

GUIDANCE H:

Integrated Pest Management (IPM)

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ALLIANCE**



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Applicable to
Farm Certificate Holders

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More information

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OVERVIEW OF KEY CHANGES

Section	Change
3	Addition: Chapter on Integrated Weed Management
5.4	Addition: Paragraph on Integrated Weed Management for Tea

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Objective

This guidance aims to provide background knowledge on Integrated Pest Management to help farmers understand and implement the requirements of the standard for successful and sustainable farming.

Scope

This guidance focuses on section **4.5 INTEGRATED PEST MANAGEMENT (IPM)** of the standard. It looks particularly at the major processes affecting occurrence of pests and the different control methods available for their management in a sustainable farming system. In this guidance the term **PEST refers to arthropods, rodents, diseases and weeds**. Sometimes interventions are specific to particular types of pests.

Audience

This guidance shall serve technical staff who are preparing farmer groups (or plantation owners) for certification to help them understand the importance of the requirements in the standard and how they can best be implemented in their particular circumstances. The document shall also be a guidance for internal inspectors/ auditors who check on compliance with the requirements, to be better able to assess the situation found on the ground as well as the suitability of farmers' management practices in the given agroecological environment.

1 INTRODUCTION

This IPM guidance does not intend to cover all possible pests or crops. The intention is to present the most common pests that affect key crops certified by the Rainforest Alliance in different regions worldwide.

For the relevant binding definitions please see Annex S1, Glossary.

1.1 Why Integrated Pest Management?

Indiscriminate use of pesticides in agriculture is associated with negative environmental and human health effects, as well as biodiversity loss, particularly in the global South.

The arrival of synthetic pesticides made it possible to grow large amounts of food but also led to the simplification of ecosystems, making them less resilient and more reliant on external inputs like pesticides and synthetic fertilizers. The reduction of pesticide use in agriculture is urgent, not only to avoid side effects on humans and the environment but also to avoid pest resistance problems and the creation of new pests.

Pesticides are frequently applied by force of habit or in situations of uncertainty, whether or not pests occur and independently of their actual need. This can create a vicious cycle of an unbalanced ecosystem leading over time to pest resistance and resurgence, and secondary pest outbreaks. This in turn can lead to the need to use ever more aggressive methods to manage the problems.



Figure 1. Flowering strips to enhance natural pest control. Photos: Jack Kelly Clark and Rachael Long. Photo source: UC Statewide IPM program Regents, University of California.

The implementation of Integrated Pest Management (IPM) programs is key to effectively reduce the use of pesticides. Good IPM implementation is an investment in the future of sustainable farming.

A solid IPM program requires a shift in the mindset on agronomic practices and continuous improvement of the farm system, which for some crops means gradual change and for others a more systemic change to managing pests and diseases or the entire agroecosystem.

What happens if pesticides are applied as first option to control pests, diseases and weeds?

If pesticides are used as the first option to control pests, or as a preventive measure, their natural enemies will also be killed leading to even greater pest problems like pest resistance. It can also lead to an increase of new pests because other natural enemies have been killed. However, the root of the problem is still there because the factors in the farms that make it possible for those pests to appear are still there. These include unhealthy soil, crops that are not properly nourished or are susceptible to pests and diseases, weather that is conducive to the pest, or that there is **not enough biodiversity in the farm**. The correct intervention would be to prevent the pest from appearing in the farm from the start.

What are the advantages of using IPM?

- Biodiversity is conserved and the risk of human and environmental contamination is reduced. The conservation of biodiversity is key to prevent pest problems.
- Crop losses and pest management costs are reduced, because pest control measures, and the use of inputs are optimized.
- Unnecessary pesticide use is avoided.
- Development of pest resistance to pesticides is reduced.
- Crop production is more stable over time and productivity is enhanced.



2 IPM REQUIREMENTS IN THE STANDARD

Overview

In the Integrated Pest Management section of the standard (4.5), there are four core requirements, two mandatory improvement requirements and one smart meter requirement¹.

2.1 Implementation of the requirements

2.1.1 Core Requirement 4.5.1

Objective

Establishment of an IPM strategy that reduces yield losses by pests, reduces or optimizes the use of pesticides and increases profitability.

How to implement

To implement Integrated Pest Management at farm level it is helpful to develop an **IPM strategy**. An IPM strategy is developed for a specific context and takes into account environmental and economic aspects of a specific region and/or farm. It is therefore based on the reality of the farm operations, and practices in the field. **An IPM strategy should always aim to prevent pest incidences in the first place** and prioritize the growth of a healthy crop, conserve/enhance natural enemies, monitor the crop regularly, minimize the use of chemicals by -for example not following calendar spraying but, instead basing the use of chemicals on where a need is observed on the farm.

An IPM strategy is not an eradication strategy, but a strategy to manage pest populations in the long-term to minimize infestations and their economic impact.

Key elements of the **IPM strategy**:

- **Pest prevention** and suppression
- **Monitoring** of pests to identify their presence and assess if intervention is required (based on thresholds)
- **Intervention** - determine pest control actions like cultural practices, physical and biological mechanisms, or non-restricted low toxicity pesticides.

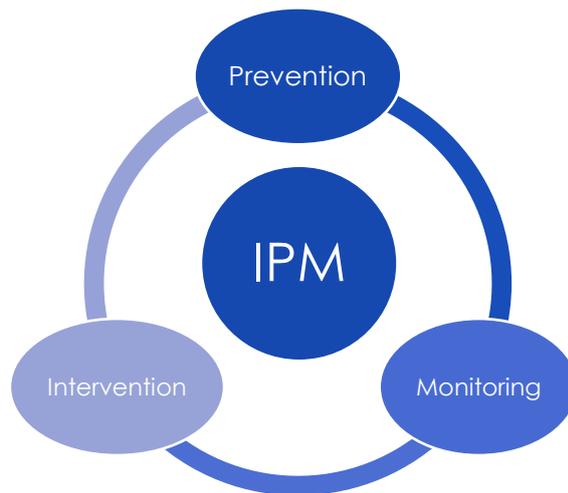
Find an example of an IPM strategy for aphids in this link:

<http://ipm.ucanr.edu/PMG/PESTNOTES/pn7404.html>

¹ **Core requirement:** These are requirements that always have to be met in order to achieve certification. Most core requirements prescribe good practices with respect to key sustainability risk topics and are formulated as compliance requirements (a binary pass/fail).

Mandatory improvement requirement: Designed to further promote and measure progress. Mandatory improvement requirements need to be included in the standard compliance as the producer or producer group advances on its journey to sustainability.

Smart meter requirement: Smart Meters aim to give farmers a structured way to incorporate continuous improvement on context-specific data. Smart Meters do not have predefined targets set by the Rainforest Alliance. Instead, the producers themselves set the targets for these indicators and define the adequate actions to take to realize these improvements. Producers conduct a baseline assessment and define targets for these indicators in year 0 or year 1 (depending on the requirement), plan and implement actions to achieve the targets, and then monitor progress towards the targets. Producers use the indicator data to reflect yearly on the progress, and to adapt the activities in case no or little progress is shown. This provides producers with a feedback loop so that they can continuously improve their practices



1. Pest Prevention and Suppression means preventing the numbers of pests going up.

Preventive measures always take priority in an IPM strategy. Activities include [but are not limited to]:

- Using tolerant or resistant plant material and avoiding plant varieties that are attractive to important pests
- Preventing the introduction of pests to the farm: keeping healthy plant material, also in nurseries
- Not planting the crop in areas of the farm where pests can build up
- Eliminating alternative hosts of insect pests and diseases (selective weeding)
- Preventing pests spreading between different fields on the farm (cleaning equipment, clothes, etc. between field visits)
- Preventing pests developing within fields on the farm (crop rotation, proper irrigation, proper plant spacing, prevent weed reproduction, maintaining good shade levels)
- Carrying out appropriate fertilization based on soil tests, keeping healthy soil with appropriate organic matter content
- No tillage (if applicable)
- Preserving and enhancing natural enemies of pests by limiting the application of pesticides or by increasing spatial and temporal diversification, for example by keeping living mulches or preserving patches of natural vegetation in or around the field which would serve as refuge and food source for natural enemies of pests.
- Use of trap cropping and / or pheromone traps
- Crop residue management

2. Pest Monitoring meaning keeping an eye on if, when and how interventions should be used to control the build-up of pest populations to prevent economic losses.

Check requirement **4.5.2** for more details

3. Intervention: this is an action to control pest numbers and bring pest populations down. Also called a **control measure**

Check requirement **4.5.3** for more details



2.2 Example Questions For Developing A Good IPM Strategy

Prevention:

- Identify which pest and diseases the planting material is susceptible or tolerant to.
- What are the most economically important pests in your farm?
- Identify areas on the farm that are susceptible to pest attack.
- Identify the underlying cause (low soil fertility, incorrect fertilization (not based on soil test), erosion, waterlogging or drought, unfavourable light conditions, unsuitable temperature, unsuitable crop variety, monoculture, etc.).
- Plan preventive measures to change these conditions, adjust fertilization, add organic matter, adjust microclimatic conditions, and add plant diversity.
- Identify common pests (insect pests and diseases, weeds) that regularly cause problems.
- Identify conditions that are favourable for increased pest incidents (time of the year or crop cycle, wet or dry conditions, temperature fluctuations, etc.). you should increase monitoring vigilance when these conditions occur.
- Always keep patches of natural vegetation (making sure there are no alternative hosts of the pest), preferably that have flowering plants and a good mixture of shrubs and bushes that can serve as refuge and food source of natural enemies.

Monitoring

- Establish monitoring and scouting procedures and schedules for main pests: answer the following questions: how many trees or plants should be monitored per hectare? How often?
- Monitor them on a regular basis (minimum every two weeks) and record their numbers and infestation levels, as well as the date and location of the sampling.
- Identify main natural enemies of pest and record their numbers, life stage as well as the date and location of the sampling
- Keep records of the monitoring results in the context of the underlying conditions (crop stage, crop state, location, climate, prevailing weather conditions, temperature, and day/night temperature fluctuations, etc.)
- Research and know the thresholds of the most important pests in your farm. Define the threshold level at which the crop can no longer tolerate pest presence and at which the loss will cause higher economic damage than the cost of the chosen intervention

Intervention

1. Intervene **ONLY** when the economic thresholds so indicate. First always use non-chemical options:
2. Identify possible control methods for each pest in the following order of preference:
3. Manage the pest using good agricultural practices like soil fertility management, adequate shade, water management and encouraging natural enemies.
4. Physical and cultural control methods: pruning infested plant parts, can you do general crop sanitation? physically killing or collecting insect, hand weeding. Is trapping a possibility? Are there pheromones and trapping systems for the pest? Can you physically cover fruits?
5. Biological control (of pests): can you buy commercially available natural enemies and release them in your farm? Can you do something to improve biodiversity conservation and create patches where natural enemies can live and feed? The natural enemy



may not be present in your farm because it lacks its habitat. Providing this home and food for the natural enemy may incentivize its establishment.

6. “Soft” pesticides or those approved for use in organic agriculture: is the application of soapy solutions or garlic extract, chili extract or neem or other plant extracts an option?
7. Spot Application of chemical pesticides which have the lowest possible toxicity following label instructions. Please note that spot applications of nematodes are difficult to carry out.
8. Chemical pesticides of the lowest possible toxicity and highest selectivity. Do not apply chemicals present in the RA list of prohibited pesticides and avoid pesticides in the risk mitigation list. If the latter not possible, please follow all the risk mitigation measures indicated.

Use the records to understand pest incident occurrence and underlying courses better and to continuously improve your IPM strategy. The IPM strategy needs to be updated annually

- Reduced
- Rotation of pesticides to avoid resistance

2.2.1 Core Requirement 4.5.2

Objective

To assess the severity of pest infestations and the presence of natural enemies to inform the decision on IPM interventions.

How to implement

After pest prevention (see above), the second most important component of an IPM strategy is monitoring. This includes inspecting fields and scouting² for early signs of possible pest or disease outbreaks or aggressive weeds to prevent further spread. Farmers and advisers should regularly inspect the farms and crops, especially during times in the crop cycle that are known to be susceptible or during weather conditions that have been identified to promote pest, disease and weed outbreaks.

It is also very important to monitor for **natural enemies** of the pests. Where there are natural enemies, the pests will not be able to reproduce and get out of control. Natural enemies can be predators, parasitoids or microorganisms like fungi, bacteria and viruses or insects that eat weeds. It is important to observe if you see 10 insect pests alone or if you see 10 insect pests together with two natural enemies. Knowing that natural enemies are present is important to inform your choice of interventions. See Chapter H for examples on natural enemies.

Scouting can be done **visually** by selecting a certain number of plants or trees and inspecting them in a randomized fashion making sure to cover all the field so as not to miss pests/natural enemies that aggregate in certain spots. Monitoring should follow a systematic approach (always use the same scouting pattern and sampling method appropriate for the pest (or specific life stage)). The recommendation is to develop protocols on how to scout for all pests and natural enemies and include those in the IPM strategy. Training of farmers and technical staff on how to scout for pests is also needed.

Another less accurate way of monitoring insect pests is using sticky **traps** or traps with pheromones, but their accuracy needs to be checked for particular pest problem.

Monitoring is not enough. It is crucial to also **record (write down) what is observed. It is important to design a template that captures information relevant to the farm's specific conditions and circumstances**, including the prevalence/infestation level of the pests, diseases and weeds observed. Always record:

² Scouting is inspecting a field for the presence of pests (including insects, weeds, and pathogens); monitoring is scouting the field in a regular manner to find out how the pest populations develop over time



- The type of pest and/or natural enemy seen
- The number of pests per tree or plant or their infestation level observed
- The date and time of the sampling and the location where the data was collected or where the trap was located

Make sure to monitor and record, as frequently as possible, to see the progression of the infestation and to avoid pests getting out of control. Start recording as early as possible in the season and pay attention to all (potential) pests even if they still only occur in very small numbers and in specific locations. **Accurate and up-to-date records assist in scheduling future monitoring visits and serve as indicators of when to intervene with control measures.**

Recommendation to groups:

Record the pests found in the area³ and identify them. Gather information about their life stages, feeding and reproduction cycles. Record the symptoms of their presence on crops. For diseases, seek advice and information from government Agricultural offices, plant protection experts or other sources to identify the disease, its cause and possible routes of disease transmission. Provide this information to all farmers, best with illustrations or as life specimens. Identify the times and conditions under which these pests usually become invasive and establish a monitoring or scouting plan accordingly. Enter this information into the IPM strategy.

Example of a monitoring and reporting schedule:

In a coffee plantation in Colombia the monitoring plan for coffee berry borer was established. The person sampling made a zig-zag path through the farm, and randomly sampled 30 trees per hectare. For each sampled tree, a representative branch in the middle section of the tree was selected and all developing berries examined for coffee berry borer entry holes⁴. Numbers of total berries per branch and numbers of infested berries were recorded. Infestation level is calculated as the percentage of infested berries out of total berries sampled.

A sample template to record information on pests and natural enemies for coffee can be found on the next page.

³ To determine the percentage of infestation samples (e.g. leaves) have to be taken over the area at random and the incidents of damage/infestation/number of pests, etc. counted. **Calculation example:** 35 out of 100 = 35% infestation.

⁴ Implementing an integrated pest management program for coffee berry borer in a specialty coffee plantation in Colombia; Luis F. Aristizábal, et al; *Journal of integrated pest management*, volume 3, issue 1, 1 March 2012, pages g1–g5



Name of farm: _____ Plot / location of sampling: _____
 Name of person collecting data: _____

Pest: Coffee berry borer

Date	Tree/ plant	Numbers	Notes	Natural enemy	Numbers	Notes
3 rd June 2020	1	30 berries with holes	Starting penetration in berry	<i>Beauveria bassiana</i>	5 berries with CBB infested	Dead borer
	2	5 berries with holes	CBB deep inside	no	no	
					
	30	0				
10 th June 2020	1					
					
	30					
17 th June 2020	1					
					
	30					

Pest: Coffee leaf rust

Date	Tree/ plant	Numbers	Notes	Natural enemy	Numbers	Notes
3 rd June 2020	1	5 leaves with X number of pustules		<i>Trichoderma</i>		
	2			no	no	
					
	30	0				
10 th June 2020	1					
					
	30					
17 th June 2020	1					
					
	30					

Note: please note that there are sample protocols for each pest. Inform yourself about the correct way and number of samples before starting the monitoring
 Please note pest and natural enemy should be carried out at least every two weeks: Ideally when conditions/time of the year are conducive for the spread of the pest/disease this should be done every week.

2.2.2 Core Requirement 4.5.3

Objective

Non-chemical prevention and control methods are used first. Thresholds levels are used to decide when to use chemical control and if used, chemical applications do not harm people or the environment.

How to implement it

Since this is a complex requirement, we have divided the explanations in three parts.

Part I: Non-chemical prevention and control methods.



Part II: Threshold levels.

Part III: Preconditions for the application of agrochemicals.

Part I: For pest prevention and control, producers use biological, physical, and other non-chemical control methods first, and document the use and the effectiveness of these methods.

There are many alternatives to choose from when it comes to non-chemical prevention and control interventions. These should be considered before even starting to think about chemical control (pesticide applications). These include cultural, physical and biological interventions.

Physical control

These are control methods aimed at using physical characteristics of the environment or using mechanical methods to injure the pests or reduce pest populations. For example, temperature, physical barriers, water applied with pressure, cutting, chopping etc.

There are many different methods of physical control. Some of them are:

- Manipulating micro-climatic conditions, like pruning or using the sun to solarize the soil
- Rain seems to knock off spider mites, therefore a forceful jet of water from a hose can be used to keep away spider mites and other small insects.
- Direct removal or destruction of the pests, like hand weeding, destruction of crop residues, pruning to remove infected parts or immature stages of pests (eggs, larvae etc), hand picking of large insects
- Traps, such as light, colour or sticky traps, or traps with attractants (pheromones, kairomones).
- Use of repellents: substances that disorient insect pests and do not let them find their host plant easily.
- Bags - valuable fruits are sometimes covered with individual bags to protect them from insect attacks. This method is time-consuming and labour-intensive, but can lead to good results
- Polyester row covers/mulches for plant beds to prevent insect egg laying and to suppress weeds or mesh, net or plastic covers over plants or fruits to keep out insects and birds.
- Burning infested trees or parts of the plants that have been attacked badly

Cultural control

Cultural control methods are very similar to methods used during prevention. These are methods that either avoid promoting environments that are conducive to pests and diseases, or methods that lead to conditions that are detrimental to pests and diseases. Examples include crop sanitation, pruning of diseased parts of the plants or eradication of entire plants (also a physical method), manipulating planting and harvesting dates to avoid pest populations etc, or introducing structures that make the agroecosystem a good place for natural enemies.

Some examples of cultural control are:

- Diversified farm or multi-cropping. Growing several crops in the farm can make it more resilient to attacks by pests
- Keeping a cover crop that can at the same time help improve soil conditions, serve as a refugee or food source for natural enemies and avoid the establishment of detrimental weeds.
- Border crops. Planted around the field



- Trap crops. These are plants that are more attractive to the pests than the main crop. Once the pests is in there, it can be killed.
- Mulches. They are a layer of material applied to the surface of an area of soil. They can be either made of materials like plastic or nets (for weed control or to exclude pests and to heat cold soils), or they can be living mulches, like flowering herbs, which help improve soil condition and increase biodiversity.
- Efficient harvest that can break pest cycles (avoid re-infestation)

Biological Control

Biological control is the use of natural enemies of pests to manage pest problems. Biological control can be highly selective, and there are rarely negative side-effects. Released organisms (microorganisms or natural enemies) may become established on the farm, and if used early may breed at a rate that keeps pest numbers within acceptable limits.

Some examples of natural enemies include:

- Predators, which are mainly free-living species that consume large numbers of prey during their lifetime, like praying mantis, ladybug beetles, spiders, wasps, bugs, dragonflies. Predators are not necessarily only insects. Birds are also very important predators that control pests, such as caterpillars or beetles.
- Parasitoids: insects whose larvae develops inside the body, eggs or larvae of another insect, ultimately killing them. Many species of wasps and some flies are parasitoids. Some of these insect parasitoids are commercially available.
- Microorganisms or pathogens like fungi, bacteria and viruses. Just as humans get sick from microorganisms, so do insects. Examples are *Beauveria bassiana* and *Metarhizium anisopliae* two fungi that can kill pests, such as termites, thrips, beetles and aphids. Some of these fungi are commercially available, but also may be present naturally in your farm.

Increasing natural enemies on the farm so they can control pests

The easiest and cheapest option is to promote the natural enemies that live in the farm and are adapted to the local environment. For this, habitats need to be prepared and conserved (flowering strips, hedges, planting aromatic plants). When you conserve the soil, manage weeds by leaving flowering plants in the plantation, and have it covered by natural vegetation, it serves as a habitat for the natural enemies. Conserved water sources become habitats for the predators. Planted native trees become habitats for birds and bats. All these practices contribute to IPM.

Well-managed conservation areas promote natural enemies that prevent the onset of pest problems, so that additional interventions such as chemical applications are not needed or may be reduced.

An alternative is to buy natural enemies the same way you buy pesticides. Many companies produce and sell natural enemies that can be very effective in controlling pests. But they can also be costly, and the natural enemies may not be well adapted to the local conditions because they haven't lived there.

Caution needs to be always given to the introduction of new insect species not endemic to a country or region as they might not be able to sustain a population, or the population might get out of control if their own natural enemies are missing and then become a pest themselves. If you are artificially releasing natural enemies in your plantation, always do so guided by a competent professional.

Part II: When threshold levels of pests are reached, producers can use agrochemical applications, as advised by a competent technician and/or upon the advice or instruction of an official national organization.



