always:

A. follow up with a farmer if the farmer has been told that will happen
B. reflect on and review the clinic data and plan to improve for the next clinic
C. collect all the samples for looking at later with the other plant health doctors
D. do all of the above

THE BIG QUIZ continued...

41. A farmer tells the plant health doctor he thinks his crops have been damaged by an evil spirit. The doctor should help the farmer by:

A. agreeing this might be the case and offering other ideas of what the farmer could do
B. sending the farmer to a priest
C. telling the farmer he cannot be helped at a plant health clinic
D. asking the farmer to bring in more samples

42. Which Pacific countries are thought to have the Guam strain of the rhinoceros beetle?

A. Samoa
B. Guam, Palau, Hawaii, Vanuatu
C. Fiji
D. Guam, Palau, Papua New Guinea, Solomon Islands

43. Good soil is likely to have a pH of around:

A. 1
B. 3
C. 7
D. 9

44. Which of these home-made pesticides is particularly harmful to fish?

A. chilli
B. gliricidia
C. neem
D. derris

45. What are the pests in this photo?

A. rhinoceros beetles on mango
B. green vegetable bugs on tomato
C. black ticks on pumpkin
D. aphids on guava

46. What is the difference between a parasite and a parasitoid?

A. there isn't one: they are the same
B. a parasite does not kill its hosts; a parasitoid does
C. a parasitoid can't be seen with the naked eye; parasites can
D. parasites have complex life cycles whereas those of parasitoids are simple

47. The picture below shows you how:

A. to spray low-growing crops
B. far apart crops should be
C. to use a mist sprayer
D. to water your plants in a drought

THE BIG QUIZ continued...

Multiple choice. Pick one answer only...

48. A farmer brings a plant with large irregular spots on the leaves. It is most likely to be:

A. a wilt

B. a deficiency disease

C. a fungal disease

D. something I know nothing about

49. You want to teach your trainees to think about how plant diseases relate to people going hungry. The best teaching strategy is probably:

A. a cause and effects diagram

B. a picture of a hungry child

C. a role play

D. a concept map

50. Which symptoms are often confused?

A. a powdery mildew and a leaf spot

B. a virus and a deficiency disease

C. a bacterial leaf spot and a bacterial wilt

D. overwatering and copper deficiency.

51. Organic matter in soil is found in:

A. the bedrock

B. humus

C. clay

D. water

52. Which of these are NOT ways in which nitrogen can be made available to plants:

A. nitrogen fixing bacteria

B. using leguminous cover crops

C. drawing in nitrogen from the atmosphere

D. applying fertiliser

53. The plant's rhizosphere includes:

A. roots, root exudates and microbes

B. rhizomes

C. flowers and leaves

D. compost

54. 'One Health' refers to:

A. the health of people in the Pacific

B. the idea that the health of all life forms is interconnected

C. how bacteria affect plant roots

D. the health of soil

55. Which of these are NOT normally found in the soil microbiome:

A. archaea

B. bacteria

C. worms

D. fungi

Appendix

Running a Plant Health Clinic (PHC)

The appendix contains the following resources:

1. The plant health clinic Prescription Form
2. Farmer Feedback Form
3. Template for making a photosheet
4. Plant health doctor self-evaluation form
5. Procedure check list for running plant health clinics
6. Glossary — Soils.

Appendix 1: The Plant Health Clinic Prescription Form

CLINIC

Date:	❑ Fiji ❑ PNG ❑ Samoa ❑ Tonga ❑ Solomon Islands ❑ Vanuatu	Code:

FARMER

Family Name:	Given Names:	Sex: ❑ M ❑ F
Village/Settlement:	Province:	Mobile:
No. of previous clinic visit:	Age: ❑ < 29 ❑ 30-55 ❑ > 56	Sample: ❑ Yes ❑ No

CROP

Crop:	Estimate planted area (m^2):
Variety:	Estimate no. of plants:
Seed source:	Estimate no. of plants damaged: ❑ Few ❑ Many ❑ All
Previous crop:	Plant problem: ❑ Common ❑ New
Crop stage:	Weather: ❑ Unusual ❑ Normal ❑ i) Wet ❑ ii) Dry

DESCRIBE WHAT YOU SEE (if no sample, write what the farmer tells you)

WHAT CONTROL MEASURES HAS THE FARMER TRIED?