What are threshold levels?

Eradication or total control of pests is in many cases not necessary (or even desirable) to ensure profitability. Almost all crops can tolerate a certain amount of pest damage without affecting yields. The focus should therefore be on determining the relationship between the level of damage that a pest causes and crop yield and establishing what are **allowable levels of damage or pest population densities**. In this way, a farmer can know if the costs of controlling the pest is higher than the damage the pest will eventually cause.

There are two threshold levels:

1. **The Economic Injury Level (EIL)**, which is the point where the value of the crop lost will be greater than the expense of a control method. If a control method is used on a pest population level below the EIL, the producer loses money because the intervention cost more than the amount earned from the crop that was saved. If the farmer waits until the pest population has increased past the EIL then he or she has lost more crop than the cost of intervention. In theory, intervening just before the EIL always maximizes profit. The producer will need to maintain pest populations below the EIL or take some action before a pest population reaches the EIL and causes economic damage.
2. **The Economic Threshold (ET)**. It is 'the pest density at which control measures should be implemented to prevent it from reaching the Economic-injury Level'. This threshold always represents a pest density or level of pest damage lower than the EIL (usually 80% of the EIL).

It is important to have a good idea of the threshold levels of the main pests in your focus crops, and to plan a specific action in case the threshold level is crossed. It is also very important to keep monitoring the population of natural enemies.

Government and research institutions might also be able to provide guidance regarding common pests and diseases thresholds in a particular region.

Please see crop specific guidance for cocoa, coffee, tea and banana at the end of this document.

Note of caution:

Threshold levels given in this document are based on literature review and should only be used as an indication. IPM strategies need to consider contextual parameters and local experience.

Part III: When agrochemicals are used:

- Agrochemicals with the lowest possible toxicity and highest selectiveness are used
- Applications are made only on the impacted plants and areas
- Active ingredients are rotated to avoid and reduce resistance
- Calendar spraying is avoided, and only allowed when recommended by a competent technician or official national organization

2.2.3 Agrochemical use

Many so-called IPM programs are based largely on the use of synthetic pesticides ('pest killers' i.e., insecticides, fungicides, nematicides, herbicides, rodenticides), but this is not in accordance with the principle of IPM.

This popular approach to combat pests and diseases first through application of pesticides is not an IPM program and has created problems like secondary pest problems, resistant pests, and an increase of new pests because of the natural enemies being killed. **Indiscriminate use of pesticides apart from being detrimental to human health and the environment, always damages the populations of natural enemies that support pest control and leads to vicious cycles of ever-increasing number of pest infestations.**



Chemical control should only be used if cultural, physical and/or biological controls have been applied, and pests still reach threshold levels.

When using chemical pesticides, the Rainforest Alliance Standard requires that:

1. The pesticide must be registered for use in your country.
2. Priority should be given to pesticides with the lowest possible toxicity. For this, always follow the label of the pesticide and the MSDS (material safety datasheet). Pesticides containers have warning labels which indicate the level of toxicity using a color code (see below⁵). This is based on World Health Organization (WHO) requirements. The WHO classifies pesticides by hazard based on their oral and dermal lethal dose (LD50) – i.e., how much of the pesticide would kill a person if they absorb it through the mouth or the skin. Each insecticide is then put into one of four classes:

Ia, extremely hazardous

Ib, highly hazardous

II, moderately hazardous

III, slightly hazardous

You must ensure that people handling pesticides also read, understand and comply with the information and instructions provided on a product's label and MSDS. If an MSDS is not available in your country, you can contact your local government agency, pesticide provider or manufacturer to obtain this information. It is your responsibility to make this information available to everyone involved in handling pesticides in your group or on your farm.

WHO – Acute toxicity (and for a limited number pesticides also chronic toxicity)

	Hazard class				
	Class Ia <i>Extremely hazardous</i>	Class Ib <i>Highly hazardous</i>	Class II <i>Moderately hazardous</i>	Class III <i>Slightly hazardous</i>	Class U <i>Unlikely to present acute hazard in normal use</i>
Hazard symbol				<i>No symbol</i>	<i>No symbol</i>
Signal word	Very toxic	Toxic	Harmful	Caution	<i>No signal word</i>
Colour band	PMS red 199 C	PMS red 199 C	PMS Yellow C	PMS Blue 293 C	PMS Green 347 C

Figure 2. Colour coding indicating the level of toxicity of a pesticide. Source: WHO. 2010. *The WHO recommended classification of pesticides by hazard and guidelines to classification 2019*. World Health Organization, Geneva [Available at: http://www.who.int/ipcs/publications/pesticides_hazard/en/index.html]

3. Chemical control should be used through **spot/patch applications**⁶, this means only where it is needed (areas with high concentration of pest) and not on the entire plot or farm. If pesticides are applied to areas where pests are not present, they will also kill the beneficial organisms.
4. Active ingredients are **rotated to avoid and reduce resistance**. All pesticides have a “mode of action” which refers to the way in which it actively disrupts pest populations at its target site. If pesticides with the same modes of action are applied continuously and repetitively, the pests will develop resistance. Meaning at some point they will no longer be killed by the pesticide. To avoid this, always rotate pesticides with different modes of action. You can find information on how to rotate modes of action in the

⁵ <http://www.fao.org/3/a-i4854e.pdf>

⁶ Spot applications are not possible in generalized nematode infestations.



website of IRAC: <https://irac-online.org/modes-of-action/>. Or you may download their application here: <https://play.google.com/store/apps/details?id=irac.moa&hl=en>.

This app is an easy-to-use searchable database which allows you to identify insecticide active ingredients and their respective Mode of Action groups, so you know how to rotate them.

5. Synthetic pesticides **should not be applied based on a fixed schedule**, by crop phenology or by calendar applications. This is only allowed when recommended by a competent technician or official national organization.

In addition, always remember that...

- Every country has its own pesticides regulations. Registered and approved products vary from country to country. That's why it is important to check your national legislation.
- If there is a difference between what is permitted in your country and on the Rainforest Alliance list, the strictest standard prevails. This means that pesticides allowed and registered in your country cannot be used if they are included on the List of Prohibited Pesticides of the Rainforest Alliance and vice versa
- The List of Prohibited Pesticides of the Rainforest Alliance (Annex 7 of the Sustainable Agriculture Standard 2020) includes the names of active ingredients and not the commercial name of the pesticide product. This is because pesticides are registered with different commercial names in different countries, but the active ingredient has the same name all over the world.
- If substances from the Rainforest Alliance Risk Mitigation List (Annex 7 of the Sustainable Agriculture Standard 2020) are used, this is within the implementation of the IPM Strategy and the respective measures are taken to minimize risks.

2.2.4 Core Requirement 4.5.4

Objective

All people involved in farm production understand the concept and principles of IPM and are able to conduct their activities properly.

How to implement

Providing training and knowledge on IPM will help to implement a good program. You will need to ensure that:

- Producers are aware of the common pests on the farm and what can be done to reduce their populations and that they know where to find information on pests and control measures
- The person responsible for developing and monitoring the IPM strategy has the required knowledge and skills
- Training is given regularly, and records or training are kept updated
- The training is of good quality, addresses the real pest problems found on the farm, includes practical examples and is given by a qualified person

Farmer Field Schools (FFS) can be established to support your members. This has been demonstrated to be an effective way to adopt IPM. Demonstration plots are helpful to show successful experiences in regard to pest control.

2.2.5 Mandatory Improvement 4.5.5 (L1)

Objective

Small farms implement the IPM strategy as developed by the group management and pest levels are kept under control.



How to implement

The following to-do list shows a set of information to collect at farm level to identify if the IPM strategy is implemented and working:

To do list	Yes/No	Pending. Why?
Preventing the problem of pests		
All the prevention components that apply to the farm are implemented		
Soil is in healthy condition		
Plant material is tolerant to the pests on the farm and it is in a healthy condition		
Producers carry out all good agricultural practices that are recommended for the crop		
The farm is diverse and has patches of natural vegetation, flowering gardens, riparian areas etc that serve as refuge and food source for natural enemies		
Identify the problem or pest and its natural enemies		
Producers have a very clear understanding about the main pests of the crop, the damage they cause and their cycles and development stages		
Producers have a good knowledge of the main natural enemies of the main pests present on the farm and know how to take care of them and promote them		
Determine the severity of the problem		
Producers know the threshold levels of the main pests of the crop. They know how much damage is tolerable and when to take action		
Producers monitor and record (minimum every two weeks), numbers of pests and natural enemies per location and know exactly when they should implement control measures		
Assess the management options (do nothing, physical, cultural, biological, chemical control?)		
Producers have a clear idea of what kind of non-chemical measures they can implement in the farm and where. They know what kind of cultural and physical control measure will work		
Producers know what the advantages, disadvantages and costs are of using each method		
Producers know if using traps is possible		
Measure the success of options employed. Record the results		
Producers have recorded the results of using non-chemical methods and know if they are successful or not		
Producers have clarity regarding when they should apply a pesticide and how to choose the lowest possible toxicity		
If producers have to apply a pesticide, they first do spot applications (not applicable to nematode control)		
Producers are familiar with the different modes of action of pesticides and know how to rotate them		

Please remember that...

For the successful implementation of the IPM strategies, group management supports its members on making sure that the above list of activities has been implemented.

2.2.6 Mandatory Improvement 4.5.6 (L2)

Objective



To have a farm where biodiversity is conserved and that has enough places where natural enemies of pests can live, feed and thrive. Natural enemies help keeping pest levels under control.

General Guidance

Large-scale monocultures, and monocultures in general, provide little room and feed for beneficial organisms. In such an environment, harmful organisms can multiply quickly because of the absence of natural enemies.

Diversity of natural enemies is directly related to plant diversity as they depend on a large variety of wild plants. Many natural enemies depend on flowering plants for provision of nectar and pollen or need hedges for protection as well as breeding grounds. To have a healthy environment where natural enemies of the pests can thrive and where prevention is the most important component of pest management, it is crucial that the natural habitats of the farm are increased and maintained. These include patches of natural vegetation, keeping a cover crop, keeping patches of native flowering plants, native trees and vegetation around small ponds and little rivers.

Some examples look like this:



2.2.7 Mandatory Smart Meter 4.5.7

Objective

To track and have accurate data on pesticide use to be able to reduce its use over time.



How to implement

Producers need to have accurate data and define feasible reduction targets. Group management is responsible to monitor this data for a representative sample of small farms.

For the first indicator: **Active ingredients per ha (a.i. kg/ha, per year or per cropping cycle)**, Producers must know which products are being applied and in what quantities. This should be indicated not as commercial name but as **active ingredient**. The amount should be given in grams or kilograms of active ingredient per year or per cropping cycle.

To calculate the **Active ingredients per ha (a.i. kg/ha, per year or per cropping cycle)**, of a given product, producers need the following information:

- Active ingredient in a given product in g or kg (found on the label as percentage)
- Amount of applied product per year or cropping cycle (total)
- # hectares where the product is applied

For example, you applied 8 litres of a product in 4 hectares over the year. The label of the product says it contains 36% active ingredient. Meaning, per each 1 litre or 1 kg of product, there are 360 grams or ml of active ingredient. Meaning 360 times 8 litres that were applied = 2,880 grams (or 2,88 kg) of active ingredient in the 4 hectares per year.

For the second indicator: **Active ingredients used that are listed in the Exceptional Use list and Risk mitigation list**, Producers must list which pesticides from the Risk Mitigation list (Annex 7 of the Sustainable Agriculture Standard) or pesticides from the Exceptional Use Policy are used.



3 INTEGRATED WEED MANAGEMENT

Some general information about Integrated Weed Management can be found here:

[Plant Production and Protection Division: What is Integrated Weed Management \(fao.org\)](https://www.fao.org/plant-production-and-protection/division-what-is-integrated-weed-management/)

A good plan for Weed Management includes:

1. **Prevent the establishment of weeds** using the following interventions when applicable:
 - Know your major weeds. The time of their flowering and seeding
 - Field margin management
 - Clean seeds
 - Use of cover crops
 - Mulching (dead or living)
 - Allelopathic compounds
 - Cover crops
 - Timing and depth of cultivation
2. **Reduce the impact** of weeds on the crops through:
 - Plant variety choice
 - Spatial arrangement of crop
 - Mechanical or manual weeding
 - Intercropping
 - Biological control (pests that attack the weed)
3. Reduce seed return by:
 - Clean machinery
 - Water and fertilizer management
 - Weed seed collection and destruction
 - Last resort: post emergence and spot application of post-emergence herbicides
Hand weeding

3.1 What is a weed?

Weeds are commonly recognized as the most important biotic factor affecting crop production, but what is actually a weed?

A weed is a plant that grows in an unwanted place, and that in agriculture competes for nutrients, water and sunlight with the crop grown. Some of them can also release root exudates toxic to crops; or they can create favorable habitat for the proliferation of other pests (arthropods, mites, pathogens and others), serving as hosts. And last, weeds can interfere with the normal harvesting process and contamination of produce.

Weeds survive under conditions where other plants would not thrive, and they share some common characteristics⁷:

- They tend to produce lots of seed — sometimes tens of thousands of seeds per plant. Or have the ability to reproduce vegetatively (without seeds)

⁷ <https://wssa.net/wssa/weed/articles/wssa-what-makes-a-weed/>



- Their seed can sometimes survive for a very long time in the soil, going dormant but then sprouting just as soon as conditions are right. Simply disturbing the soil is often enough to trigger new growth.
- They can establish themselves quickly.
- They can grow in inhospitable places.

The more of these characteristics a plant has, the more problematic it will be. Weeds may directly reduce crop yield and quality and increase harvest costs. In general, the most sensitive phase of a crop is in its early growth stage, when the plant is young, vulnerable, and highly dependent on nutrients, light, and water/moisture supply. If it competes with weeds at this stage, the crop may become weak and prone to pest and disease infections. Once the plant has grown, weed competition for nutrients and water is less of a problem.

However, there is another way of looking at weeds. In the context of ecosystem management, as Ralph Aldo Emerson once said: *“What is a weed? A plant whose virtues have not yet been discovered”*. There are also “good weeds”. These weeds are not aggressive, do not have such a big reproductive potential (do not produce so many seeds or rhizomes), create a permanent cover of the soil without competing with the crop, have flowers, and some can fixate nitrogen. They can have a beneficial role by providing biological diversity, supporting ecosystem services, and the conservation of the soil.

For example, they can provide refuge and food (nectar and pollen) to pollinators, natural enemies, and mycorrhizal fungi. They cover bare soil keeping beneficial soil microorganism communities alive through their root exudates of sugars and proteins. And protect the soil from erosion.

3.2 What happens if herbicides are applied as first control methods for weeds?

Weeds are often seen as the enemy that has to be eliminated, and often an indicator of failure as a farmer. Good farmers are usually perceived as those that have only crops on their farms. That's why many farmers mis/overuse herbicides in their fields as a first strategy of control.

But this strategy of having crops with absolutely or minimum soil cover is not only uneconomic but also not desired from the ecological standpoint.

The use of herbicides, particularly broad spectrum, as the first resort is simply wrong and unsustainable. Their application can lead to changes of weed species composition in cropping areas, to herbicide resistance if herbicides applications are not carried out properly, to changes in the physical and chemical properties of the soil⁸. The consequent unhealthy soil leads to plant that are not properly nourished (making necessary the application of chemical fertilizers – implying more costs!) and crops being more susceptible to pests and diseases. A vicious cycle is created and the plantation enters the “pesticide treadmill”. Meaning more and more external and costly inputs are needed to keep the system going.

The use of herbicides, if well-applied, offer some advantages to the farmer; however, it is important to emphasize the need to use other methods to reduce the dependency on herbicides and associated problems, e.g., herbicide resistance.

To protect soil fertility (and therefore have a stable and increased crop production), ecosystem services, and human and environmental health, there is a need to reduce and gradually overcome the dependency on herbicides and other pesticides. The key is to invest in sustainable agriculture strategies⁹, like Integrated Weed Management.

⁸ <http://www.fao.org/3/a0884e/a0884e.pdf>

⁹ https://www.pan-europe.info/sites/pan-europe.info/files/public/resources/reports/Alternative%20methods%20in%20weed%20management%20to%20glyphosate_PAN%20Europe_171026.pdf



3.3 What is Integrated Weed Management (IWM)?

Integrated weed management is the use of multiple strategies to manage weed populations in a manner that is economically and environmentally sound. The use of IWM may help to reduce the use of herbicides, thus improving the productivity (cost-benefit ratio). Methods include cultural, mechanical, chemical, and biological. These methods can be integrated according to the locally problematic weeds. The application of more than one control measure will greatly depend on the type of weeds present and their density. It is important to always keep in mind local geographic and climatic conditions, soil texture and profile, irrigation practices, topography and cost, when choosing the control practices.

As with Integrated Pest Management (see the guidance), it can also be divided into prevention, monitoring and intervention.

- **Preventive** practices to reduce weed germination.
- **Monitoring** - observation and identification of weeds throughout the process.
- **Intervention** - Physical control of weeds (mechanical, thermal), and as last resort spot applications of herbicides if necessary.
- Please keep in mind that an IWM strategy is not fixed, but it needs to be adjusted according to the context-specific requirements and from year to year

Prevention

Prevention is better than cure: it is the most effective method for dealing with weeds.

Step 1: Get to know your weeds

Preventing the establishment of new weeds and existing weeds from producing seed are the most cost-effective methods of weed management

A successful weed management approach should take into consideration the biological and ecological characteristics of weeds that are present in the farm and understand how their presence can be regulated by agronomic/agricultural practices.

It is crucial to have an idea of the composition of weed species in the farm. The correct identification of the species is indispensable in evaluating the weed population.

Weeds can be classified in numerous ways. Sometimes they are classified as broadleaves and grasses. Another common way to categorize weeds is by their lifecycle – annuals, biennials, and perennials.

We recommend you separate the weeds in your farm in two groups: noxious and good. Noxious are aggressive highly competitive weeds, and "goods" are the ones that bring benefits to the farm.

Knowledge of the biology of weeds and losses caused by them is vital for developing appropriate weed control strategies. Above all to reduce the seed bank of noxious weeds in the soil.

It is recommended to list the top 3-5 key species and make maps of their location in the farm. Help with the identification of weeds can be obtained from local advisors, apps or on the internet. In many countries there are locally available crop specific manuals.

Step 2: Keep noxious weeds at bay

Weeds are naturally dispersed by wind, water, birds and animals. However, human activities contribute with a much larger proportion of spread compared to natural dispersion. Meaning that the spread of weeds in the farm can be reduced by proper planning.

When moving equipment or animals from a weed-infested field clean the tools and the feet of animals to stop spread, and pay special attention to seed banks of noxious weeds that can form along fences, farm borders, canals etc.



Another strategy is not to leave patches of bare soil. Noxious weeds will tend to colonize these empty areas. A strategy is to keep a permanent live cover with good weeds.

Finally, closely monitor new plants in the nursery to prevent introducing weeds as small plants or seeds that are in the substrate of the plants in the nursery.

Monitoring

Monitoring fields is a key component of an integrated weed management system. It allows farmers to make decisions about weed control practices that will be most effective in specific fields. Detection of new weeds and those that escaped previous control efforts is an important component of a weed management plan.

The collection of data on the composition, distribution and number of weed species is useful in:

The short term it helps to make immediate weed management decisions to avoid crop losses.

The long term because records tell the farmer how effective the weed control practice or strategy is

Note: we strongly encourage you to set up a monitoring and record system of the weeds in the farm. Records over a period will show the kind of weeds present and help determine the most effective control strategy.

How to monitor

Walk a chosen plot in the farm and use visual inspection. Record and map infestations (noting their location), paying particular attention to noxious and perennial weeds.

It is very important to regularly collect data on the following:

- The composition of weed species in the farm (The prior correct identification of the species is crucial);
- The general weed cover.
- The cover of the most abundant weed species

Follow a similar data collection sheet to monitor the weeds in the farm:

Plot number: _____	Date: _____
Soil surface texture: sandy___ loamy___ clay___ other_____	
Weed control method used: IWM_____ herbicide only_____ mechanical_____	
Stage of growth of most important weeds (list weed species):	
1.	
2.	
3.	
4.	
5.	
Degree of infestation (what percent of total vegetation on the site is weed species) (list weed species)	
Total area sampled _____ This is a key area because _____	
<1%)	
1-5%	
5-25%	
>25%	
Where are the weeds located (add sketch of plot)	



Intervention

Intervention means that the time to control has come due to the high prevalence of noxious weeds.

Common methods used for weed control are

- **Cultural** methods like crop rotation, land preparation, use of cover crops, multicropping, mulching)
- **Mechanical** methods like hand or mechanical weeding
- **Biological** methods in the form of introduction of exotic natural enemies and increasing the population of already existing natural enemies. Although they exist they are rarely use commercially (and therefore will not be covered in this guide);
- Chemical methods - use of herbicides

Cultural control

Refers to agronomic practices used to maintain field conditions in a way that are not conducive for weeds to become established or reproduce out of control.

Some methods are:

- Mixed cropping: or multi-cropping, inter-cropping, under-sowing or co-cultivation means planting two or more plants simultaneously in the same field, so that the properties of one plant facilitate the growth of the other. Benefits of mixed cropping include a balanced input and output of nutrients in the soil, suppression of weed growth, suppression of insects and plant diseases and an increase in overall productivity. In diversity lies the strength of the farm.
- Mulching: means covering the soil with plant residues or synthetic mulches. They work by preventing weed seed germination or by suppressing the growth of emerging seedlings. Mulches cut the supply of water and sunlight to the weeds and regulate the temperature of the soil (keeping the soil from excessive increases of temperature in hot climates). Mulches can be straw, plant residues or even synthetic.
- Appropriate fertilization management in the plantation to allow optimum crop uptake while starving the weeds can also be part of the cultural control practices
- **Living cover:** is a type of intercropping or a selection of good weeds in the field that guarantees the presence of a sort of carpet that will protect the soil, possibly providing it with nitrogen (e.g. leguminous plants) and that it is so dense that doesn't allow for the establishment of noxious weeds. Living cover planted in the inter-row of perennial crops is highly advisable for reducing weed infestation and avoiding problems of soil erosion. Living covers in the form of soft weeds has the benefit of reduced costs once they are established. The cover can be the habitat of natural enemies and pollinators that can benefit production of the crop.

Mechanical

This means the removal of the weeds using physical methods, e.g., the hands or the help of weeding machines.

The choice of methods depends on several factors like costs of machinery or labour.

On small areas or where sufficient labour is not a constrain, hand-weeding remains a possibility, particularly in high value crops. Mechanical weeders or tractor devices can be used in bigger plantations. But please keep in mind that tillage is not recommended as a weed management option.

Perennial weeds should be cut/uprooted before seed production, preferably during flowering and if cut, as close to the ground as possible.



Chemical

Chemical control refers to the use of herbicides, which are substances used to kill or suppress the growth of plants (Weed Science Society of America). A wide number of different types of herbicides have been produced and are used in the field. They can provide a convenient, economical, and effective way to help manage weeds but also have many unintended negative effects on the environment, soil health and people. Therefore, **they should not be used alone but integrated, only as last resort, with effective nonchemical tactics**. This is because the perfect herbicide does not exist. No single herbicide can control all weeds that can be present in a plantation¹⁰.

Please note: before deciding to apply herbicides in the farm, consult the list of prohibited and risk mitigation pesticides of the Rainforest Alliance (<https://www.rainforest-alliance.org/business/resource-item/annex-7-pesticides-management/>). And please also follow all the good pesticide management practices as described in the Standard.

3.4 An example of a good Integrated Weed Management strategy

Take this example for tea:

Weed control is among the main cost factors in tea production and in most tea estates the common practice is to eradicate by using chemical herbicides, all plant growth in a tea field, except the tea bushes and shade trees. With labour shortage getting more acute with each passing year, farmers have become heavily dependent on herbicides and see it to be the only option. The excessive use of herbicides, especially in the last three decades, is affecting the sustainability of the tea sector, particularly because of its effect on the quality of the soil. This can be seen in many ways:

1. Loss of vegetative cover (in and around the estates) and loss of biodiversity.
2. Compaction of soils that increases run-off and thus soil wash, leaching and reduced ground water recharge.
3. Formation of soil algae on bare soils that, in dry periods, peel off, exposing topsoil that then becomes susceptible to erosion by rain and wind. *(see the picture on the right)*
4. Effects on living organisms in soils (including archaea, bacteria, actinomycetes, fungi, algae, protozoa, and a wide variety of larger soil fauna such as springtails, mites, nematodes, earthworms, ants, insects, burrowing rodents....) is devastating.

This problem has contributed greatly to the decline in land productivity, threatening the industry's viability.

By eradicating weeds the competition of the weed with the crop is minimized. But it has become almost standard practice to brand the entire "weed" vegetation in a tea field as noxious and, as a result, the farmers tend to eradicate all other vegetation other than the crop. However, do we really need to control all "weeds" in the tea plots? And is weed control impossible without herbicides? It has been claimed that this would cause the "cost of production" to increase and profits to dwindle. But effective non-chemical/'low-chemical-use' weed control is certainly possible.

In a tea plantation if one wants to start with an Integrated Weed Management (IWM), the principle here is to first categorize weeds into 'noxious' and 'soft & more acceptable'. Then try to uproot (or spot-spray with herbicides) the noxious ones to reduce their numbers and promote the proliferation of the softer weeds. The increase of soft weeds will reverse the current management system which has made the weeds predominantly noxious and requiring increasing use of herbicides.

¹⁰ See page 38 onwards of: <https://growiwm.org/wp-content/uploads/2019/11/IWMguide.pdf?x60544>



Once "soft" weeds are carefully managed, they will form a thick ground cover that will compete out the noxious weeds, minimizing soil erosion and land degradation. The soft weeds are cut (after seed formation so that they can spread and add to the ground cover) at regular times and the cuttings are left as mulch in the field, particularly around the tea bushes. This biomass provides additional soil cover but also nutrients to the tea bushes. By this combination of practices, we can convert the weed control practice to genuine **weed management**.

Monitoring:

To find out if there is progress in terms of weed control, it is recommended that in such a management system in tea, the following parameters are collected:

- Get baseline data collected on all soil parameters (including microbial, percolation rates, soil compaction) (if possible). Periodically this will be repeated to see changes.
 1. Costs (man-days, materials, inputs),
 2. Record the species of weeds at the start and every three months.
 3. Record crop and crop patterns, general observation on pest and disease incidence

Advantages of having such system:

- Reduced incidence of noxious weeds → reduced herbicide use and costs
- Soil protected from rain, sun, wind and compaction → less erosion
- Huge increase in Organic Matter at very low cost → increased soil fertility → reduced application of chemical fertilizer
- Protect/increase soil life - insects, fungi, microbes, etc. → increased soil fertility → reduced application of chemical fertilizer
- More natural enemies (predators, parasites) of pests and more alternate food for some pests → reduced incidence of pests → reduce use of pesticides
- The natural selection of noxious weeds that takes place with repeated herbicides does not take place → reduce development of herbicide resistance

Besides, certain soft weeds can be used as food or for medicinal purposes. Eliminating the blanket application of herbicides will increase the presence of these weeds.

This IWM method was originally developed in India but became more widespread. This weed management system was introduced to Sri Lanka, Vietnam and China as well as the Assam and Darjeeling regions of India. In all these countries, but particularly in Sri Lanka and Sulawesi, smallholder farmers reacted very positively to the method.



4 COFFEE SPECIFIC GUIDANCE

Disclaimer

This crop specific IPM guidance does not intend to cover all possible pests per crop. The intention is to present the most common pests /diseases that affect certain crops in several regions worldwide.

Introduction

It is important to realize that the **coffee plant** is only **one element** of the complete coffee ecosystem. Every part of the ecosystem plays its part and so other elements of this need to be considered.

General information

Coffee (arabica and robusta) Recommendations		
Choice of adequate site for the crop		Subtropical and equatorial regions at higher altitudes that provide adequate rain fall and moderate temperatures. Robusta coffee is better suited to higher temperatures than Arabica. Shade conditions that mimic the original coffee forest conditions and provide sufficient shade during the hottest time of the day but don't produce an overly wet microclimate are ideal for high quality coffee.
Growing conditions for Arabica	Altitude	Above 1000 meters above the sea level (m.a.s.l.) up to 2500 m.a.s.l. (frost line) depending on latitude
	temperature	optimum daily temperature: 15° - 25°C.
	Rainfall	>1000 to 1500 mm annually evenly distributed over 7 months per year, with a dry, stress period afterwards to induce a uniform flowering
	Slope	Above 15%
Growing conditions for Robusta	Altitude	200 m.a.s.l. – 1000 m.a.s.l.
	temperature	20° to 30°C
	Rainfall	1000 – 3000 mm annually distributed over 9 months per year with a well-defined wet coffee growing season and a dry and warm maturation season.
	Slope	Minimal slope > 7% slope
Choice of healthy crop varieties suitable for the site		Preference should be given to resistant varieties where possible. Bourbon Pointu/Laurina e.g., is known to be very susceptible to leaf rust
Maintenance of soil health and fertility		Weakened plants not only produce a poor crop but are also more susceptible to pest and disease attack. Ideally soils are tested once per year before flowering and the recommended type and amount of input is applied. For every 1 ton of green bean removed from the plants, appr. 40 kg N, 2.2 kg P and 53 kg K must be replaced annually ¹¹ . Organic manure applications alongside inorganic fertilizer applications increase the uptake rate for nutrients. Recommended pH (H ₂ O) range: 5.5 - 6.0, if soil acidity is below this range, application of calcium is recommended to facilitate uptake of P and other nutrients. (For more details, please refer to the Soil Guidance document).

¹¹ Fertilization rates need to be calculated by taking soil type, SOM levels, soil nutrient levels and average loss rates into account. Average loss estimate: N = 30-70% (higher at higher temperatures, and if exposed to O₂ and H₂O), P = 50-100% (higher at low pH and high Al or Fe levels in the soil), K = 30%, Ca = 10%, Mg, Cu, Fe, Zn, B = 25%



<p>Maintenance of adequate soil organic matter (SOM) levels</p>	<p>Adequate SOM of 1 – 3 % is necessary to sustain beneficial microorganisms' levels, ensures good drainage (coffee is sensitive to water logging), as well as adequate water retention levels. To increase and maintain adequate SOM levels frequent additions of animal or compost manure are necessary as well as mulching or the use of cover crops with suitable materials (e.g., leguminous crops or even a weed like <i>Paspalum conjugatum</i>)</p>
<p>Maintenance of adequate microclimatic conditions in the plantation</p>	<p>Creating a microclimate in the plantation that is favorable for the coffee variety grown and unfavorable for pests and diseases can be a critical prevention factor or at least reduce the severity of an outbreak. This is especially important during unusually dry and hot seasons, which may more frequently occur due to climate change in some areas. This can be achieved with adequate shade levels, but also through soil covers in form of mulch or cover crops (mixed cropping). Mulch is kept away from the base of the plant to reduce the risk of disease. Mulch is re-applied at the end of each rainy season. Beneficial insects, such as bees and natural enemies, can be attracted to the area by allowing patches of indigenous flowering plants to grow in the plantation, creating a more diverse and resilient ecosystem as a habitat for them to proliferate. For the same reason, selective weeding is encouraged. Selective weeding means eliminating the most invasive weeds, keeping low & slow growing weeds if possible Leguminosae with small roots, which in the end will look like a green carpet on the farm and will conserve soil moisture as well as prevent other weeds to grow, reducing the need for herbicides.</p>
<p>Maintenance of adequate shade levels</p>	<p>Shade levels of 15% - 50% are recommended, depending on the life zone. Shade protects young coffee plants from drought stress and over exposure to sun, which causes yellowing and death of leaves, tree overbearing and/or dieback in older trees. Too much shade however can reduce flowering and create a too humid microclimate as which can increase fungal diseases. Therefore, the shade level needs to be managed closely according to the local climatic conditions as well as pest and disease pressure. Leguminous shade like <i>Erythrina subumbrans</i>, <i>Gliricidia sepium</i>, <i>Cassia siamea</i>, or <i>Albizia polycephala</i>, <i>Albizia coriaria</i> can also contribute to soil fertility.¹² Suggested spacing for smaller, deciduous trees like <i>Erythrina</i>, <i>Gliricidia</i>, and <i>Cassia</i> is 5 x 5 m (400 trees/ha), while that of larger timber trees a is 10 x 10m or more depending on canopy size (max. 100 trees/ha) planted within the coffee rows. Lower branches need to be regularly removed.</p>
<p>Timely and adequate pruning and desuckering</p>	<p>Diseased plant material must not remain in the plantation as it provides feeding and breeding ground for pests and diseases. Injuries caused by inadequate pruning or broken are vulnerable to fungal infections.</p>

The free mobile app "HabitApp" helps to give an instant reading of coffee shade cover. It can be downloaded through the following link: [HabitApp - Apps on Google Play](#)

¹² Availability and suitability of tree species need to be checked with competent local technicians or research centers.



4.1 Common coffee pests

Key:

Pest type	Life stages of the pest that cause damage
	life stages of the pest that do NOT cause damage

Grain/bean borers and Weevils (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Egg	< week	inserted into the seed/berries/beans
	Larva	2 - 3 weeks	inside the seed/berry/bean
	Pupa	4 - 9 days	inside the feeding chamber
	Adult	Few days up to 5 months	moving around to find seeds/berries/beans



Coffee berry borer (*Hypothenemus hampei*)



CBB grubs inside the berry



Berries damaged by CBB

i



Coffee berry borer (CBB) (*Hypothenemus hampei*)

- Most serious pest of coffee. Tiny (1.5 to 2.5 mm long), cylindrical black brown beetle. Females emerge from infested berries left on the trees and on the ground and bore tunnels and chambers into berries of around 90-100 days old to lay eggs. After hatching, larvae (grubs) feed inside the beans, rendering them unsuitable. Pupation and adult development take place in the berry. There are 10 females per every male.
- **Symptoms:** One or more small round holes near the apex of the berries with brown frass over the holes. Berries show a distinct blue-green staining. When cut open the seed reveals the female or eggs, grubs, pupae and new young adults.
- **Damage:** Crop losses from 50-100% of berries attacked if no control measures are applied. If consignment is not dried properly CBB will continue breeding in the stored crop. Coffee berry borer damage also encourages secondary fungal infection.
- **Favored by** a too low altitude (high temperatures), abandoned/infested plantations nearby, as well as over-ripe berries left on the tree or ground.
- CBB survives between cropping periods in old dry berries remaining on the tree and ground.
- **Prevention:** Reduce shade if microclimate is too wet. Prune properly and timely. Heavy shade and/or inadequately pruned coffee cause unfavorable conditions for the natural enemies of the berry borer.
- **Behavioral control:** Starting 8 weeks after flowering use red multi-funnel traps baited with a 1 : 1 mixture of ethanol and methanol at 0.5 doses or commercial BROCAP traps¹³ to attract mobile females before they bore into berries.
- **Mechanical control:** Sanitation. Remove infested berries.
- Harvest and collect all coffee berries on trees as well as dropped berries on the ground; Pick berries fortnightly in infested areas.
- **Biological control:** Parasitoids like *Cephalonomia stephanoderis*, *C. hyalinipennis*, *Prorops nasuta* or *Phymastichus coffea*; fungus *Beauveria bassiana* using a dose of 10¹⁰ to 10¹² spores per coffee tree (especially effective in humid conditions).
- **Chemical control:** Neem products sprayed during early berry development may be applied to repel female borers. Once the female has penetrated the berry chemical control is not effective.
- Also *Milletia pinnata* on its own and as a combination with Neem works well for managing pests
- **Threshold level:** Sample monthly from eight weeks after flowering until harvest (>32 weeks). Randomly select 30 trees for every 5000. Select a branch in the middle of a tree, containing 30-100 green berries and examine all for coffee berry borer holes. Calculate percentage infestation ($100 / (\text{total green berries} / \text{infested berries}) = \% \text{ infestation}$). Another sampling method is using the Brocap trap
- Start intervention (like crop sanitation) when infestation rate is > 2-5%.

¹³ <https://www.cirad.fr/en/innovation-expertise/products-and-services/brocap-r-near-processing-and-coffee-washing-areas>.



Thrips (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Eggs	7 days	Inserted into plant tissue
	Nymph	3 weeks	Before morphing into adults nymphs hide in the ground without feeding
	Adult	< 30 days	Underside of leaves

 <p>Coffee thrips (<i>Diarthrothrips coffeae</i>) on the underside of a leaf</p>	<p>Coffee thrips (<i>Diarthrothrips coffeae</i>) Minute (1.5mm) slender insects scratching and sucking on leaf tissue, during heavy infestation also berries. Nymphs spend the last stage before maturing inside the ground around the tree.</p> <ul style="list-style-type: none"> • Symptoms: Affected leaves show yellow-white patches. Leaves might shrivel and die. • Damage: Heavy infestation, cause death of leaves or total leaf drop. • Favored by drought and high temperatures. repeated use of Carbaryl or other insecticides that kill predatory mites. • Prevention: Maintain adequate shade tree cover. Mulching reduces thrips considerably especially during the dry season. Remove infested leaves. • Mechanical control: use of blue sticky traps • Biological control: Predatory mites that breed in areas of natural vegetation are good natural enemies. Also predatory mites are commercially available. they should be introduced at the beginning of the crop season and released several times over the season. Minute Pirate Bug species are also very effective in controlling thrips. • Chemical control: Horticultural oil or oil-soap solution can be sprayed to suffocate the pest. • Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard. • Threshold level: 1-2 per leaf during drought and 2-3 during rains. Release of predatory mites or other control methods
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Moths and Butterflies (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Egg	1 - 3 weeks	On the surface or inserted into host plant
	Larva	3 - 4 weeks	Feeding on or in tissue of host plant
	Pupa	1 - 2 weeks	Hanging from the host plant or rolled up into a leaf. Some pupate in the soil.
	Adult	< 1 month	Mobile winged



Coffee leafminer moth *Prophantis smaragdina* damage



Coffee Leafminer moth (*Leucoptera coffeella*)



Coffee Leafminer moth (*Leucoptera coffeella*) damage



Coffee leafminer cocoon

Coffee leafminer (*Leucoptera* spp.) Coffee leafminer moth (*Prophantis smaragdina*)

- **Symptoms:** The mines of *Leucoptera meyricki* caterpillars are initially separated eventually form one large mine. The caterpillars of *L. coffeella* produce one communal mine, which appears as irregular brown blotches on the upper side of leaves.
- **Damage:** The mining activity causes a reduction of the active leaf surface, reducing assimilation. Attacked leaves are usually shed prematurely.
- **Favored by** hotter and drier weather.
- **Prevention:** Intercropping with *Artemisia* sp drastically reduces the incidence of coffee leafminer. First infested leaves can be removed and destroyed manually. Provide sufficient room for beneficial insect populations in form of indigenous flowering plants and thick mulch layers.
- **Biological control:** Parasitic wasps, which occur naturally in the field, control larvae. Predacious mites feed on leafminer eggs. Entomopathogenic fungi can also control the pest.
- **Chemical control:** Chemical control is difficult as the damage causing caterpillars are protected inside the leaves, instead it will only damage beneficial insect populations. It is therefore not recommended.
- Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** If the tree is shaken vigorously and more than 35 moths are seen, the yield of coffee can be affected.
- A density of 4 mines per leaf causes leaf-drop and may cause yield loss of 50%.



Nematodes (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Cyst	Several weeks	In the soil near roots, or inside the roots' cortex, usually host specific
	Egg		
	Juvenile		
	Adult		
 <p>Root-knot nematode damage on coffee root system</p>		<p>Root-knot nematodes (<i>Meloidogyne</i> spp., <i>Pratylenchus coffeae</i>, <i>Radopholus similis</i>, <i>Rotylenchus</i> spp.) Attacks the roots, disrupting root function.</p> <ul style="list-style-type: none"> • Symptoms: Stunted, poorly growing plants with yellowing, droopy leaves. Infected root systems show characteristic knots. • Damage: Reduces the ability of the coffee tree to absorb water and nutrient, causing a decline in the general health and vigor of the tree also impacting yield and bean quality. • Yield may be reduced by 20-25%. Plants can eventually succumb to nematode infestation. • May cause secondary fungi infections, such as <i>Rhizoctonia solani</i>. • Caused by transport of diseased plant materials between farms, or by downstream water. • Prevention: Ensure the use of nematode-free plant material or resistant or tolerant rootstocks. Soil used in the nursery for seedlings can be heat, treated with calcium or ashes, or mixed with Entomopatjogenic fungi like <i>Beauveria bassiana</i>, <i>Metarhizium anisopliae</i> or <i>Paecilomyces sp</i> sterilized prior to planting. • Mixed cropping with groundnut or maize, which are both poor or non-hosts to <i>M. incognita</i>, have been used to manage this nematode. • Adequate soil fertility and organic matter may assist the trees to partially overcome the effects of nematode attack and thereby help to minimize impact on yield. • Chemical control: is extremely expensive and not economically effective if larger areas have to be treated. Best treatment is during nursery. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard. • Threshold level: ranges from 100 to 5000 nematodes per kg of • soil depending on the nematode genera, and needs to be determined by a soil test. 	



Scales (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Eggs	< 1 month	Protected under the female scale
	Nymph	< 2 months	Mobile crawlers
	Adult	♀ dies after laying eggs	Immobile ♀ along midrib of leaves, twigs, branches, stems. ♂ mobile with wings.



Soft green scale (*Coccus viridis*) along leaf veins



Soft green scale on green berries



Soft green scale adults and nymphs on young stem and bud

Soft green scale (*Coccus viridis*) Common, depending on location, minor to serious pest. More serious on transplanted seedlings during the first 2 years. Immobile and usually found settled at underside of leaf, close to central vein or near tips of green shoots. Flat and oval scales (about 3 x 2 mm). They are often tended and spread by ants. Their exuded honeydew encourages the development of sooty black mould.

- **Damage:** sucking will lead to decreased yield and low quality coffee beans. Excessive feeding causes wilt and can result in the death of the tree.
- **Favoured by** low humidity and long, hot dry seasons and too little shade.
- **Prevention:** Only use scale-free seedlings for planting. Improve shade to create a more humid microclimate. Control ants e.g. by placing sticky bands around the stems. Absence of ants encourages control by naturally occurring enemies. Planting pumpkins as a cover crop encourages beneficial insect populations. Avoid alternate hosts of the scale.
- **Biological control:** predators (*Chilocorus melanophthalmus*, *Chilocorus nigrita*), *Azya luteipes*, *Chilocorus cactii*; parasitic wasps (*Coccophagus cowperi*, *Diversinervus stramineus*, *Metaphycus stanleyi*, *Metaphycus baruensis*); parasitic fungus (*Verticillium lecanii*), particularly effective in the rainy season.
- **Chemical control:** Weekly spray applications until scales disappear of either Neem products, horticultural oil (200ml/20l water (or homemade oil-soap solution). Chili extract mixed with soapy water. Indian soapnut tree (*Sapindus Mukorossi*) aka Indian Soapberry) these nuts soaked for 48 hours produce soap that also has insecticidal properties. This combined with Neem/*Pongamia pinatta* works well against scale insects & mealy bugs.
- Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** >10 leaves infested with 1+ scales



Bugs (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Eggs	5 - 26 days	Inserted into plant tissue of a host plant
	Nymph	10 - 30 days	Young nymphs often aggregate
	Adult	Varied	Mobile, often host specific but also hide in crevices of bark, structures, etc.