WHAT DO YOU THINK IS THE CAUSE OF THE PROBLEM?

YOUR RECOMMENDATIONS

WHAT CAN THE FARMER DO NOW?

CULTURAL CONTROL	CHEMICAL CONTROL

WHAT CAN THE FARMER DO IN FUTURE (WHEN GROWING THE SAME CROP)?

CULTURAL CONTROL		CHEMICAL CONTROL (remember natural enemies)
Before planting:	Any resistance varieties?	
During growth		
After harvest:		

Photo(s) taken: ❑ Yes ❑ No	Sample sent to lab? ❑ Yes ❑ No

Plant doctor:	Signature:	Mobile no.:

Appendix 2: Farmer Feedback Form

1. Did the plant health doctor diagnose your problem? (please tick)

   ❑ Yes ❑ No ❑ Not sure

   Why?

2. Do you think you can carry out what the doctor said you should do?

   ❑ Yes ❑ No ❑ Not sure

   Why?

3. Was the clinic useful?

   ❑ Yes ❑ No

   Why?

4. Do you have any suggestions on how to improve the plant health clinic?

5. Would you recommend the clinic to other farmers?

   ❑ Yes ❑ No

   Why?

6. If there is another clinic in your area would you come again?

   ❑ Yes ❑ No ❑ Maybe

Appendix 3: Photosheet template

.... (insert country)

.... (insert organisation)

.... (insert date)

Insert photo 1	Insert photo 2
Insert photo 3	Insert photo 4
Insert photo 5	Insert photo 6

This Plant Health Clinic was held at .... and organised by ....

The .... *(insert clinic name)* is located .... Km in the N/S/E/W from .... town.

.... *(insert number)* farmers participated at the clinic; there were .... *(insert number)* men and .... *(insert number)* women.

.... *(insert number)* samples were received.

Some of the key problems presented were:

The plant doctors were .... *(insert name/s).*

Other information: *(you could add if any specimens were sent for identification)*

Prepared and reported by: .... , organisation.

For more information contact: .... *(insert name)*

Ph: ....

Email: ....

Photos by: .... *(insert name, if a different person).*

Plant clinics are held as part of the *ACIAR project: Responding to emerging pest and disease threats to horticulture in the Pacific islands.*

Appendix 4: Plant health doctor self-evaluation form

1. How confident are you in your abilities to make correct disease diagnoses?

   1 2 3 4 5

2. How confident are you in your ability to correctly diagnose pest problems?

   1 2 3 4 5

3. How confident are you in your ability to make correct recommendations?

   1 2 3 4 5

4. Do you feel you need more training?

   ❑ Yes ❑ No

5. If 'Yes' what training is needed? Please specify (e.g. IT, diagnosis, filling out the prescription forms, interviewing farmers, etc.)