 <p>Coffee lace bug (<i>Habrochila placida</i>)</p>	<p>Coffee lace bug (<i>Habrochila placida</i>) Sporadically severe pest.</p> <ul style="list-style-type: none"> • Symptoms: Infestation often starts on the lower leaves of a small group of coffee trees. Small winged bug (4 mm long). Both adults and nymphs suck on the leaves. Nymphs always feed in groups on the underside of the leaf. • Damage: Their feeding causes yellow patches on the leaves. The underside of affected leaves is covered with black spots from their excretes. Severe attack causes leaves to turn yellow and drop-off. • Favored by hot dry weather and injudicious use of pesticides. • Prevention: Avoid use of broad-spectrum pesticides to protect natural enemies. Maintain soil fertility by regular manure additions and fertilization as needed. • Biological control: Predatory mirid bug, (<i>Stethoconus</i> sp.), parasitic wasps, predatory assassin bugs, lacewing larvae, lady beetles, jumping spiders, pirate bugs, and predatory mites. • Chemical control: Insecticidal soap, Horticultural Oil, Neem oil, and pyrethrin products. • Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides applications, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard. • Threshold level: For early detection sample bushes at random, beating the bush and collecting the dislodged lace bugs on a white sheet of nylon. Alternatively green sticky plates can be used for monitoring. Intervention is recommended at 2 lace bugs per trap/day.
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Antestia bugs (*Antestiopsis spp*)

Antestia bugs (*Antestiopsis spp*) is a major pest of Arabica coffee in East Africa.

- **Damage:** Adults and nymphs feed on beans causing rot through infection *Nematospora coryli fungus*. Also attacks flower buds which turn black and fail to set fruit. Attacked branches grow side shoots (fan branching). Dried beans show "Zebra" beans produce poor quality coffee (potato taste) and are possible avenues for fungal infection.
- **Favored by** dense foliage. Another important role might be played by alternative host plants, especially uncontrolled herbaceous weeds near the coffee trees.¹⁴
- **Prevention:** regular and timely pruning and desuckering.
- **Biological control:** Naturally occurring parasitic wasps attack antestia eggs. Attacked eggs are black while normal eggs are white.
- **Chemical control:** Spraying with Neem extracts.
- Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** > 2 bugs / tree

¹⁴ For an extensive list of possible alternative host plants refer to Régis Babin et al, "The Antestia Bug Complex in Africa and Asia", in: "Invasive Stink Bugs and Related Species[...]", Chapter: 10, Publisher: CRC Press, pages 465-494



Stemborer beetles (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Egg	2 weeks	Inserted into the host plant
	Larva	0.5 - 3 years	Inside woody parts of the host plant
	Pupa	≅ 4 weeks	Inside the host plant
	Adult	< 4 months	Mobile, winged beetle in search of host plant and mating partner



White Stemborer (*Xylotrechus quadripes*) adult



White Coffee Stemborer (*Monochamus leuconotus* / syn. *Anthores leuconotus*)



White Stemborer larva



White Stemborer damage on bark

White Stemborer (*Xylotrechus quadripes*) and **White Coffee Stemborer** (*Monochamus*/ syn. *Anthores leuconotus*)

- **Symptoms:** Frass (sawdust-like) on the ground, missing bark. =
- **Damage:** Leaves wilt and branches or entire trees die.
- **Favored by** insufficient shade, low altitude and weak seedlings. Coffee trees cultivated on shallow or eroded soils or near shade trees are more likely to be attacked. Younger trees are also more prone to damage.
- **Prevention:** Plant at adequate altitude (> 800m). Do not plant seedlings with twisted/deformed taproots. Ensure good soil fertility to keep trees strong. Remove and burn infested trees or branches.
- **Biological control:** None commercially available yet. Natural enemies include woodpeckers and ants. Larvae get attacked by the parasitoid *Aprostocetus* ssp. and the fungus *Beauveria bassiana*. Smearing cooking oils or animal fats on the holes made by larvae of the coffee stem borer attracts ants to feed on oils and fats and eventually enter and kill stem borer larvae in the tunnels.
- **Chemical control:** as the feeding are hidden inside the stem they are impossible to control chemically. Timely removal of early infestation is the best control method.
- **Threshold level:** Farmers should be alert with the first sighting of stemborers. At a level of 2 to 3 stemborers / tree interventions are necessary.



	Stage	Duration (depends on species and environmental conditions)	Habitat
Mealy Bugs (General Info)	Eggs	1 week	In a sticky sac on axils of stems or leaves
	Nymph	1 - 2 months	Mobile crawlers
	Adult	Female dies after laying eggs	Males are mobile with wings. Female are sessile on shoots, leaf axils and midribs or roots.



Mealybugs (*Planococcus spp*)



Mealybugs (*Planococcus kenyae*) affecting coffee berries

Mealybugs (*Planococcus spp*, *Dysmicoccus spp.*, *Coccidella spp.*, *Ferrisia spp.*, *Formicoccus spp.*, *Nipaecoccus spp.*, *Rhizoecus spp.*, *Puto spp.*, *Neochavesia spp.*, etc).
Common pest, often tended by ants.

- **Damage:** Infected plants shed their leaves. Heavy infestation can cause plant death. Secondary infection with sooty black mold is common. Negatively impacts coffee aroma (off-flavors, acidity) and quality.
- **Favored by** warm weather and drought or high humidity and cold. Often found in areas with high insecticide (especially organo-phosphate) usage, as natural enemies have been eradicated. Excessive shade tree removal causes flare ups.
- **Prevention:** Control ants. Stop ants from climbing up into the tree by placing a sticky band around the trunk. This will help natural enemies to control smaller mealybug colonies. Maintain adequate shade levels (25-30%). Manage a healthy microclimate in the plantation (mulch).
- **Biological control:** Best control is achieved by the predatory *Cryptolaemus montrouzieri* ladybug, whose nymphs resemble the mealybug. Recommended release rate: 5 beetles/infested Robusta coffee tree, 3 beetles/infested Arabica coffee tree.
- In India, the caterpillars of *Spalgis epeus*, which also resembles a mealybug, is the most common mealybug predator. Natural enemies include also different species of parasitic wasp and lacewings.
- **Chemical control:** Homemade neem oil-soap solutions can be sprayed to suffocate the pest.
- Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** Infested trees can be treated individually by spot applications.



Root Mealybug (*Planococcus* ssp.)

Root Mealybug

Dysmicoccus cryptus, *Planococcus* ssp.)

In some cases associated to a soil fungus (*Polyporus coffeae*) and ants.

- **Damage:** Attacks the roots of coffee, sucking sap from the roots causing wilt like symptoms - yellowing and drooping of leaves and death of entire trees.
- **Favored** by old, weak or trees stressed by inadequate nutrition or drought. Possible alternative hosts are other stressed plants, and turf grasses.
- **Prevention:** Inspect roots of seedlings before transplanting. Only transplant strong and healthy seedlings free of pests. Improve soil nutrient status by manure and fertilizer additions. Apply mulch to avoid stress in the root area and to promote the growth of fungal mealybug pathogens.
- **Mechanical control:** Uproot and burn affected or dead trees.
- **Biological control:** The fungus *Beauveria bassiana* and the nematode *Steinernema carpocapsae* are known to cause high mortality in short time of adult female root mealybugs. They need certain humidity levels in the soil.
- **Chemical control:** Pyrethrins or pyrethroids may show some sort of efficacy but their applications should be avoided if possible. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** Monitor for ant activity in the stem/root area. Every infested tree needs to be uprooted or treated.



4.2 Common coffee diseases

Most coffee diseases are caused by pathogenic fungi and less frequently by bacteria and viruses. Root rot disease, rust, and coffee berry disease can attack healthy trees without any particular physiological weakness, whereas most of the other diseases of economic importance only occur in trees that are physiologically weakened (Fabienne Ribeyre, CIRAD, 2012)

4.2.1 Coffee leaf rust (CLR)



Coffee leaf rust CLR (*Hemileia vastatrix*)



Defoliation and die-back caused by **Coffee leaf rust**

Coffee leaf rust CLR (*Hemileia vastatrix*) fungal disease that attacks mostly older leaves.

- **Symptoms:** Rust lesions show as yellow – orange spots on the underside of the leaf that coalesce as the disease progresses.
- **Damage:** Can lead to defoliation of the plantation if not controlled. The disease has a weakening effect on the trees over successive seasons. Severe infestation can cause up to 75% yield losses and reduced coffee quality.
- **More prevalent in** *C. arabica* plantations grown under humid conditions at lower altitudes (1000m.a.s.l. - 1500 m.a.s.l.).
- **Favored by** humid or wet conditions (e.g. night temperatures > 15°C), when leaves remain wet for 3+ hours. Low soil fertility, low pH increases the damage.
- **Prevention:** Use of resistant varieties (please consult your local agronomic extension officer or research institute to choose the correct one).
- Optimize spacing and pruning to improve aeration and avoid humidity remaining on the leaves for prolonged periods, which encourages fungus growth.
- **Biological control:** Naturally occurring enemies of CLR are parasitic pathogen like *Verticillium lecanii* and *Darlucina ssp.*, Some insects and mites also feed on the rust spores but none of these are yet commercially exploited.
- **Chemical control:** commonly controlled by fungicides, which are however very expensive. Application before the start and during the early period of the rainy season. The fungicide has to be reapplied after each rain. Care must be taken to apply the fungicide to the underside of the leaves.
- Applications of copper have been used in coffee producing countries to control the disease.
- **Threshold:** 1% infected leaves necessitates cultural and hygiene control actions. 20% infected leaves is regarded as severe infection.



4.2.2 Coffee Wilt Disease (CWD)



Coffee Wilt Disease CWD (*Fusarium xylarioides*) showing on the the left



Prematurely ripened berries and blackened branch due to CWD



Typical blue-black discoloration underneath the bark of a stem infected by CWD

Coffee Wilt Disease (CWD), also known as 'fusarium wilt', affects arabica and robusta coffee, as well as wild coffee species. It is a vascular wilt disease caused by the fungus *Fusarium xylarioides*.

- **Symptoms:** Drooping of the leaves is the first signs of CWD. The leaves are limp, yellow, then dry up and eventually drop off, leaving affected trees completely leafless. A unique symptom to identify CWD is a blue-black discoloration of the wood directly beneath the bark towards the base of the stem.
- **Damage:** The 'dieback' often starts on one side of the tree but rapidly spreads to the entire tree. Immature beans ripen prematurely, having a negative impact on aroma and bitterness.
- **Favored by** low pH, water logging, injuries to the roots.
- **Prevention:** Plant material must not be obtained from areas with known CWD infections. Only use disease-free seeds and material for cuttings.
- Infected trees must be uprooted and burned immediately. Regular inspections aid in early disease detection and help contain a spread of the disease. Affected areas should be taken out of coffee production for several years.
- **Chemical control:** unlikely to be effective as the pathogen lives in the soil or inside the plant, making it hard to target even with systemic fungicides.
- **Threshold level:** Immediate action required if symptoms are observed



4.2.3 Coffee berry disease (CBD)



Coffee berry disease (*Colletotrichum kahawae*)



Typical lesions and sporulation on green berries affected by CBD

Coffee berry disease (CBD)

which affects only arabica coffee. It is caused by the fungus *Colletotrichum kahawae* and is endemic to Africa.

- **Symptoms:** Berries at any stage become black, dry, wrinkled and decayed, with a hard skin. Berries are most resistant during the first month and when fully mature.
- **Damage:** mummified berries, which can cause considerable yield losses of up to 75% if not adequately controlled.
- **Favored by** humid conditions or high rainfall and temperatures around 22°C. Prevalent in areas with bi-modal rainfall patterns. Plantations with regular copper applications are more susceptible to CBD.
- **Prevention:** Use of resistant varieties like Ruiru 11, Hibrido de timor, Rume Sudan, 45 K7 and several Catimors. Planting at wider spacing and adequate pruning to prevent prolonged wetness and high relative humidity following periods of rainfall. For the same reason avoid too dense shade. All berries should be removed at the end of the cropping season as they act as a source of inoculum for the new crop.
- **Biological control:** Naturally occurring funguses and bacteria act as antagonists to CBD, but none are yet commercially available.
- **Chemical control:** Fungicides. Insufficient applications are more harmful than no application at all.
- **Threshold level:** No information available as effectiveness of fungicide use has not been proven yet.



4.2.4 American Leaf Spot Disease (ALSD)



American Leaf Spot Disease (ALSD) (*Mycena citricolor*) spots on leaves and green berries

American Leaf Spot Disease (ALSD) (*Mycena citricolor*) Fungal disease in the neotropics

- **Symptoms:** dry, brown spots on all above-ground plant parts.
- **Damage:** can cause significant defoliation, resulting in reduced growth, berry shedding and subsequently yield loss of up to 20 %, as well as reduced quality.
- **Favored by** coffee grown at high altitude, humid conditions, too much cloud cover (low radiation) and high shade levels. Also promoted by erratic climatic conditions and spread by lack of hygiene.
- **Prevention:** Adjust shade levels to reduce humidity. Hygiene is key in controlling this disease. Remove all inoculum sources.
- **Biological control:** Research regarding antagonistic Bacteria seems successful, but has not yet been commercialized.
- **Chemical Control:** Fungicides like Bordeaux mixture and other copper fungicides or in severe cases Triazole. Application of calcium hydroxide has been shown to suppress symptoms. (Rao and Tewari, 1988). Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** Hygiene measure and shade adjustment must start with the occurrence of first symptoms. Chemical control threshold level: 15 lesions/leaf.



4.2.5 Coffee brown-eye spot



Coffee brown-eye spot (*Mycosphaerella coffeicola* and *Cercospora coffeicola*) on leaves



Coffee brown-eye spot on seedling



Berry Blotch caused by *Cercospora coffeicola*

Coffee brown-eye spot (*Mycosphaerella coffeicola* and *Cercospora coffeicola*)

- **Damage:** Infected berries shrivel and ripen before the beans are mature, resulting in off flavors. Other fungi often invade the berries following infections of *Cercospora*.
- **Favored by** cooler, wet growing conditions above 600 m.a.s.l., under low shade, high humidity and rain, or warm temperatures and drought after flowering. Usually occurs in areas of poor nutrition (especially nitrogen and potassium deficiency) or insufficient shade.
- **Prevention:** Improve soil fertility and shade management. Improve aeration through adequate spacing and pruning that allows sufficient air movement. Avoid water-logging. Control competition from weeds through sufficient mulching or cover crops. Remove pruned materials from infected plants as spores remaining in the plantation will infect more plants. Increase shade density.
- **Chemical control:** 3 applications/month of copper products starting from flowering. Warning: copper overuse can cause copper toxicity in the soil and also be harmful to beneficial insects controlling coffee scales. Monthly applications of captafol (0.3% a.i.) are recommended for use in nurseries. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** 20% - 35% attacked plants



4.2.6 Bacterial Blight of coffee BBC



Bacterial Blight of coffee BBC (*Pseudomonas syringae* pv. *garcae*) symptoms on leaves



BBC symptoms on twigs and leaves

Bacterial Blight of coffee BBC (*Pseudomonas syringae* pv. *garcae*)

- **Symptoms:** Leaves dry up, roll inwards, but do not shed. Twigs die back as infection extends downwards from the terminal bud.
- **Damage:** Both, flowers and pin heads shrivel, turn black and the entire crop may be lost.
- **Favored by** cool and wet weather, injuries on the plant and high nitrogen fertilization rates.
- **Prevention:** Don't use seedlings or plant material from BBC prone areas. Avoid wounding the tree during pruning. Split N application or apply animal manure instead of N-fertilizer. Cut off and burn infected twigs and branches. Frequent de-suckering. Avoid pruning when trees are wet. Use resistant varieties.
- **Chemical control:** Copper based products are most effective but attention must be paid to toxicity of copper accumulating in the soil.
- **Threshold level:** Hygiene measures should be taken immediately on every infested tree.

Damping off



Damping off (*Phytophthora* spp)

Damping off (*Phytophthora* spp. or *Rhizoctonia solani*) is a fungal disease affecting seedlings in the nursery.

- **Symptoms:** Patches of young seedlings die quickly, their stems are dark and rotten.
- **Damage:** Economic loss due to seedling failure.
- **Favored by** wet soil, too much shade and high plant densities that prevent sufficient air movement.
- **Prevention:** Ensure seedbed conditions that allow sufficient drying of the soil. Space seedlings 2.5cm x 10cm apart. Don't reuse old soil as the disease is soil borne and can be carried over.
- **Chemical control:** Soil drenches with Benomyl are possible but often not warranted. Improving drainage conditions is usually sufficient.
- **Threshold level:** none, as disease kills and treatments can only be preventive.



Further Information

Rainforest alliance app on pesticides and its alternatives:

<https://play.google.com/store/apps/details?id=org.ipmcoalition.pesticidealternatives>

<https://apps.apple.com/app/id1461460997#?platform=iphone>

CABI and infonet biovision have both published comprehensive lists of coffee disorders, which can be found here: <https://www.plantwise.org/FullTextPDF/2018/20187800554.pdf> and here: <https://www.infonet-biovision.org/PlantHealth/Crops/Coffee#simple-table-of-contents-3>

KALRO has published a coffee growing manual that features East African coffee diseases and pest. It can be found here: http://www.kalro.org/sites/default/files/Coffee-Propagation_Production_Manual_13_Feb_2019_ed_LW.pdf

A very informative article by C. Staver, et all. on shade management in coffee plantations to control pests and diseases can be found here: <https://sites.evergreen.edu/terroir/wp-content/uploads/sites/134/2015/10/Designing-pest-suppressive-multistrata-systems-coffee.pdf>

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AVELINO, Jacques (CIRAD/IICA-PROMECAFE/CATIE)

LADERACH, Peter (CIAT)

COLLET, Laure (CIAT)

BARQUERO, Miguel (ICAPE)

CILAS, Christian (CIRAD)

Infonet-biovision

<http://www.fao.org/3/ae939e/ae939e0b.htm>

CABI - Plantwise Knowledge Bank

Georg Goergen/IITA Insect Museum, Cotonou, Benin

Kohler F, Pellegrin F, Jackson G, McKenzie E (1997) *Diseases of cultivated crops in Pacific Island countries*. South Pacific Commission. Pirie Printers Pty Limited, Canberra, Australia.

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5 TEA SPECIFIC GUIDANCE

Disclaimer

This crop specific IPM guidance does not intend to cover all possible pests per crop. The intention is to present the most common pests /diseases that affect certain crops in several regions worldwide.

General information

Tea (<i>Camellia sinensis</i> var. <i>sinensis</i> and <i>C. sinensis</i> var. <i>assamica</i>) Recommendations		
Choice of adequate site for the crop	Tea needs a moderately hot and humid climate which is found under cooler tropical conditions. Tea is a forest plant and grows best on cleared forest soils but does also well on any fertile soil, especially red soils as it tolerates high Aluminum levels well. Soils should be free draining with a depth of about 1.0 to 1.5m, which nevertheless provide sufficient moisture throughout the year. Close proximity to original forest helps provide an ideal microclimate as well as protection against wind. In the right agro-ecological environment it is not difficult to grow tea without the use of pesticides. Disease and pest pressure are a sure sign of inadequate growing conditions or wrong management.	
Growing conditions	Altitude	800 - 2000 m.a.s.l.
	Slope	Some slope is needed to allow for good drainage. 15 – 25° = very highly suitable gentle slope (>5–7°) = highly suitable very steep slope" (> 35°) unsuitable In relatively flat lands there has to be adequate drainage to drain out subsoil water
	Temperature	16 - 30°C with an average temperature of 21 – 26°C during the growing season
	Rainfall	1250 – 2000 mm, well distributed over 8-9 months/year
	Humidity	~ 80% throughout the year
Choice of healthy crop varieties suitable for the site	Preference should be given to varieties adapted to the climatic conditions of the location. <i>C. sinensis</i> , although lower yielding, is known to be a hardier, being more resistant to both cold and drought. For Kenya NGC15, NGC17, NGC19, C235, C357 were shown to be highly insect pest resistant. It is also recommended that a single clone should not exceed 10% of the plantation, but instead a blend of different clones be planted.	
Erosion control measures	Contour planting in single or double hedgerows. Deep cultivation or intensive weeding must be avoided as it would also damage the roots of the tea bushes. Weeds need to be controlled however, therefore soil cover should be planted between rows like: <i>Eragrostis curvula</i> , <i>Tephrosia candida</i> , <i>Crotalaria anagyroides</i> or <i>Crotalaria usaramoensis</i> . Adequate shade levels also regulate leaf temperature, add organic matter to soils, work as wind breaks, increase biodiversity, attract birds & suppress weeds.	
Maintenance of soil health and fertility	Weakened plants not only produce a poor crop but are also more susceptible to pest and disease attack. Ideally soils are tested once a year and the recommended type and amount of inputs are applied. Balanced nutrition(NPK),	



	<p>based on soil analysis, crop yields and the geographical location is recommended.</p> <p>Organic manure applications alongside inorganic fertilizer applications increase the uptake rate for nutrients.</p> <p>Recommended pH (H₂O) range: 4.5 - 5.0 (For more details please refer to the Soil Guidance document.)</p>
<p>Maintenance of adequate soil organic matter (SOM) levels</p>	<p>Adequate SOM varies with geographies and altitudes: whereas 1.2 to 3 % might be ideal for low altitudes 3 – 6 % is ideal for higher elevations. SOM helps sustain beneficial microorganisms' levels, ensures good drainage (tea does not tolerate water logging), as well as adequate water retention levels. To increase and maintain adequate SOM levels frequent additions of animal or compost manure are necessary as well as mulching (including with tea prunings left in situ). Leaf litter from shade trees also provides substantial amounts of SOM.</p>
<p>Maintenance of adequate shade levels</p>	<p>Shade levels of 20% - 50% are recommended. Shade is necessary to protect tea bushes from drought stress and over exposure to sun, which causes yellowing and or dieback. Too much shade however reduces production and can create a too humid microclimate as which can increase fungal diseases. Therefore the shade level needs to be managed closely. On the other hand is the dispersion of pathogens by rain-splash and wind minimized if the force of rain and wind is reduced by shade trees. Leguminous shade trees like <i>Erythrina subumbrans</i>, <i>Erythrina lithosperma</i>, <i>Gliricidia sepium</i>, <i>Cassia siamea</i>, or <i>Albizia polycephala</i> <i>Albizia coriaria</i>, <i>Albizzia chinensis</i>, <i>Albizzia Procera</i>, <i>albizzia odrotissima</i>, <i>albizzia chinensis</i>, <i>acacia lenticularis</i>, <i>dalbergia sericea</i> established at 7 x 10 m also contribute to soil fertility. Suggested spacing for larger timber trees like <i>Grevillea</i>, cypress or pine is 10-12 x 10-12m planted within the tea rows. For windbreaks banana or <i>Hakea salign</i> may be used. In the plains when young tea is planted it is advisable to have a quick growing temporary shade tree planted between the permanent shade species.</p>



5.1 Common Tea Pests

Pest type	Life stages of the pest that cause damage
	Life stages of the pest that do NOT cause damage

Tea Mosquito Bugs (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Egg	5 - 26 days	Inserted into plant tissue of a host plant
	Nymph	10 - 30 days	Young nymphs often aggregate
	Adult	Varied	Mobile, often host specific but also hide in crevices of bark, structures, etc.

 <p><i>Helopeltis antonii/theivora</i></p>  <p>Damage on leaf caused by Tea mosquito bug</p>	<p>Tea mosquito bug (<i>Helopeltis antonii/theivora</i>)</p> <ul style="list-style-type: none"> • Alternate hosts plants: Weeds like <i>Mikania cordata/micrantha</i>, <i>Bidens biternata</i>, <i>Emillia sp.</i>, <i>Polygonum chinese</i> and <i>Lantana camara</i>. Cashew, neem, moringa and guava. • Symptoms: Adult bugs and hairy orange nymphs suck the sap from fresh leaves and tender shoots, causing brownish-red necrotic spots. • Damage: leaves curl up, dry and die. • Active during early morning and late evenings and during the day on overcast days. • Favored by incomplete removal of stalks/breaking stalks during plucking. Tea mosquito bugs lay their eggs preferably on these broken ends of plucked shoots. Temperatures > 15°C. • Prevention: Collect and destroy bugs and damaged plant parts during the initial stages as best as possible. Suppress weeds through thorough mulching. Avoid planting China jats and susceptible clonal material like TV-1, P-126A in Mosquito bug prone areas. • Biological control: Parasitoids: <i>Mymarid</i>, <i>Erythmelus helopeltidis</i>. Predators: <i>Chrysoperla zastrowii sillemi/carnea</i>, <i>Mallada sp</i>, Predatory Lynx spider (<i>Oxyopes sheweta</i>), Reduviid bug, Praying Mantids. Pathogens: Nematodes (<i>Hexameris ssp.</i>), fungus <i>Beauveria bassiana</i> • Mechanical control: Skiff severely affected patches. Pluck hard removing all leaf above the plucking table and all affected leaf visible. Pluck on short rounds. • Chemical control: 'Spinosad', diatomaceous earth or pyrethrum sprays during early morning hours. Spraying with a 5% chloroform extract of <i>Pongamia pinnata</i>. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard. • Threshold level: 5% infestation or 8 adult <i>Helopeltis</i> bugs/2 m²
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Stemborer beetles (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Egg	2 weeks	inserted into the host plant
	Larva	0.5 - 3 years	inside woody parts of the host plant
	Pupa	≅ 4 weeks	inside the host plant
	Adult	< 4 months	mobile, winged beetle in search of host plant and mating partner

 <p>Shot-hole borer (<i>Xyleborus fornicatus</i>)</p>  <p>Typical Shot-hole borer damage on stem</p>	<p>Shot-hole borer (<i>Xyleborus fornicatus</i>)</p> <ul style="list-style-type: none"> • Symptoms: Bores typical “shot-holes” in the roots and the lower part of main trunk; frass protruding from the holes. • Damage: Larvae tunnel the woody parts of bushes. Crop losses of 18 – 40 % • A serious problem in low and mid elevation areas on badly draining soils. Weak host plants. • Prevention: Avoid water logging. Remove affected branches. Apply nitrogen and potassium at 1:2 ratio. Place 400 wilted stems of <i>Montanoa bipinnatifida</i> per ha to attract shot hole borer adults and burn regularly. Avoid susceptible planting material, like TRI2024 and TRI2025 clones in shot-hole borer prone areas. • Biological control: Spray <i>Beauveria bassiana</i> wettable powder • Chemical control: Cover main stem with Carbaryl paste. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard. • Threshold level: 15% infestation
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Mites (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Egg	4 - 5 days	Underside of leaves
	Nymph	5 - 6 days	Before morphing into adults nymphs hide in the ground without feeding
	Adult	2 - 4 weeks	Underside of leaves

  <p>Scarlet mite (<i>Brevipalpus californicus</i>) damage on tea leaves</p>	<p>Red spider mite (<i>Oligonychus coffeae</i>), Scarlet mite/tea mite (<i>Brevipalpus californicus</i>), Purple mite (<i>Calacarus carnatus</i>), Pink mite (<i>Acaphylla theae</i>), and Yellow mite (<i>Polyphagota rosnemus latus</i>)</p> <ul style="list-style-type: none"> • Symptoms: Damage usually shows first along the midrib, spreading along the veins. Leaves turn greyish or brownish-pale and brittle. • Damage: Nymphs and adults pierce the leaf tissue and suck sap plant loses vigor and infested leaves are no longer consumable. Severe infestation can lead to drying of leaves and defoliation. • Favored by drought and delayed plucking or over-plucking. Absence of shade. Temperatures above 25°C, low humidity; elevations below 1500.m.a.s.l. • Prevention: Improve microclimate and Soil Organic Matter levels to avoid drought stress. Increase shade levels. • Mechanical control: Remove all infested parts. • Biological control: Predatory mites (<i>Amblyseius ssp.</i>, <i>Agistemus ssp.</i>, <i>Zetzellia ssp.</i>, etc.) Predatory thrips (<i>Oligota spp.</i>), Pirate bug (<i>Orius ssp.</i>, <i>Wollastionella testudo</i>), Hover flies, Mirid bug, <i>Chrysoperla carnea</i>. Pathogenic fungi: <i>Penicillium ssp.</i>, <i>Aspergillus ssp.</i>, <i>Cladosporium ssp.</i>, <i>Botryosporium.</i>, <i>Verticillium lecanii</i>. • Chemical control: Horticultural oil or homemade soap-oil spray(white oil) • Threshold level: 50% infested leaves or 5 adult mites or 25 eggs per leaf
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Thrips (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Eggs	7 days	Inserted into plant tissue
	Nymph	3 weeks	Before morphing into adults nymphs hide in the ground without feeding
	Adult	< 30 days	Underside of leaves



Thrips (*Scirtothrips bispinosus*) damage



Thrips damage on leaf –lines parallel to the midrib

Thrips (*Scirtothrips bispinosus*)

- **Symptoms:** Leaf surface becomes uneven, curly and mottled exhibiting parallel lines of silver feeding marks on either side of the midrib.
- **Damage:** young nymphs and adults prefer to suck sap from young leave and buds plants lose vigor, leaves shrivel. Infested leaves become distorted, crinkled and unusable. At threshold level thrips may cause up to 13% yield loss. Virus vector.
- **Favored by** lack of shade, warm and humid conditions; in some growing areas dry weather is conducive to their growth
- Frequent copper applications.
- **Prevention:** Maintain optimum shade levels.
- **Biological control:** *Anthocoris* and *Orius spp.*, *Wollastoniella testudo* bugs, predatory thrips (*Aeolothrips intermedius*, *Mymarothrips garuda*), predatory mites of the subfamily *Stigmaeidae*. *Chrysoperla carnea*, *Mallada ssp.*, praying mantids, ladybird beetles, syrphid flies, spiders etc. Pathogens: *Steinernema ssp.*, *Verticillium lecanii*, *Beauveria bassiana*, *Metarhizium anisopliae*, *Paecilomyces fumerosus*
- **Chemical control:** Horticultural oil, or a prescribed insecticide. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** 3 thrips per shoot,



Moths and Butterflies (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Egg	1 - 3 weeks	On the surface or inserted into host plant
	Larva	3 - 4 weeks	Feeding on or in tissue of host plant
	Pupa	1 - 2 weeks	Hanging from the host plant or rolled up into a leaf. Some pupate in the soil.
	Adult	< 1 month	Mobile winged



Tea semilooper moth (*Biston suppressaria*)



Tussock moth caterpillars (*Euproctis pseudoconspersa*)



Bunch caterpillar moth (*Andraca bipunctata*)

Caterpillars of Lepidoptera butterflies and moths, like case-bearers (*Coleophora scaleuta* or *C. vigilis*), Bunch caterpillar (*Andraca bipunctata*), tussock moth (*Euproctis pseudoconspersa*), Tea semilooper (*Biston suppressaria*), or *Endoclitia ssp*

- **Symptoms:** caterpillars appear in aggregated masses and defoliate leaves.
- **Damage:** 2 generations per year may destroy several bushes of tea plantation.
- **Favored by** chemical control of shot-hole borer that also eradicates Parasitoids of caterpillars.
- **Prevention:** Increase monitoring vigilance each time a fresh flush grows and react early, before several generations develop.
- **Mechanical control:** Smaller populations can be removed/squashed by hand if detected early enough.
- **Biological control:** Larval Parasitoids: Tachinid fly, *Cylindromyia sp.*, *Cotesia ruficrus*, Braconid wasps (*Macrocentrus homonae*); Pathogen: *Bacillus thuringensis*. *Euproctis pseudoconspersa* NPV (EupsNPV) is pathogenic to the tea tussock moth.
- **Chemical control:** Neem oil applications.
- **Threshold level:** 15% damaged leaves or 4 -5 caterpillars per plant.



Tea leaf rolled up by caterpillars of *Caloptilia theivora*, *Adoxophyes honmai* or *Homona magnanima*

Caterpillars of **Tea leafroller moths** like (*Caloptilia theivora*, *Adoxophyes honmai* or *Homona magnanima*)

- **Symptoms:** The larvae roll up leaves and feed on the inside. Some also pupate inside a rolled up leaf-nest.
- **Damage:** Cause sporadic damage.
- **Favored by** chemical control of shot-hole borer that also eradicates parasitoids of caterpillars.
- **Prevention:** 5 pheromone traps/ha, suspended 30cm above the crop canopy; lures replaced once or twice per month, depending on weather conditions.
- **Biological control:** Braconid wasps (*Macrocentrus homonae*); *Bacillus thuringensis*
- **Chemical control:** Not recommended
- **Threshold level:** 5 rolled up leaves per bush or 8 moths per day/trap.



Red stem borer (*Zeuzera coffeae*) larva inside branch

Red stem borer moth (*Zeuzera coffeae*) (larvae)

- **Symptoms:** Caterpillar bores into stem or branches which then show wilting. Pellet-like excrement accumulates at the base of the plant.
- **Damage:** In advanced cases, the branch dries up.
- **Favored by:** high light conditions.
- **Prevention:** Sufficient shade.
- **Mechanical control:** Cut off and burn affected branches, proven to be the most effective control.
- **Biological control:** Fungus (*Beauveria bassiana*) or *Gibberella fujikuroi*; Braconid wasp (*Amyosoma zeuzerae*); Parasitoids: *Bracon zeuzerae*, *Isosturmia chatterjeeana*, *Myosoma chinensis*, *Senometopia kockiana*.
- **Chemical control:** Neem oil or Lime sulfur sprays.
- **Threshold level:** 15 holes per 45 bushes.



Red stem borer (*Zeuzera coffeae*) adult moth



Aphids (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Eggs	10 – 14 days life cycle	Underside of leaves, young shoots, green branches
	Nymph		
	Adult		
 <p>Tea aphid (<i>Toxoptera auranti</i>) infestation</p>	<p>Tea aphid (<i>Toxoptera auranti</i>)</p> <ul style="list-style-type: none"> • Symptoms: Tiny blackish round insects aggregate on young shoots and underside of leaves. Often tended by ants. • Damage: Nymphs and adults pierce the leaf tissue and suck sap Plant growth is stunted. Heavy infestation can cause leaves and shoots to yellow and get distorted/stunted. Typically causes secondary infection with sooty black mold. Virus vector • Favored by stressed plants, low soil fertility, drought. Lack of natural predators. • Prevention: check transplants for aphids before planting; use tolerant varieties if available (e.g. Aa /NTRI 101 of Rupi, Aa /NTRI 117 of Chuye and Bb /NTRI 470, Bd/NTRI 180 of Qi-men) • Mechanical control: If aphid population is limited to just a few leaves or shoots then the infestation can be pruned out to provide control; sturdy plants can be sprayed with a strong jet of water to knock aphids from leaves; • Biological control: Lacewings, ladybugs, gall midge, predatory bugs, hoverflies, parasitic wasps, as well as <i>Metarhizium anisopliae</i> or <i>Entomophthorales ssp fungus</i> • Chemical control: Oil-soap spray or neem oil. • Threshold level: 20% infestation 		



Hoppers and locusts (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Eggs	7 - 70 days	Locusts: soil, hoppers: midrib of leaves
	Nymph	< 2 months	Mobile, feeding while roosting on plants mainly in the evening
	Adult	< 5 months	

 <p>Tea green leaf hopper (<i>Empoasca flavescens</i>)</p>	<p>Tea green leaf hopper/Jassid /Green fly (<i>Empoasca flavescens</i>) especially nymphs cause damage through sap sucking. Virus vector</p> <ul style="list-style-type: none"> • Symptoms: So-called 'Rim Blight': Leaves margins curl downwards, becoming curved, turn purplish-brown and dry. Affecting especially tissue of new tea buds and shoot, particularly in the internode. • Damage: Hoppers suck sap. Their saliva causes leaf damage. Reduced photosynthesis leading to stunted growth. • Favored by higher temperatures and reversed rain/drought patterns. • Prevention: Moderately shaded tea shows less leafhopper problems, however, heavy shade can increase the incidence. Mulching improves the microclimate and also reduces leafhopper populations. • Mechanical control: Use of light taps/Yellow sticky traps • Biological control: Ladybeetles, lacewings, praying mantids, Damsel fly. <i>Verticillium lecanii</i> spray (2 gm/ltr). • Chemical control: Pyrethrum spray, Neem oil or a mixture of menthol and camphor oils. • Threshold level: 50% (50 jassids/100 leaves)
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	Stage	Duration (depends on species and environmental conditions)	Habitat
Nematodes (General Info)	cyst	Several weeks	In the soil near roots, or inside the roots' cortex, usually host specific
	egg		
	Juvenile		
	Adult		
 <p>Nematode damage on roots</p>	<p>Nematodes like (<i>Meloidogyne</i> spp.)</p> <ul style="list-style-type: none"> • Symptoms : Infested roots develop galls and branch profusely. • Damage: Severely infected plants show a reduced root system which seriously hampers their function of water and nutrient uptake. Plants wilt during the hot periods and are often stunted . Nematode infection predisposes plants to fungal and bacterial root pathogens. • Favoured by soil temperature of 21 – 26°C and light soils. • Prevention: Never re-use old potting soil or heat-sterilize nursery soil before use. • Threshold level: > 6 – 7 nematodes per 10g of soil tested 		



5.2 Common Tea Diseases

Most tea diseases are caused by pathogenic fungi and less frequently by bacteria and viruses. Most diseases in tea can be prevented or managed with good agricultural practices and plantation management.

Blister Blight

 <p>Blister Blight (<i>Exobasidium vexans</i>)</p>	<p>Blister Blight (<i>Exobasidium vexans</i>) Fungal disease.</p> <ul style="list-style-type: none">• Symptoms: Infects young leaves (less than one month old). Tiny translucent spots develop, become larger turn light brown. After a week the lower leaf surface develops blisters with water-soaked zones surrounding the blisters. After spores are released blisters become white-brown and soft. Affected leaves are distorted-irregularly rolled. Stem infection leads to goose neck shape, dieback and snapping at the point of infection.• Damage: Young infected stems bend and get distorted and may snap off or die. Losses up to 43%.• Favored by humid or wet conditions under too much shade or during cloudy and wet weather conditions. Temperatures between 17 and 22 °C . High altitudes >1500m.a.s.l. and sunshine below 4 - 5 hours/day. Spores are dispersed by wind. The fungus survives in infected leaves.• Prevention: adjusting the time of shade regulation in susceptible areas before conditions normally get conducive for blister blight infection.• Biological control: <i>Ochrobactrum anthropi</i> BMO-111 applied weekly. If temperature exceeds 30° C then treat it as a round of a Fungicide spray.• Mechanical control: Skiff off and destroy all affected branches.• Tolerant varieties: Clone PS1 is highly resistant to blister blight in Indonesia. GMB-1, GMB-2 and GMB-3 show some resistance. TV34 and TV35 are high yielding clones that can be grown under dry conditions to reduce fungal diseases.• Chemical control: Spraying of Bordeaux mixture or Copper oxychloride (350g in 67 l of water) in combination with nickel chloride¹⁵ in pruned field at 3 days intervals. Alternatively spray 2-3 rounds of 5-10% aqueous extracts of <i>Cassia alata</i>/<i>Polygonum hamiltoni</i>/<i>Acorus calamus</i>/<i>Adhatoda vasica</i>/<i>Equisetum arvense</i>/<i>Polygonum hydropiper</i>/<i>Tagetis petula</i> fortnightly.• Threshold level: 25 - 35% infected plants. Biological control and mechanical control should start with first signs of infection.
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¹⁵ Should be used as last resort



Grey blight
(*Pestalotiopsis theae*)



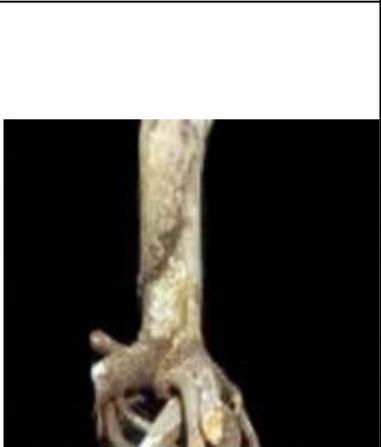
Brown Blight (*Colletotrichum* spp)

Grey and Brown Blight (*Pestalotiopsis theae* and *Colletotrichum camellia*)

Fungal disease.

- **Symptoms:** Starting on younger leaves round, irregular, grey or brown necrotic leaf lesions develop. Leaves often also show some yellowing. Later black spores become visible.
- **Damage:** Leaf drop leading to defoliation. Declines in yield leading to crop loss of ~17%.
- **Favored by** shear harvesting or stripping, during rainy season. Mostly attacks weak or damaged tea bushes. Secondary infection after inadequate blister blight control.
- **Prevention:** Avoid plant stress. Adequate spacing to allow sufficient air circulation and reduce humidity and the duration of leaf wetness. Use of resistant varieties, such as IRB88-15 from Yakubita variety (Japan), CP-1 and TV-26 in SE-Asia, and 31/11 and 303/199 in Africa (Kenya).
- **Chemical control:** Fungicides. Alternatively spray 2-4 rounds of 5% aqueous extracts of *Amphineuron opulentum*/ *Cassia alata*/ *Polygonum sinensis* fortnightly.
- **Threshold level:** 35% infected plants



 <p>White strands of the fungus <i>Pellicularia koleroga</i> on the Underside of a coffee leaf</p>	<p>Black blight, Thread blight (<i>Corticium/ Pellicularia koleroga, C. invisum</i>) Fungal disease that also affects coffee, black pepper, capsicum, citrus, ginger, and mahogany. Caused by these two fungi. More prevalent in the plains than in the hills</p> <ul style="list-style-type: none">• Symptoms: Leaves and twigs turn brown with a mat of white fungal threads on the underside of leaves. Dead leaves are hanging on thin threads from the branches.• Damage: Acute defoliation.• Favored by humid, warm conditions• Prevention: Plucking tea only in dry weather avoids disease transmission. Pluck regularly. Improve aeration and drainage.• Mechanical control: Pruning off and burning affected shoots at least 30cm below the affected area.• Biological control: <i>C. invisum</i> is controlled by the bacterium <i>Bacillus subtilis</i>.• Chemical control: New growth is protected with copper or fungicide sprays.• Threshold level: Immediate mechanical control. Chemical control at 35% infected trees.
 <p>Black root disease (<i>Rosellinia arcuata</i>)</p>	<p>Black root diseases (see end of the document for more information) (<i>Rosellinia arcuata</i>) Fungal disease</p> <ul style="list-style-type: none">• Symptoms: Black mycelium on infected roots, white star shaped mycelium between bark and wood. A ring of swollen tissue develops above the dead area and surrounds the stem.• Damage: Infection at 60-90% and can cause about 27% and infection over 90% can cause 36% yield reduction respectively.• Favored by high humidity and water-logging (usually prevalent during the rainy season).• Prevention: Avoid water-logging. After pruning always remove diseased material.• Mechanical control: dig a trench around affected bushes to dry out the soil and prevent the spread of the mycelium. In severe cases remove and destroy infected bushes.• Biological control: <i>Trichoderma sp.</i> and <i>Gliocladium virens</i> applied in the planting pits for prevention of root diseases.• Chemical control: Soil drenches with fungicides. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.• Threshold level: Each individual infected tree needs to be treated immediately.