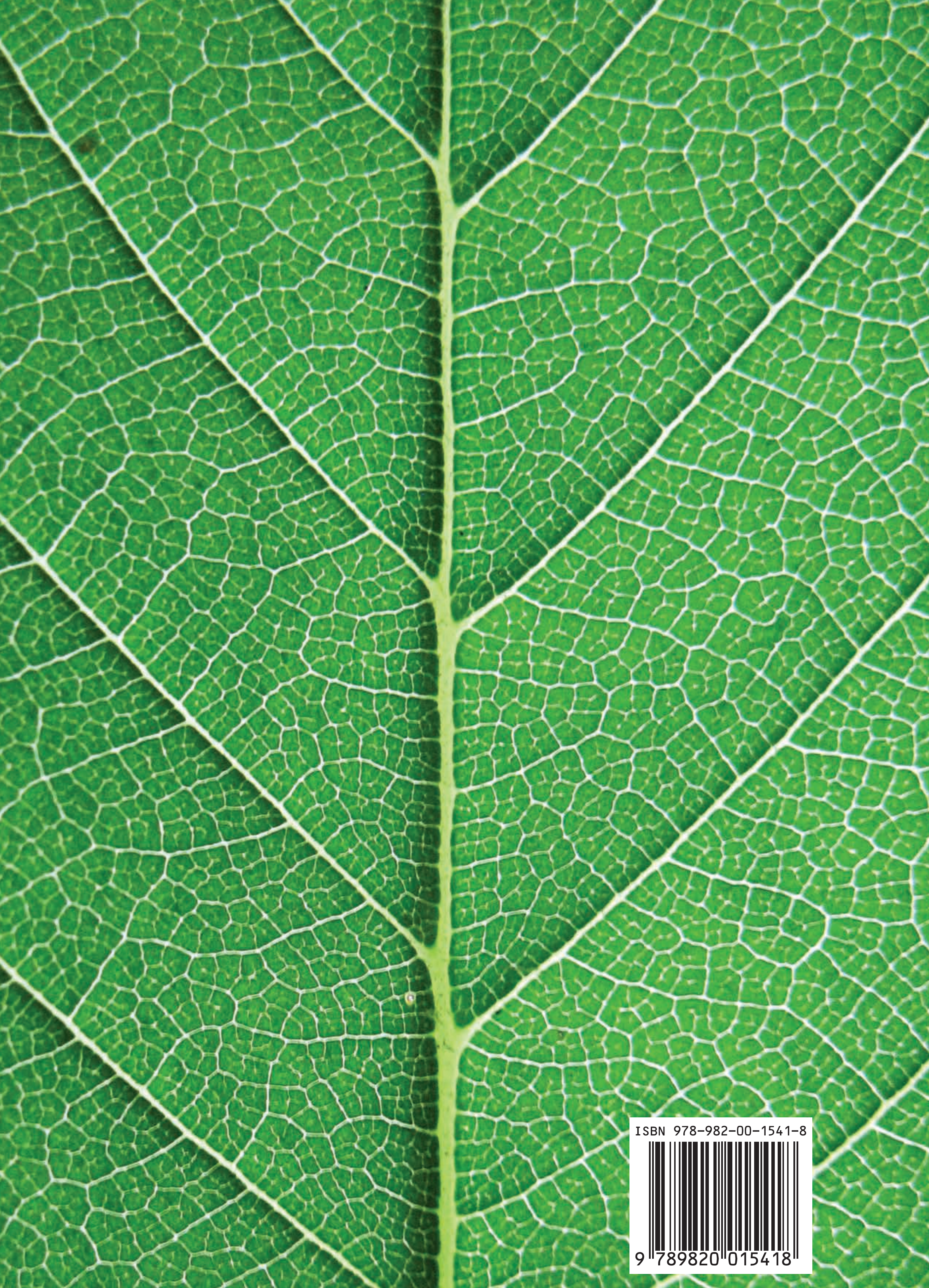
Appendix 5: Plant health clinic procedure checklist

Checklists for Plant Health Clinics	
Tick	**Task**
General preparation for PHCs	
	Clinic timing: ▪ how often should they be held? ▪ make a strategic PHC plan for your country ▪ always plan subsequent clinics in advance, so you can announce the next date at your current clinic
	Samples: ▪ clinics run best when farmers bring samples that are kept for reference. Discuss with your team how you are going to collect, label, manage, store and follow up with any samples before planning a PHC
	Staff: ▪ are there enough staff appointed to the PHC team to effectively run clinics in the field and conduct the administration before and after them?
Before the clinic	
	Location — is it: ▪ accessible? ▪ visible? ▪ conveniently timed?
	Awareness: ▪ radio ▪ TV ▪ phone calls ▪ emails ▪ encourage whole plant samples to be brought ▪ give farmers plenty of notice
	Budget: ▪ stationery ▪ advertisement ▪ other materials
	Staff: ▪ clinic manager ▪ data entry ▪ plant protection officers (extension, research, biosecurity) ▪ country's WhatsApp community on stand-by
At the clinic	
	Setting up: ▪ table, chairs, tarpaulin ▪ banner and pull-ups advertising the clinic ▪ access to Wi-fi, if possible ▪ a decision on what to do with 'unknowns'
	Plant health doctors - what is needed? ▪ materials for assessing samples, recording data, camera/phone for taking photos, providing Prescription Forms (see detailed list in section 7.2.3)