	<p>Red root disease (<i>Poria hypolateritia</i>) Fungal disease that also affects Coffee, Grevillea, Albizia and Erythrina.</p> <ul style="list-style-type: none">• Symptoms: White mycelium later turning blood red on infected roots and also growing into the soil.• Damage: Spreads fast, slowly killing the bushes. Yellowing and wilting of foliage; sudden death of part of plant; withered leaves remain attached to the plant for several days.• Favored by close spaced planting as spread happens from root to root.• Prevention: Increase drainage in the soil and avoid too close spacing.• Biological control: <i>Trichoderma</i> sp. and <i>Gliocladium virens</i> applied in the planting pits for prevention of root diseases. Soil drenches with fungi of the genus <i>Cunninghamella</i>. <i>Streptomyces griseus</i> and <i>Streptomyces lydicus</i>• Mechanical control: Uproot and burn infected bushes including all root material.• Threshold level: Every infected plant needs to be uprooted immediately. Surrounding area needs to be treated and rehabilitated before replanting.
 <p>Root rot caused by Brown root disease (<i>Fomes noxius</i>)</p>  <p>Wilt caused by Brown root disease (<i>Fomes noxius</i>/ <i>Fomes lamaensis</i>)</p>	<p>Brown root disease (<i>Fomes lamaensis/noxius/Phellinus noxius</i>) Fungal disease that also affects Coffee, Grevillea, Albizia and Erythrina.</p> <ul style="list-style-type: none">• Symptoms: A netted pattern of brown mycelium shows under the bark. Infected roots turns soft and spongy.• Damage: Spreading slowly, quickly killing the bushes.• Favored by low elevations. Close spaced planting.• Prevention: Avoid too close planting as infection spreads from root to root.• Mechanical control: Uproot and completely remove affected bushes.• Biological control: <i>Trichoderma</i> sp. and <i>Gliocladium virens</i> applied in the planting pits for prevention of root diseases.• Threshold level: Each infected bush needs to be treated individually.



	<p>Stem canker (<i>Macrophoma theicola</i>) Fungal disease</p> <ul style="list-style-type: none">• Symptoms: The first symptoms include browning and drooping of affected leaves. As the disease spreads into the shoots, they become dry and die.• Damage: The entire branch can die from the tip downward. Dying branches show shallow, slowly spreading lesions surrounded by a thickened area of bark.• Favored by too deep planting and water-logging.• Prevention: Plant in well-draining, acidic soils.• Biological control: <i>Trichoderma harzianum</i> and <i>Gliocladium virens</i>, applied both to the soil around the bush and used for wound dressing.• Mechanical control: Remove diseased twigs by cutting several inches below cankered areas and disinfecting them.• Chemical control: Spray appropriate protective fungicides during periods of wet weather or natural leaf drop to protect leaf scars from infection. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.• Threshold level: Each infected bush needs to be treated individually.
	<p>Rust (<i>Cephaleurus parasiticus</i>, <i>C. virescens</i>) An algal pathogen of tea plants.</p> <ul style="list-style-type: none">• Symptoms: Rust-red colored sports covering leaves and branches• Damage: Crop loss of >20%• Favored by low soil fertility. Starts with onset of rains.• Prevention: Ensure sufficient fertilization with Nitrogen and potassium. Avoid water-logging. Improve air-circulation between bushes.• Partially resistant clones: (0-10% susceptibility), such as TV-17, TV-23, TV-24, TV-25, TV-26 and TV27. Avoid broad leaved Assam jats.• Biological control: Bacteria <i>Streptomyces sannanensis</i> or <i>Streptomyces griseus</i>.• Chemical control: Spraying with systemic fungicides. Alternatively spray 4-6 rounds of 5% aqueous extracts of <i>Argimone maxicana</i>/ <i>Polygonum hemiltonii</i> at 15-days intervals.• Threshold level: 30% infected leaves.

Stem canker (*Macrophoma theicola*)

Twig dieback caused by *Macrophoma theicola*



Rust or Red Rust (*Cephaleurus parasiticus*)



Pink Disease (*Erythricium ssp.*)



Pink Disease (*Corticium salmonicolor*) crust on a died-back branch

Pink Disease (*Corticium salmonicolor* syn. *C. salmonicolor*)

Fungal disease.

- **Symptoms:** Early warning sign is often the presence of a cobweb. Followed by appearance of salmon-colored spots that develop into a smooth mat of fungus towards the tips of shaded twigs and branches.
- **Damage:** The part above the outbreak dies off and causes dieback.
- **Favored** by humid and hot conditions.
- **Prevention:** Avoid overcrowding by regular pruning. Closely spaced plantings should be avoided. Maintaining healthy, vigorous plant growth reduces disease incidence.
- **Mechanical control:** Improve spacing to allow free air movement. Prune off and destroy infected branches well below the affected areas.
- **Chemical control:** copper-based fungicides application directly on the main stem and woody parts of branches. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** Each infected bush needs to be treated individually.



5.3 Additional information on Root Diseases

Primary

1. Charcoal stump rot (*Ustilina zonata*)
2. Red Root rot (*Poria hypolateritia*)
3. Brown Root rot (*Fomes lamaensis/noxius*)
4. Terry Root Rot (*Hypoxylon asarcodes*)
5. Purple Root rot (*Helicobasidium compactum* Boedijn)
6. Balck Root Rot (*Rosellinia arcuate*)
7. Armillaria (*Armillaria mellea*) in Africa. Uproot the affected bushes with all the roots and remove the rootlets in a bag from the field & burn. Ensure that when land is prepared for planting all roots of trees/shrubs removed are extracted from the soil and taken away to burn/firewood. Trees that have to be removed must be ringbarked to ensure that their starch reserves are depleted as then the fungus can not live long on any rootlets left by mistake.

5.4 Integrated Weed Management-Tea

Like with many other crops, weeds compete with tea bushes mainly for light, water and nutrients, thereby affecting their growth and yield. Factors that contribute to profuse weed growth in tea fields have been well recognized, and it includes herbicide resistance due to indiscriminate use of this type of pesticides. Other factors are patches of land without vegetation (ground exposure), high rain fall (2500-3500 mm per annum) and regular use of nitrogenous fertilizer without taking into account the nutritional needs of the crop.

When are weeds a problem in tea plantations?

There are three critical periods for weed control in tea. These are:

1. New clearing (during the first two years after planting), particularly in young tea (8-16 weeks after planting)
2. During the pruning phases
3. In old tea fields where plants are missing, or where there are neglected and abandoned bushes. These conditions provide very conducive conditions for weed proliferation

Some considerations for weed control in tea plantations

Identification of weeds: not all weeds are bad . Many weeds are heavy competitors with the crop but many others can bring benefits. For example, many weeds can be of high medicinal or food value, or help with erosion control; serve as habitat for natural enemies of pests and pollinators, help with water retention in the soil, and prevent soil compaction Therefore, the idea is to identify and manage only those species that can affect the productivity of the crop and leave the “soft ones” on the field.

What criteria to apply when classifying the weeds?

Noxious weeds:

- Have strong root systems - Compete with the tea for resources such as nutrients, water, space and sunlight
- Difficult to kill using herbicides (herbicide resistance)
- Release chemicals which are harmful for tea bush

Some examples of noxious weeds in tea plantations are:

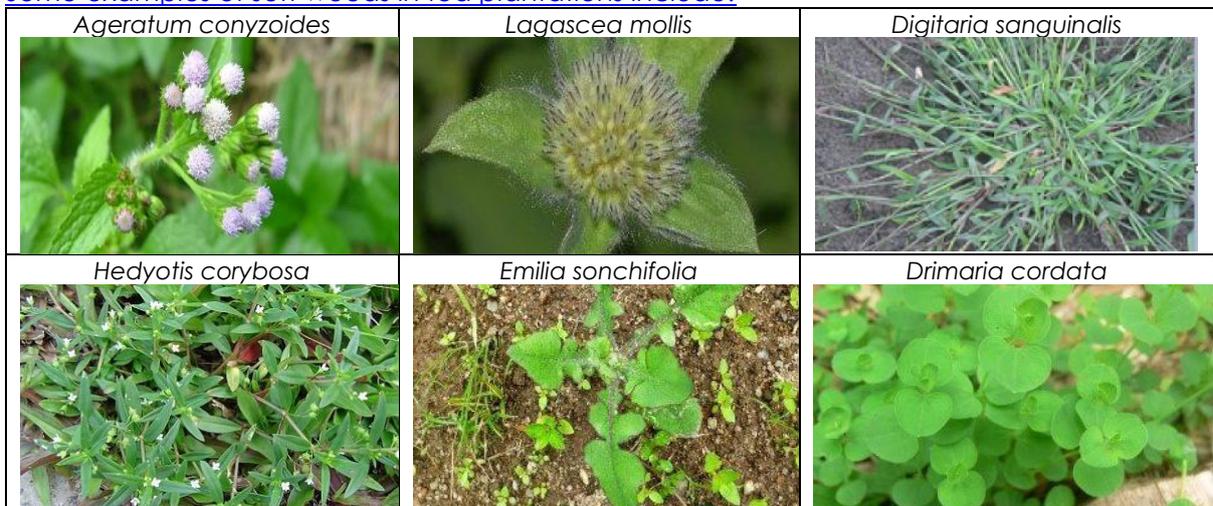


Source: <https://aslm.lk/2018/08/15/herbicidesfree-weedmanagement/>

Soft weeds:

- Have weak roots system - compete less with the tea bushes
- Spreads covering the soil thereby helping with retaining moisture in the soil
- Protect and enrich the soil – some can fixate nitrogen or provide organic matter
- Provide habitat for predators and pollinators (e.g., nectar/pollen)

Some examples of soft weeds in tea plantations include:





Source: <https://aslm.lk/2018/08/15/herbicidesfree-weedmanagement/>

Removal of noxious weeds before they flower:

The objective of doing this is to interrupt the reproductive cycle of the noxious weeds, eliminating them before they can flower and produce seeds, and therefore a second generation of weeds. Complete manual uprooting or spot application with a low toxicity herbicide may be necessary for those noxious weeds that do not reproduce by seed. The removed noxious weeds can be used to make compost.

By continuously doing this, the seed bank of these weeds in the soil gradually reduced over time and soft / beneficial weeds takeover the space and establish permanently. The establishment of soft weeds leads to more stable productivity, better soil moisture, better organic matter content in the top soil, less insect pests and finally reduction of production costs.

Weed control at different stages of the Tea crop

Before the plantation is set up, at the beginning of planting or following uprooting of old tea:

1. Prevent the entry and establishment of weeds to/in the crop area
2. Minimize the weed seedbank in the soil by frequently removing noxious weeds before they flower or vegetatively reproduce further. Delayed weeding results in the weed seedbank in the plantation growing.
3. Be mindful of cuttings or not properly decomposed noxious weeds in the compost. Preferably use hot composting. There is a risk of propagating cuttings or seeds of noxious weeds if they are not properly composted.
4. Do not leave clean neglected land areas to avoid seed weed banks growing. Leaving exposed bare soil is the most critical factor that determines the growth of weeds in young tea plantations (particularly during the first and second year after planting), or during first year after pruning. Use these unused areas to establish patches of natural vegetation or trees.
5. The border areas of tea fields, roadsides, steep terrains etc. should be kept free of noxious weeds , but still cover with "soft" vegetation in order to avoid continuous dispersal of noxious weed seeds to adjoining tea fields.

Nursery management

Hand weeding/uprooting weeds while soils are moist is encouraged as opposed to chemical control. Healthy and well nourished plants establish better in the field, therefore decreasing the chances of mortality of plants thus reducing vacancies in the plantation.

Establishment and early crop stage



1. During land preparation all stubs, rhizomes and other reproductive propagules of noxious weeds should be removed and the establishment of soft weeds promoted (see above)
2. Start with good planting material: healthy and vigorous nursery plants should be selected for field planting as they establish fast and outcompete weeds better. In addition, use of quick growing planting material will help uniform ground coverage and thereby reduce weed growth.
3. Spacing: In order to attain an early ground cover, planting of tea at closer spacing would be more favourable than planting at wider spacing, although too close can create plant to plant competition. The correct spacing will depend on the cultivar selected for planting (please inform yourself). The purpose of this is to have a close canopy that impedes the sunlight on the ground and therefore the growth of weeds.
4. Hand weeding around collar region of young tea bushes, and brush cutting between the bushes is recommended and then this region can be mulched.

Established crop

1. Mulching the ground with live or dead material is the recommended practice for tea, especially in the new clearings as it smothers the weed growth, conserves the soil moisture and improves soil fertility through addition of organic matter. Mulching should be done at least 2-3 times per year and care should be taken to use only uncontaminated vegetation without vegetative parts of noxious weeds species.
2. Soft weeds tend to grow slowly and laterally, covering the soil surface. As long as you keep them at low height with regular weeding, they do not compete with tea for nutrients. Soft weeds, when sickled, die easily and take time to come back. The sickled soft weeds can be laid over the soil surface and used as mulch. They get decomposed and add organic matter to the soil.
3. Infilling vacant patches with a tea clone which exhibits fast growth, is also important to establish an early ground cover to make minimum room for weeds.
4. Ideally herbicides should not be used, but if their use is necessary, please consult the list of prohibited and risk mitigation pesticides in Annex 7. Follow all the criteria regarding pesticide management section 94.6) of the standard

Some useful links to tea weed management materials from the Rainforest Alliance:

Video 1: <https://stichtingra.resourcespace.com/?r=2117&k=44b3f8615d>

Video 2: <https://stichtingra.resourcespace.com/?r=2116&k=0c89f77daa>

Video 3: <https://stichtingra.resourcespace.com/?r=2134&k=a799a43c72>

Secondary

1. Violet Root rot (*sphaerostilbe repens*)
2. Thorny Blight (*Aglaospora.sp*)

Resources

Rainforest Alliance app on pesticides and its alternatives:

<https://play.google.com/store/apps/details?id=org.ipmcoalition.pesticidealternatives>

<https://apps.apple.com/app/id1461460997#?platform=iphone>

References

A list of recommended Sri Lankan clones for different elevations and their resistance to pests can be found here:

https://www.tri.lk/userfiles/file/Advisory_Circulars/TRI_Advisory_Circulars_PN_01.pdf



An extensive list of pests and diseases of tea in India can be found here:
<http://www.upasitearesearch.org/pests-and-diseases/>

A comprehensive AESA manual for tea growers can be found here:
<https://nipm.gov.in/IPMPackages/Tea.pdf>

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Nan Jiang, Dayong Xue, Hongxiang Han - A review of *Biston Leach*, 1815

Satyajit Sarkar, S. E. Kabir, Department of Tea Science, University of North Bengal

www.vikaspedia.gov.in

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6 COCOA SPECIFIC GUIDANCE

Disclaimer

This crop specific IPM guidance does not intend to cover all possible pests per crop. The intention is to present the most common pests /diseases that affect certain crops in several regions worldwide.

General information

<u>Cocoa (<i>Theobroma cacao</i>) Recommendations</u>		
Choice of adequate site for the crop		Successful cocoa growing requires reliable, year-round rainfall or else irrigation will be necessary. Cocoa is typically grown under remnant forest, planted shade trees or intercropped with other commercial crops that give cocoa sufficient shade and protection from wind, especially during the first 5 years of development.
Growing conditions	altitude	< 1200 m.a.s.l.
	temperature	Temperature: in addition to Rainfall, it is one of the most critical climatic factors for the growth and development of cocoa. optimum daily average: 24°C. min. 15°C; max. 35°C, but fluctuations reduce yield.
	rainfall	1500 - 2000 mm annually evenly distributed. Dry spells (with <100mm/month) should not exceed 3 months. Otherwise irrigation is necessary.
	humidity	80% - 100% A hot and humid atmosphere is essential for the optimum development of cocoa trees.
Choice of suitable varieties and plant material for the site		Preference should be given to drought and disease resistant and approved by local or national competent authority varieties/hybrids where possible like UF-18 (released by the National Seed Industry Council in the Philippines). Use good and healthy planting material, as well as vigorous and healthy seedlings from genuine or reputed certified nurseries. Seedling or budded or grafted which are 4-6 months old. Disease free, high yielding, drought resistant and resistant varieties that are approved by local or national competent authority should be used.
Maintenance of soil health and fertility		As cocoa has a 1.5m long taproot deep, friable soil, free of hardpans is necessary to successfully grow cocoa trees. The ideal pH range is 6.5 - 7.0. For every 1 t of dry bean harvested, 25 kg N, 4 -10 kg P, 40 - 60 kg K, 8 - 11kg Mg, and 5 - 9kg Ca must be replaced per hectare annually. (For more details please refer to the Soil Guidance document.)



Maintenance of adequate soil organic matter (SOM) levels	Cocoa is sensitive to drought as well as waterlogging therefore high soil organic matter content is a must (> 3%). Adequate SOM ensures adequate drainage as well as water retention and sustains beneficial microorganisms levels. As cocoa is often established on previously cleared forest soils the SOM levels usually rapidly decrease if not replenished through frequent additions of animal or compost manure or mulching. Suitable cover crops can also be used, if the organic material remains as a mulch cover in the plantation.
Maintenance of soil temperature and humidity	Creating a microclimate in the plantation that is favorable for cocoa and not favorable for pests and diseases can be a critical prevention factor or at least reduce the severity of an outbreak. This is especially important during unusually dry and hot seasons, which may occur more frequently due to climate change. This can be achieved with adequate shade levels, but also through soil covers in form of mulch or cover crops (during the first 5 years). Mulch is kept away from the base of the plant to reduce the risk of disease. Mulch is re-applied at the end of each rainy season.
Maintenance of adequate shade levels	Shade protects young cocoa trees from drought stress and exposure to sun. Diversity of tree species, providing Shade levels of 30% - 50% are recommended. Shade levels can be as high as 70% for young cocoa and as the cocoa trees grow and start self-shading, the number of other shade trees can be decreased gradually. Agroforestry settings which provide several different layers of shade might however be advantageous for greater biodiversity and a favorable microclimate.
Important cacao pests and diseases by region	<p>West Africa: Black pod (mainly <i>Phytophthora megakarya</i>), Cocoa Swollen Shoot Virus (Badnavirus), Mirids (<i>Sahlbergella singularis</i> and <i>Distantiella theobroma</i>)</p> <p>South America: Witches' broom (spread all the way up to Panama) (<i>Moniliophthora perniciosa</i>), Moniliophthora pod rot (except Brazil) (<i>Moniliophthora roeri</i>), Black pod (mainly <i>Phytophthora palmivora</i>, <i>P. capsici</i>), Mirids</p> <p>Mesoamerica: Moniliophthora pod rot (<i>Moniliophthora roeri</i>), Black pod (<i>Phytophthora palmivora</i>), Mirids</p> <p>Southeast Asia: Vascular streak dieback (<i>Oncobasidium theobromae</i>), Cocoa pod borer (<i>Conopomorpha cramerella</i>), Mirids (<i>Helopeltis</i> spp.)¹⁶</p>

The free mobile app "HabitApp" helps to give an instant reading of cocoa shade cover. It can be downloaded through the following link: [HabitApp - Apps on Google Play](#)

¹⁶ Source: ICCO (2015), <http://www.icco.org/about-cocoa/pest-a-diseases.html>.



6.1 Common Cocoa Pests

Key:

Pest type	Life stages of the pest that cause damage
	Life stages of the pest that do NOT cause damage

	Stage	Duration (depends on species and environmental conditions)	Habitat
Tea mosquito bugs (General Info)	Eggs	5 - 26 days	Inserted into plant tissue of a host plant
	Nymph	10 - 30 days	Young nymphs often aggregate
	Adult	Varied	Mobile, often host specific but also hide in crevices of bark, structures, etc.



Tea mosquito bugs (*Helopeltis antonii*)



Damage caused by the Tea mosquito bug



Tea mosquito bugs (*Helopeltis antonii*)

Slender reddish-brown insects, <10 mm long with antennae, that are almost twice as long as the body.

- **Symptoms:** Infested pods develop circular water soaked spots caused by multiple feeding injuries. These punctures subsequently turn black. Pods appear deformed and scarred.
- **Damage:** Eggs are inserted into the soft tissue near the tips of flowering or vegetative shoots as well as developing fruits. Feeding damage appears as a discolored lesions. Heavy infestations result in pod malformations and premature drop. Secondary disease pathogens can enter through damaged plant tissue. Dropped fruits attract pests.
- **Favored by:** Rainy season or erratic rains leading to flush of young shoots. Populations usually build up during wet, sunny seasons. Temperatures > 28°C.



- **Prevention:** Regular monitoring as attacks occur suddenly. Conserve the numerous natural enemies like weaver ants. Do not intercrop with alternative host plants like cashew, tea, sweet potato, guava, cotton and mango. Maintain good plantation management in regard to pruning, weeding and shading.
- **Biological control:** parasitoidids: *Telenomus* ssp, *Chaetostricha* sp, *Erythmelus helopeltidis*. predators: *Panthous bimaculatus*, *Sycanus collaris*, *Rihirbus trochantericus luteous*, *Chrysoperla* sp; entomopathogen: *Beauveria bassiana*
- **Chemical control:** Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** Damage level of 1- 5%



Sahlbergella singularis



Distantiella Theobroma



Dieback in a young tree caused by **mirid bug** damage.

Cocoa mirid bugs (*Sahlbergella singularis*) or (*Distantiella theobroma*)

- **Symptoms:** mirid bug nymphs and adults pierce the surface of cocoa stems, branches and pods to suck sap, causing necrotic lesions.
- **Damage:** can result in the death of terminal leaves and branches, causing dieback. Entire young trees can die. Mirids are vectors of fungal infections (*Calonectria rigidiuscula*, etc.) that may cause cocoa dieback.
- **Favored by** trees being exposed to sunlight, trees bearing the first fresh flush of leaves, shots and pods. Populations usually build up during wet, sunny seasons. Temperatures > 28°C.
- **Prevention:** Shade should be designed to achieve a balance between mirid control, flowering and black pod management. Alternative hosts should not be used as shade trees on cocoa farms. Timing of interventions is key to successful control. Acquire forecast information from farmers groups or extension officers. Populations usually start to build up from June already and scouting/ monitoring should start then.
- Some new clones seem to be less attractive to mirid bugs. In Ghana for example, the hybrids (commonly called mixed) from COCOBOD authorized seed gardens, are known to have some tolerance for mirids. CIRAD identified a few resistant genotypes from French Guyana. As



mirids lay their eggs in the bark of stems or inside the pod husks, painting the stems with lime to cover crevices and collecting all husks could help reduce infestation rates.

- **Biological control:** The black ant (*Dolichoderus thoracicus*) has been used in some farms as a control measure. Maintenance of abundant weaver ant (*Oecophylla longinoda*) colonies in the plantation
- **Chemical control:** Resistance to commonly used insecticides is increasingly becoming a problem in mirid bug control. Therefore the use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard. Spraying is most effective from September to May.
- **Threshold level:** Sticky glue traps and pheromone traps can be used for monitoring. 1 - 4 mirid bugs per tree



Stink bugs (*Bathycoelia thalassina*) on cocoa pod with mirid bug damage.



Prematurely ripened immature cocoa pod caused by **stink bug** (*Bathycoelia thalassina*) damage.

Stink bugs (*Bathycoelia thalassina*)

use long mouthparts to penetrate through the pod husk to suck the contents of the beans.

- **Symptoms:** Stink bugs do not leave feeding marks on the pods but cause premature ripening of the pods. Pods turn yellow, cherelles are deformed.
- **Damage:** Loss of pods causes yield reduction. Also attack new flushes and chupons.
- **Prevention:** Maintain sufficient shade and canopy levels. If stink bugs are a major pest in the area avoid using alternative host trees like: also mangoes (*Mangifera indica*), kola (*Cola acuminata*), and *Citrus spp* as shade. Remove chupons frequently as these attract stink bugs and are also used as egg-laying sites.
- **Biological control:** Release of parasitic wasp (Hymenoptera) or Tachinid fly species. Research on other stink bug species shows success with pheromone baited lure traps placed on the ground.
- **Chemical control:** Pyrethroids sprayed in infested localized areas. Otherwise keep insecticide applications at a minimum to maintain healthy natural enemy populations. the use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** 10% prematurely immature pods or a total of 25 stinkbugs on 10 trees that are exposed to the sun.
- Monitor for peak population levels from March to June and August to September.



Mealy Bugs (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	eggs	1 week	In a sticky sac on axils of stems or leaves
	nymph	1 - 2 months	Mobile crawlers
	adult	Female dies after laying eggs	Males are mobile with wings. Female are sessile on shoots, leaf axils and midribs or roots.



Planococcus lilacinus



Paracoccus marginatus



Rastrococcus iceryoides

Mealybugs (*Planococcus lilacinus*, *Planococcus citri*, *Paracoccus marginatus*, *Drosicha mangiferae*, *Planococcoides jalensis*, and *Rastrococcus iceryoides*)

- **Symptoms:** Mealybugs colonize on tender parts of the plant as well as mature pods, which appear to be covered with fluffy white spots.
- **Damage:** Feeding of mealy bugs induces cherelle wilt. Vector of Cocoa Swollen Shoot Virus (CSSV) and other viral diseases.
- **Favored by** presence of *Philidris* ants, hot and dry conditions, excessive nitrogen fertilization.
- **Prevention:** Control ants. Stop *Philidris* ants from climbing up into the tree by placing a sticky band around the trunk. This will help natural enemies (parasitic wasp and lacewings). Birds play an important role in reducing mealybug populations.
- **Biological control:** Best control is achieved by the predatory *Cryptolaemus montrouzieri* ladybug, whose nymphs resemble the mealybug. Recommended release rate: 5 beetles/infested cocoa tree. In India, the caterpillar of *Spalgis epeus*, which also resembles a mealybug, is the most common mealybug predator. Predators that resemble mealybugs can be differentiated from their prey by their high level of mobility while mealybugs are immobile.
- **Chemical control:** Indian soapnut tree (*Sapindus Mukorossi* aka Indian Soapberry) these nuts soaked for 48 hrs produce soap that also has insecticidal properties. So this combined with Neem/*Pongamia pinatta* works well against scale insects & mealy bugs.
- Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** Infested trees can be treated individually by spot applications. Spraying is recommended if 5% of trees are affected at fruit-set stage.



Hoppers and locusts (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Eggs	7 - 70 days	Locusts: soil, hoppers: midrib of leaves
	Nymph	< 2 months	Mobile, feeding while roosting on plants mainly in the evening
	Adult	< 5 months	

 <p>Flatid Plant hoppers nymphs (<i>Melormenis basalis</i>)</p>  <p>Adult Flatid Plant Hopper (<i>Metcalfa pruinosa</i>)</p>	<p>Flatid Plant Hoppers several <i>Flatidae</i> spp. Serious pest in Asia and the Pacific region.</p> <ul style="list-style-type: none"> • Damage: Nymphs and adults suck the sap from flowers, tender shoots and pods. They excrete honey dew resulting in the development of sooty mold fungus on the leaves and pods. They can also be virus and disease vectors. • Favored by reversed rain/drought patterns. Populations build-up during low sunshine seasons. • Prevention: Shade-grown tree show less leafhopper problems. Mulching improves the microclimate and also reduces leafhopper populations. • Mechanical control: Use of light taps • Biological control: Ladybeetles, lacewings, praying mantids. <i>Verticillium lecanii</i> spray (2 gm/ltr). • Chemical control: Pyrethrum spray, Neem oil or a mixture of menthol and camphor oils. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard. • Threshold level: 5% of trees affected at fruit-set stage.
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Aphids	Stage	Duration (depends on species and environmental conditions)	Habitat
	Egg	10 – 14 days life cycle	Underside of leaves, young shoots, green branches
	Nymph		
	Adult		



Toxoptera aurantii on young leaves and bloom



Aphis gossypii on the underside of a leaf

Aphids (*Toxoptera aurantii* and *Aphis gossypii*)

- **Symptoms:** Aphids form colonies on the underside of tender leaves, succulent stem, flower buds and small cherelles.
- **Damage:** nymphs and adults pierce the leaf tissue and suck sap. Plant growth is stunted. Virus vector. Premature shedding of flowers and curling of leaves.
- **Usually occur during** hot summers and after the rainy season. **Favored by** stressed plants, lack of natural predators.
- **Prevention:** Improve plantation management to avoid plant stress, especially microclimate and SOM levels to ensure sufficient nutrient and water supply. Provide areas with flowering host plants to attract predator populations long-term.
- **Mechanical control:** If aphid population is limited to just a few leaves or shoots then the infestation can be pruned out to provide control; sturdy plants can be sprayed with a strong jet of water to knock aphids from leaves
- **Biological control:** Lacewings, ladybugs, gall midge, predatory bugs, hoverflies, parasitic wasps, as well as *Metarhizium anisopliae* or *Entomophthora* spp fungus
- **Chemical control:** Oil-soap spray or neem oil. Use of locally approved synthetic pesticides only as a last resort.
- **Threshold level:** 20% infestation



Moths and Butterflies (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Egg	1 - 3 weeks	On the surface or inserted into host plant
	Larva	3 - 4 weeks	Feeding on or in tissue of host plant
	Pupa	1 - 2 weeks	Hanging from the host plant or rolled up into a leaf. Some pupate in the soil.
	Adult	< 1 month	Mobile winged



Hairy caterpillars defoliation



Pericallia ricini adult



Typical hairy caterpillar (*Eupterote Testacea*)

Caterpillars (*Lymantria sp.*, *Euproctis sp.*, *Dasychira sp.*, *Pericallia ricini*, *Spilosoma obliqua*, *Metanastria hyrtaca*, *Hyposidra talaca*, *Parasa lepida*)

- **Damage:** serious leaf damage on seedlings and young trees. Skeletonized leaves
- **Favored by** reversed dry/rainy seasons.
- **Prevention:** Maintain high levels of biodiversity to provide alternative food sources for caterpillars as well as high numbers of natural enemies. Inspect plants regularly and remove early colonies before the damage gets out of hand.
- **Biological control:** Entomopathogenic bacterium *Bacillus thuringensis* (*Bt*); predatory bugs like *Macrolophus pygmaeus* or *Nesidiocoris tenuis*; parasitic wasps (*Trichogramma ssp*)
- **Chemical control:** Neem oil or Pyrethrum products. In worst case: foliar spray of acephate @ 2g/liter targeted only at the infested section of the plant.
- **Warning:** this insecticide is on RA's risk mitigation list and needs to be used within an IPM program and following risk mitigation measures as explained by Annex 7. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.
- **Threshold level:** 10% of trees affected



Camouflaged **CPB** (*Conopomorpha crammerella*) moth underneath a horizontal branch



Internal damage of **CPB** (*Conopomorpha crammerella*)



Damage of **CPB** (*Characoma stictigrapta*)

Cocoa Pod-borer/CPB (*Characoma stictigrapta*, *Conopomorpha crammerella*)

Pod-borers are serious pests of cocoa. *Characoma stictigrapta* occurs in West Africa.

- **Damage:** CPB attacks pods at all maturity stages. Infested pods ripen unevenly and prematurely. Pod-borer larvae bore holes into pods of all sizes producing a mass of frass held together by silk at the entrance of the holes. If infestation happens during Cherelle stage it wilts. Infestation at an early stage leads to heavy losses because the quantity and quality of the bean becomes seriously affected.
- **Favored by** inadequately drained soils and bad plantation management.
- **Prevention:** Adjust shade level and improve aeration through appropriate spacing or pruning. Improve soil drainage if necessary. Harvest and remove diseased pods completely and regularly.
- **Mechanical control:** Wrap pods in paper bags or a polythene sleeve to create a physical barrier to oviposition when they are 8 – 10cm long.
- **Biological control:** Ants such as *Dolichoderus thoracicus* and *Oecophylla smaragdina* The fungus *Beauveria bassiana* has also been found to infect larvae and pupae, causing a 100% death rate. The use of traps with synthetic pheromones or female pod borer moths can control the attack if enough males are caught, thereby interrupting their reproduction cycle.
- **Chemical control:** CPB can be controlled by relatively small amounts of contact pyrethroid applied to the undersides of lower branches, keeps the CPB population below economic damage levels. However, this is usually not economically viable. Use of locally approved synthetic pesticides only as a last resort.
- **Threshold level:** The insect is usually not controlled except for improved sanitation and plantation management. If pheromone traps are available the threshold level can be set to 10 males per trap per week.



Cocoa stem borer (*Eulophonotus Myrmeleon*) larva inside a branch



Hole in a stem caused by the tunneling of the **Cocoa stem borer** (*Eulophonotus Myrmeleon*) larva.



Adult stem borer moth (*Eulophonotus myrmeleon*)

Cocoa stem borer (*Eulophonotus Myrmeleon*) used to be considered a minor pest but has increasingly become a problem in West Africa.

- **Damage:** Larvae tunnel in the cocoa trees, causing damage to around 5% of trees. Recovery from the damage is unlikely. Stems show holes, sometimes with protruding frass at the base of the tree or gum oozing out of the holes. Tunneling causes discoloration on stems and shoots. Two periods of severe attacks occur during the rainy seasons with peaks in June and December/January.
- **Prevention:** Weekly monitoring to prevent infestation.
- **Monitor for** adults appearing in August and February. Strict sanitation. Encourage woodpecker populations.
- **Mechanical control:** Pruning of infested branches. Uproot and destroy heavily infested trees. Planting of barriers like dense stands of taro has been suggested. Barriers need to be 15m wide and established before new plantings. Removing alternative host plants is also recommended. Plugging holes to prevent adult moths from emerging could help.
- **Biological control:** Release of parasitoids like *Bracon zeuzerae* or *Glyptomorpha ssp.* Fungus *Beauveria bassiana* where commercially available.
- **Chemical control:** Sprays are ineffective and not recommended.
- **Threshold level:** As soon as bore holes are observed action needs to be taken, even on an individual tree basis.



Spiny bollworm (*Earias biplaga*)



Earias biplaga adult moth

Spiny bollworm (*Earias biplaga*) attacks cocoa amongst a wide range of other host plants.

- **Damage:** The larva eats the growing tips of the stems and young soft leaves. Feeding activity prevents the plant from growing properly to form canopy.
- **Favored by** high light (no shade) conditions.
- **Prevention:** Plant fast growing shade trees in newly established plantations. Increase biodiversity, as the bollworm prefers wild host plants and will use those as food source instead of cocoa. In a ecosystem with higher biodiversity the number of natural enemies is also increased.
- **Biological control:** Entomopathogenic bacterium *Bacillus thuringiensis* (*Bt*); predatory bugs like *Macrolophus pygmaeus* or (*Nesidiocoris tenuis*); parasitic wasps (*Trichogramma ssp*)
- **Chemical control:** Not necessary. Biological control measures are sufficient.
- **Threshold level:** 40% of trees are affected.



Fruit flies (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Egg	30 hours	Inserted into fruit tissue
	Larva	> 1 week	Tunnel inside fruits
	Pupa	6 days	Inside the fruit or in the ground
	Adult		Mobile, winged fly in search of host plant and mating partner



Fruit fly adults (*Bactrocera dorsalis*)



Fruit fly adults (*Ceratitis capitata*)

Fruit flies (*Bactrocera dorsalis* and *Ceratitis capitata*) tiny flies (4 - 6mm long) attack Cocoa in Kenya.

- Damage:** caused by maggots developing inside the pod after adult flies lay their eggs in maturing fruit pods.
- Secondary rot infections increase the level of damage.
- Worsened by** infected fruit pods remaining on the ground where maggots develop and re-infest the crop. Temperatures of 20°C - 30°C.
- Prevention:** Thorough monitoring and crop sanitation. Collect and destroy all dropped and infected pods to avoid pest numbers build up and to cut re-infestation cycles. Threshold level monitoring is usually done with bait traps and calculated as captured flies / week. Wrap pods at early stage in paper bags or a polythene sleeve to create a physical barrier to oviposition.
- Biological control:** bait traps
- Threshold level:** 4 flies per trap/week



Thrips (General Info)	Stage	Duration (depends on species and environmental conditions)	Habitat
	Eggs	7 days	Inserted into plant tissue
	Nymph	3 weeks	Before morphing into adults nymphs hide in the ground without feeding
	Adult	< 30 days	Underside of leaves

 <p>Red-banded Thrips (<i>Selenothrips rubrocinctus</i>)</p>  <p>Thrips damage on leaf</p>	<p>Thrips (<i>Selenothrips rubrocinctus</i>, <i>Heliethrips rubrocinctus</i>) and Red-banded thrips (<i>Selenothrips rubrocinctus</i>)</p> <ul style="list-style-type: none"> • Symptoms: Thrips attack older leaves, flowers and shoots, rasping plant tissue and sucking sap. Attacked leaves drop off, leaving bare shoots with few young leaves at the tip. Plants lose vigor and leaves shrivel. • Damage: Infestation of flowers causes poor fruit formation. Even locally limited infestations may cause considerable damage. Virus vector. • Favored by drought stress. Temperatures of 25°C - 30°C, low humidity, presence of pollen. • Prevention: Conserve natural enemies. • Mechanical control: Blue sticky traps (use only during the infestation period. As soon as you see no targeted pest being trapped, it is best to remove them to prevent unwanted insects being trapped, which might break the balance in the environment) • Biological control: Anthocorid bugs are important in natural control of thrips. Predatory mites can be used to control thrips. they should be introduced at the beginning of the crop season and released several times over the season. • Chemical control: horticultural oil or soap-oil solution can be sprayed to suffocate the thrips. • Threshold level: 1-2 per leaf during drought and 2-3 during rains.
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6.2 Common Cocoa Diseases

Fungal diseases are of major importance both to the trees and the pods, and the disease severity usually varies with variety. Of major importance are *Botryodiplodia theobromae*, *Oncobasidium Theobroma*, and *Moniliophthora spp* strains. The other large group of diseases is caused by oomycetes, fungus-like microorganisms, like *Phytophthora spp* strains.

Infection with *Phytophthora palmivora* can lead to different disease expressions. During nursery stage it usually causes root rot, which leads to damping off, called seedling blight. In mature plantations it leads to black pod rot. However, similar diseases that are also classified as black pod rot can also be caused by several other *Phytophthora* species. In West Africa and in Trinitario cocoa hybrids *Phytophthora palmivora* causes stem cankers.



Seedling blight (*Phytophthora palmivora*)

Seedling blight (*Phytophthora palmivora*)

- **Damage:** Lesions can appear on leaves or stems. Lesions develop into complete blighting of leaves or blackened stem, quickly causing the death of seedlings. More severe on 1 - 4 months old seedlings.
- **Favored by** waterlogging and high rainfall.
- **Prevention:** Remove and destroy all infected seedlings in the nursery. The disease is soil-borne and infected soil must therefore not be reused or at least be sterilized. Provide adequate drainage and avoid waterlogging.
- **Biological control:** none yet.
- **Chemical control:** Prophylactic soil drenches with Bordeaux mixture 1% or copper oxychloride 2 -2.5%.
- **Threshold level:** Immediate action to improve drainage and to remove diseased seedling is needed.



Black Pod rot (*Phytophthora palmivora*) damage on pod



Black pod rot internal damage (left) and white fungus starting to cover the pod (on the right)

Black Pod rot (*Phytophthora palmivora*, *P. megakarya* and *P. capsica*) fungal disease which can be caused by a variety of pathogens

- **Damage:** Pods can be attacked at any stage of development, and the initial symptoms are small, hard, dark spots on any part of the pod. Internal tissues, including the beans, shrivel to form a mummified pod, turning dark brown. It can eventually be covered with white fungus growth. The internal tissues as well as the beans become discolored. If beans are almost ripe at the time the pod gets infected, they might escape damage because they are already separated from the husk.

P. palmivora causes global yield loss of 20-30% and tree deaths of 10% annually,

P. megakarya is the most important and aggressive pathogen in Central and West Africa. If not treated can cause entire crop yield loss in a season

P. capsici is widespread in Central and South America, causing significant losses.

- **Favored by** conditions of excessive rain or high humidity, insufficient sunshine, and temperatures below 21 °C. Inadequate spacing and low aeration. In dry conditions or seasons, the fungus survives in flower cushions, mummified (dry) pods, pod husks and in the soil. Pods and other tissue injured by pests are highly susceptible to infection.

- **Prevention:** Regular and complete harvesting is key. Maintain high levels of sanitation by periodically removing and disposing infected pods and debris. Optimize shade and aeration through appropriate spacing and pruning to reduce surface wetness. Improve soil fertility and apply sufficient mulch layers.

- **Chemical control:** Copper-containing fungicides at frequent intervals from the start of the main rainy season.

- **Threshold level:** Immediate sanitation is required once first symptoms appear.



Purple discoloration visible once the lesion caused by Stem Canker (*Phytophthora palmivora*) is scraped off.



Lesion caused by **Stem Canker**

Stem Canker (*Phytophthora palmivora*)

- **Damage:** Cankers appear either on the main trunk, jorquettes or fan branches. Starts as greyish brown oval or round lesion on the outer bark, oozing a liquid, that forms rusty-brown crusts. The tissues beneath the outer lesion is purple (rot). If uncontrolled lesions will completely cover the stem hindering water circulation in the plant tissue, eventually causing the death of the tree. Causes significant losses in West Africa and in Trinitario hybrids.
- **Favored by** wet, damp conditions, and inadequate drainage. Bark damage is necessary for wood infection and canker development.
- **Prevention:** Increase soil organic matter levels to improve drainage. Avoid injuries to the bark. Cut and remove wilted branches.
- **Biological control:** none available yet.
- **Chemical control:** It can be controlled in the initial stages by the scraping off of diseased bark followed by wound dressing with Bordeaux mixture or copper oxychloride paste.
- **Threshold level:** Immediate sanitation is required once the first symptoms appear.



Whitish fungal growth on the midveins of leaves killed by **Witches' Broom** (*Moniliophthora perniciosa*)



Cocoa beans inside the pod destroyed by **Witches' Broom**

Witches' broom (*Moniliophthora perniciosa*) is one of the most devastating and widespread diseases in South America, the Caribbean and Panama.

- **Damage:** cocoa trees produce branches with no fruit and ineffective leaves. Pods are distorted and show uneven ripening. Drastically reduced yields.
- **Favored by** high level of humidity (=80%) and temperatures between 20 - 30°C. Spread by water, wind, seeds on workers or through infected plant material moved between plantations.
- **Prevention:** Plant resistant varieties/ clones e.g. those derived from Sca6 parent trees. Pruning provides the best control of Witches' Broom. Completely remove of all infected plant parts. Improve aeration. CIRAD identified a few resistant genotypes from French Guiana.
- **Chemical control:** Fungicides. Use of locally approved synthetic pesticides only as a last resort. Before carrying out insecticides application, always consult the list of prohibited and risk mitigation insecticides of Annex 7 of the Rainforest Alliance's 2020 Standard.