Tick	Task
Steps to ensure a successful PHC	
	Farmer registration and direction: ▪ make sure farmers' samples are processed appropriately ▪ ensure the Prescription Form and the Farmer Feedback Form are filled in accurately ▪ have the farmers complete an interview feedback form ▪ provide farmers with factsheets, leaflets, other information sheets or resources
What to do with unknowns	
	▪ tell the clinic manager if you have an unknown. He or she should ask other plant health doctors who might be able to identify it ▪ make sure unknowns are assessed by one or more plant health doctor ▪ ask the WhatsApp community for help ▪ make sure the clinic manager follows up with SPC or other research/biosecurity divisions for identification ▪ do not forget about unknowns! If you tell farmers you will follow up after the clinic to help them, do not forget to get an answer for them **If there is no follow up, farmers will not come to future clinics.**
Immediately after the clinic	
	▪ enter all the data from the Prescription Forms in the database if you are not using the Kobotoolbox app ▪ collate Farmer Feedback forms (the clinic manager usually does this) ▪ follow up on any unknowns that have not been solved
	Review and reflection: ▪ what went well? ▪ what could have been better? ▪ what changes will you make the next time?

Glossary — Soils

Clay	Smallest of the soil particles. Often with plate-like shapes, feels sticky when wet. Refers to a soil texture of more than 40% clay particles.
Humification	Process by which organic matter decomposes to form humus.
Humus	The result of the decomposition by microorganisms of the organic components of the soil.
Micronutrients	Chemical elements required in trace amounts for the growth of plants.
Infiltration rate	How quickly water enters the soil (usually measured in cms per hour).
Ion	Atom or group of atoms that are electrically charged.
Macronutrients	Chemical elements needed by plants in relatively large quantities.
Mineralisation	Conversion of an element from an organic to an inorganic state as a result of microbial decomposition.
Minerals	Naturally occurring solid with defined physical, chemical, and crystalline properties.
Mycelium	A network of thread-like growths of a fungus.
Mycorrhiza	A fungus that forms a close relationship with the roots of plants, exchanging chemicals that each cannot otherwise obtain, for the benefit of both.
Organic matter	The breakdown of plants, animals and microoganisms. Soil organic matter forms humus. Always contains compounds of carbon.
Percolation/permeability	The ease with which water and air move through the soil.
Porosity	Amount of pore space. Infiltrations rates are higher if porosity is high.
Rhizosphere	The soil surrounding and directly influence by plant roots.
Sand	Largest of the soil particles. Feels gritty and coarse to the touch. Refers to soil texture of at least 85% sand particles.
Silt	Its size is between that of sand and clay. It feels smooth to the touch (like flour). Refers to soil texture of 80% silt particles.
Soil aggregates	Soil particles of various sizes held together by organic matter and other substances. Sometimes called peds when formed naturally, or clods when formed by tillage.
Soil structure	Arrangements of soil particles into aggregates (peds) of various shapes and sizes by wetting and drying, fungal activity, tillage and activity of roots.
Soil texture	The coarseness or feel of soils. Measured by the relative amounts of sand, silt and clay using the USDA soil texture triangle.
Symbiosis	Living together of two dissimilar organisms to the benefit of both.
Till	The act of cultivating or ploughing the land, preparing it for seeding or planting.
Water-holding capacity	Ability of water to retain water.
Weathering	The physical, chemical and biological disintegration of rocks and minerals belonging to the earth's crust.
Workability	Ease with which soil can be tilled, and how long takes to reach a certain level of cultivation (tilth).



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