Damage of **Charcoal Pod Rot**

Charcoal Pod Rot (*Botryodiplodia theobromae*)

- **Damage:** Light yellow spot develop anywhere on the pod surface and spread rapidly later turning dark brown. The entire pod including the beans turn black. Beans don't develop fully and get mummified if infected at an early stage.
- **Favored by** dry season, on trees which are under stress. Caused by wounds on pods from insect or rodent damage. Typical disease in badly managed plantations.
- **Prevention:** Control insect pests or rodents that could cause injury to the pods. Improve shade and soil management as well as sanitation. Increase water retention capacity by adding sufficient amounts of organic matter (mulching) to avoid drought stress.
- **Biological control:** none yet
- **Chemical control:** Spraying with Bordeaux mixture 1%.
- **Threshold level:** Plantation management should be improved immediately once first symptoms appear.



Frosty Pod Rot damage



Frosty Pod Rot damage on beans

6.2.1 Frosty pod/Watery pod rot (*Moniliophthora roreri*) fungal disease.

- **Damage:** affects only immature pods. Spots appear on the on surface of immature pods, turn brown and rapidly enlarge to cover the entire pod surface. Causes serious losses in South-Western parts of South America.
- **Favored by** periods of high rainfall.
- **Prevention:** Selecting varieties that produce pods during the dry season. Remove pods showing symptoms of disease.
- **Biological control:** none yet.
- **Chemical control:** application of copper containing fungicides will help reduce disease incidence.
- **Threshold level:** Immediate sanitary action once first symptoms appear is recommended to avoid spread.



Vascular Streak Dieback (VSD)

Vascular Streak Dieback VSD (*Oncobasidium theobroma*) fungal disease

- **Damage:** The first indication of the disease is a characteristic yellowing of one or two leaves on the second or third flush behind the growing tip. Diseased leaves fall within a few days of turning yellow and the other leaves on the shoot show similar symptoms. When the infected shoot is split lengthwise there is always a characteristic brown streaking. Causes the tree to dry out, starting from the branch tips, usually resulting in the death of the tree.
- **Favored by** dry weather conditions and wind that disperses spores.
- **Prevention:** Can be controlled by regular pruning of chupons and disposing of diseased branches. Pruning diseased material about 30cm below the discolored tissue prevents further expansion of infection. Don't locate cocoa nurseries near a diseased area, and don't receive seedlings from diseased areas. Seedlings can also be raised under plastic to prevent infections from nearby plantations.
- **Resistant Varieties:** like CCRP-1 to CCRP-7 from India.
- **Chemical Control:** Not effective.
- **Threshold level:** Sanitation measures need to be undertaken immediately first symptoms appear.



6.2.2 Cocoa Swollen Shoot
Virus/CSSV

Swollen Shoot is a viral disease transmitted by mealybugs. It is a problem only in Togo, Ghana, Cote d'Ivoire and Nigeria.

- **Damage:** Swelling of shoots or stems accompanied by red leaf veining, especially in younger leaves with chlorotic interveinal mottling. Pods are uncharacteristically smooth and mottled, with reduced beans. Progressive defoliation may occur ultimately leading to the death of the tree.
- **Favored by:** high levels of mealybug infestation. Alternative hosts: several tree species such as *Ceiba pentandra*, *Sterculia tragacantha*, *Adansonia digitate*, *Cola chlamydantha* and *Cola gigantea* have been shown to be alternative host of CSSV in Ghana.
- **Prevention:** If infections are detected early, this spot treatment of removing and destroying infected trees and those surrounding (up to 5 m from infected tree if <10 trees are infected and up to a distance of 15m if >100 trees are infected) to prevent further spread is carried out; Establish a non-host plant (e.g. oil palm) barrier of at least 10m to isolate cocoa plantations from each other.
- **Control mealybugs.**
- **Chemical control:** none
- **Threshold level:** immediate sanitation action is needed once first symptoms appear.



Cherelle wilt

Cherelle/Young Pod Wilt: Physiological disorder

- **Damage:** Cherelles die off and mummify to a degree this is a natural process to avoid overbearing but can lead to significant losses. Also encourages secondary infection with Anthracnose.
- **Favored by** tree-weakening factors like pest or disease attack, low soil fertility or bad plantation management.
- **Prevention:** Improve soil fertility and soil organic matter levels. Appropriate planting density or avoiding overcrowding of trees.
- **Biological control:** none
- **Chemical control:** none
- **Threshold level:** Signs of infection should prompt improvements in soil fertility management.



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7 BANANA SPECIFIC GUIDANCE

Disclaimer

This crop specific IPM guidance does not intend to cover all possible pests per crop. The intention is to present the most common pests /diseases that affect certain crops in several regions worldwide.

Introduction
For producing and exporting countries, banana crops (*Musa AAA*) are of utmost economic importance. Besides contributing towards food security, banana cultivation is a source of direct and indirect jobs and foreign exchange. However, banana production offers many challenges, since it is an extensive crop with long production periods (the average plantation spans 25 year), making it susceptible to attack from pests and diseases. Among the most relevant pests and diseases for banana production are black sigatoka (*Mycosphaerella fijienses*), insects (diverse genera and species attacking the bunch, leaves and rhizome), weeds (diverse plant genera and species), post-harvest fungi (*Fusarium* spp., *Colletotrichum* spp.) and moko disease (*Ralstonia solanacearum*). In addition to the above, a new threat has appeared in recent years, Fusarium wilt (*Fusarium oxysporum* f.s. *cubensi* race 4), which could devastate entire plantations.

As a consequence of losses caused by pests, Integrated Pest Management (IPM) (Stephen and Hansen, cited by Cubillo, 2013) was established in 1959 as an integral strategy for lowering production costs and protecting human and environmental health. The IPM strategy was adopted in banana production after a series of historic crises in plant protection of the crop, characterized by dependence on pesticides and their undesirable effects, such as surging of new pests, resistant organisms, cost increases, and pest-associated losses.

The ultimate goal of an integrated pest management strategy is to grow healthy crops minimizing pesticide use.

General recommendations

Site selection for the crop		Latitude between 0 and 15°; Class 1 and 2 soils; 0-1% sloped planes; 1.20 m deep; loamy, light-loamy, loamy-sandy; loamy-silty textures; pH 5.5-7.0; water table > 1.20 m; soils without rocks; no flooding threat.
Growth conditions	Altitude	Optimum altitude between 0-300 meters above sea level for lowland banana. Between 350 and 1500 meters above sea level for midland and highland banana.
	Slope	Optimum slope between 0-1%
	Temperature	Between 21 and 30 °C; mean optimum temperature at 25 C.
	Rainfall	100-180 mm/month. Less precipitation requires supplementary irrigation.
	Humidity	50%, although this is not a limiting variable.
Selection of adequate varieties by site		The three most important varieties in the Cavendish subgroup (AAA) worldwide are: Grand Dwarf (normal Grand Dwarf, Oaxacan, French) Williams and Valery.



<p>Measures for erosion control</p>	<ol style="list-style-type: none"> 1. Plant on leveled ground or level the ground when preparing soils. 2. Keep a good natural vegetation cover (between 50 and 60%) without affecting production. 3. Maintain an adequate population density according to the variety and type of soil. 4. Reduce the chemical burden on the crop by reducing synthetic pesticide usage and increasing biological and botanical pesticide usage. 5. Place sedimentation or sediment gauges in both the cultivation area and at the base of drainage canals (primary, secondary and tertiary canals). 6. Establish vegetative coverage in the drainage canals (in the entire drainage network) to prevent canal embankment and base erosion. 7. In operations that use irrigations, apply only the layer of water necessary for the crop.
<p>Maintaining soil health and fertility</p>	<ol style="list-style-type: none"> 1. Use and conservation of organic matter; this is the source of fertility for the soil and improves its physical and chemical characteristics. 2. Reduction of synthetic fertilizer use (if production not compromised), specially of those that are a source of nitrogen. 3. Adequate maintenance of the drainage network in order to have good soil aeration and permeability. 4. Maintenance of a good vegetative coverage in the crop area. 5. Determine need for additional nutrient application to the crop, based on results of foliar and soil analyses. 6. Use soil conditioners containing calcium sources (dolomite limestone, gypsum rock, silicon) to improve soil structure. 7. Adequate and responsible use of agrochemicals is essential for maintaining good soil health.
<p>Maintaining adequate levels of organic matter in the soil</p>	<ol style="list-style-type: none"> 1. Leave crop residues on the field. 3. Keep good vegetative coverage on the field. 4. Maintain adequate crop population density. 5. Carry out additional applications of sources of organic matter. 6. Good drainage. 7. Establish plant coverage in drainage canals (in the entire drainage network). 8. Maintain adequate soil moisture. 9. Apply bioconditioners, such as marine algae and others. 10. Reduce use of synthetic fertilizers.



7.1 Common banana pests

 <p>Adult female <i>Pseudococcus elisae</i>¹⁷</p>  <p>Ants associated with banana mealybugs (<i>Pseudococcus elisae</i>)¹⁸</p>	<h3>Mealybugs</h3> <h4>General Information</h4> <p>Mealybugs (scales), mealy or cottony scale, are insects belonging to the Hemiptera order and the Pseudococcidae family. It is considered a quarantine pest. The main mealybugs associated with bananas are: <i>Planococcus citri</i> Risso, <i>Dysmicoccus brevipes</i> Cokerell, <i>Pseudococcus jackbeardsleyi</i> Gimpel and Miller, <i>Pseudococcus elisae</i> Borchsenius and <i>Ferrisa virgata</i> Cokerell (Cubillo, 2013). Diverse species participate as vectors of the Banana Streak Virus (BSV).</p> <ul style="list-style-type: none">• Symptoms: the following are the symptoms caused by infestation of the different organs: terminal and axillary bud deformities; leaves drying up and falling off; small and deformed fruit that fall due to the impact of injected toxins; and lastly a severely infested host may die (Palma et al., 2019).• Damage: Mealybugs are known for their commercial importance, because they can affect all stages in crop development and cause crop losses and fruit rejection for export. It causes direct damage to the plant, due to suction of sap, as well as indirect damage from the amount of sugar substances (honeydew) excreted, which attract ants and favors leaf and bunch sooty mold development. Damages caused by mealybugs are evident as plant weakening and also by discoloration of leaves with necrosis along their edge.• Predisposing Conditions: Periods with prior spells of high precipitation (> 400 mm/month) favor mealybugs.• Prevention:<ul style="list-style-type: none">○ Destruction of the habitat where the insect breeds or develops and of alternate host plants²⁰; moisture reduction.○ If allowed in the production country, sulfur application at the base of the plant, pseudostem and bud up to the stalk necktie knot (a practice used for organic banana in Peru) (Pasapera 2013).
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¹⁷ Taken from Cubillo 2013

¹⁸ Source: Taken from Cubillo 2013

²⁰ Wide range of families: Aizoaceae, Arecaceae, Asclepiadaceae, Asteraceae, Boraginaceae, Cactaceae, Cannaceae, Chenopodiaceae, Convolvulaceae, Crassulaceae, Cruciferae, Euphorbiaceae, Lauraceae, Fabaceae, Liliaceae, Malvaceae, Musaceae, Nyctaginaceae, Portulacaceae, Proteaceae, Rutaceae, Scrophulariaceae, Solanaceae, Verbenaceae (Williams and Granara-de-Willink, 1992; Ramos and Sema, 2004; Ben-Dov et al., 2013, cited by Palma et al., 2019). In species such as: *Acalypha setosa* (Cuban copperleaf), *Cissus sicyoides* (princess vine), *Physalis pubescens* (husk tomato, husk cherry or strawberry tomato), *Piper tuberculatum* (cord), *Rivinia humilis* (pigeonberry), *Ureria elata* (nettle) and *Zingiber officinale* (ginger) (Williams y Granara-de-Willink, 1992, cited by Palma et al., 2019).



Presence of **banana mealybugs** (*Pseudococcus elisae*) and sooty mold in a banana bunch.¹⁹

- Proper population density management, desuckering and defoliation (cycles as appropriate).
- Avoid accumulation of vegetative residue at the base of the banana plant to disfavor ants and their colonies, as they transport mealybugs.
- **Eliminate leaves that are in contact with the fruit and separate stems from pseudostems.**
- **Carry out good premature bagging practice with closed inflorescence or an open bract.**
- Maintain adequate drainage throughout the plantation to prevent puddling.
- Avoid applying nematicides and insecticides that affect natural enemies.
- Good undergrowth grass management or control, especially Cyperacea (González & Cubillo, 2014).
- Avoid applying excess nitrogenated fertilization that favors plant susceptibility to increased pests (Hernández et al., 2011).
- Mealybugs are generally carried by ants, thus control of this pest is recommended, as well as correctly folding the flag leaf so ants have no access to the bunch (Melendez, 2019).

- **Mechanical Control** :When recently harvested bunches have pests, pressure washing with water is necessary in order to eliminate the pest in the terminal ends of harvested bunches.
- **Biological control** : Diverse natural enemies have been determined, such as parasitoids particularly from the Encyrtidae family and predators from the Coccinellidae family. Other natural enemies are entomopathogenic fungi, lacewings and mites. Specific parasitoids for mealybugs are **Anagyrus kamali** Moursi and **Gyranusoidea indica** Shafee (Hymenoptera: Encyrtidae) (Palma et al., 2019). **Koppert, cited by Meléndez (2019), stated that Anagyrus pseudococci is a parasitic wasp widely recognized for its use in biological control for mealybugs.** *Anagyrus* spp parasites different species and mealybug stages.
- **Threshold**: The basis for management is a sampling system at the pseudostem or on the bunch. This allows for the definition of areas with the greatest problems, the age of the bunch when the pest is entering and the management option can be selected promptly (Cubillo, 2013). At this time, there is no tolerance, as it is a destination port quarantine pest.

¹⁹ Source: Taken from Cubillo 2013.



Scales



Presence of *Diapsis boisduvalii* scale on banana fruits.²¹⁾



Presence of *Diapsis boisduvalii* scale on the foliage.²²⁾

General Information: Scales are insects belonging to the order Hemiptera and family Diaspididae (Loor, 2016). The most economically important species for banana cultivation is *Diaspis boisduvalii*, known as banana scale or white scale. These insects are circular to stretched oval in form, thin, flattened, white to pale yellow in color, semitransparent and between 1.2 and 2.25 mm in diameter (Orellana, 2007). They are not an important pest in all banana growing countries; however, boisduval scale is currently one of the main insect pests in banana crops in Costa Rica and Ecuador, as well as in the Philippines; for this reason, this scale is considered one of the 43 most severe pests of this kind in the world (Miller and Davison cited by Solano, 2019; Loor, 2006). Their main hosts are bananas and plantains (Cota and Saunders, cited by Cubillo, 2013). It is a quarantine pest in destination ports (Cubillo, 2013).

- **Symptoms:** It is a sucking insect covered with a layer of proteins (nymphal exuviae) and other substances that make up a carapace, cover or armor that although deposited on the body, it may be separated from it, constituting a true shield or scale (Beardsley and González; Guillén and Laprade; Antonelli cited by Solano, 2019; Cubillo, 2013). They cause concave and chlorotic lesions (Vargas et al., 2017).
- **Damage**
 - The female adult and nymph scales feed on pseudostem sap, crown leaves and necks of the fruit. The fungus *Capnodium* spp. grows on the insects' excrement, forming sooty mold affecting photosynthesis and reducing fruit quality and appearance. The sooty mold causes the fruit to lose presentation quality (cosmetic quality), while also causing necrosis in affected parts (Pasapera, 2013). These lesions cause irregular ripening of the fruit.
 - It increases production costs and banana fruit rejection in packing plants and destination ports.

²¹ Source: González and Cubillo, 2014

²² Source: Solano, 2019



- **Favored by:** Generally, conditions of high precipitation levels (high relative humidity) and high temperatures, inadequate control of weeds that act as alternate hosts for both scale insects and ants; inadequate cleansing of the pseudostem (poor or inadequate removal of dry sheaths from the pseudostem); excess accumulated water in drainages and a high water table due to inadequate drainage; excessive nitrogenated fertilization; application of nematicides-insecticides that affect populations of their natural enemies.
- **Prevention:**
 - Deep removal of dry sheaths from the pseudostem,
 - Refresh the pseudostem meaning every so often, usually every 6 weeks, eliminate old rotting or dried out sections.
 - Elimination of rotten/dried out sections at harvest time.
 - Application of sulfur at the base of the plant, pseudostems and shoot or bud as far as the rachis “necktie knot” (a practice used in organic bananas in Peru) (Pasapera, 2013).
 - Good management of population density, up to date removal of leaves (cycles as appropriate).
 - Elimination of leaves touching the fruit.
 - Separation of the bunch from the pseudostem.
 - Implement a good premature bagging practice, in such a way that the person carrying out this activity avoids touching the leaves of infested plants.
 - Maintain adequate drainage in the plantation avoiding puddling.
 - Avoid application of nematicides and insecticides that may affect natural enemies.
 - Avoid excessive nitrogenated fertilization that may favor plant susceptibility for increased pest attacks (Hernández, et al., 2011).
 - In some farms in Ecuador, the most affected pseudostems are removed, being very careful not to propagate scale insects and transmit them to the remaining plants in the area (Meléndez, 2019).
 - Adequate weed management and/or control, since some weeds may become alternate hosts for ants living in symbiosis with scale and favor increasing their colonies by not allowing their predators and parasites to regulate populations (Loor, 2016).
- **Mechanical Control:** In the event of pest presence in recently harvested bunches, it is important to pressure wash them with water, in order to eliminate the pest from terminal parts of harvested bunches.
- **Biological control:**
 - Guillén cited by Vargas, et al., 2017, indicates and confirms that scales have a very broad group of natural enemies, such as parasitic wasps of the *Aphytis* family, predators from the Coccinelidae family (*Pentilia* sp., *Delphatus* sp.) and chrysopas (*Ceraeochrysa* sp.). In addition to the aforementioned, populations of white scale or *D. boisduvalii* have been regulated by net-winged insects, such as *Chrysoperla* sp. (Cubillo, 2013). (Cubillo, 2013).



- Solano, 2019, reports on the presence of three parasitic species for boisduval scale (*Diaspis boisduvalii*; Hemiptera: *Diaspididae*) in banana plantations (Musa AAA, Cavendish sub-group) from the Costa Rican Caribbean slope, which were identified at the genus level as *Coccobius* spp. (Hymenoptera: Aphelinidae), *Plagiomerus* spp. (Hymenoptera: Encyrtidae) and *Aphytis* spp. (Hymenoptera: Aphelinidae) as well as one hyperparasitic specimen grouped in the *Ablerus* genus (Hymenoptera: Aphelinidae).
- Use of entomopathogens such as *Beauveria bassiana* and *Metarhizium* sp. if the products are available in the area (González and Cubillo, 2014).

Threshold: **There is no specific threshold; for quarantine pests, the threshold is zero. Sampling is carried out to determine entry times of the pest and to determine the effectiveness of management measures.**

Weeds (diverse plant genera and species)



Paspalum conjugatum Berg.²³



Parthenium hysterophorus L.²⁴

General Information:

- Weeds are plants that compete quantitatively but not qualitatively with crops; they are detrimental by means of additive effects (competition) and allelopathy. Furthermore, it has been proven that some weeds are alternate hosts for pests. However, not all is untoward. Most weeds provide good soil coverage, preventing erosion. Grasses in drainage or irrigation canals are magnificent at preserving slopes.
- Furthermore, they add organic matter to the soil and allow recycling and conservation of minerals in the soil; some fix nitrogen and all of them help maintain wildlife and natural biological balance.
- **Weed control** should be integrated and should follow a study of each weed, their growth habits and control.
- **Symptoms:** Among the effects caused by the interference of weeds in banana cultivation the following have been reported: reduction in height, pseudostem thickness and bunch weight; nitrogen deficiency caused by competition and reflected in yellowing of young leaves; slower

²³ Source: Taken from fr. wikipedia.org

²⁴ Source: Personal files 2019



Cyperus rotundus (L.) Retz²⁵

growth with few suckers; flowering delay with the consequent lengthening of the crop's cycle; reduced yield.

- **Damage:** A critical period of weed competition during crop establishment is recognized in banana production. A second period of weed competition occurs between blooming of the flower or budding of the bunch and thickening of the fruit. Costs related to weed control are estimated to be around 5 to 6% of total agronomic operation costs (Quintero y Carbono, 2015), as well as lower yields in perennial crops, such as banana, in the order of 23 to 62%.
- **Prevention:** The best method for the fight against weeds is to prevent introducing new species in the fields, as well as the systematic reduction of the weed seed bank in the soil. Another measure is the establishment of an effective monitoring system.
- **Mechanical Control:** The most common methods for weed control are:
 - Soil preparation before planting, which is the basis for eliminating perennial weeds; if present.
 - Manual control (clearing), which is a routine practice to eliminate weeds between plant rows.
 - Use of mulch (padding) for weed control and soil moisture preservation.
 - Use of vegetative cover interspersed with banana plants; aside from aiding production, could help improve soil fertility preservation.
- **Biological control:** No references of practical use for biological control against specific weeds are known.
- **Threshold:** 40-60% weed cover

²⁵ Source: Taken from plants.ces.ncsu.edu



Weevil borer (picudo)



Adult *Cosmopolites sordidus* ²⁶.



Plants overturned or fallen due to weevil borer damage. ²⁷

General Information

- **The weevil borer** (*Cosmopolites sordidus* Germar; Coleoptera: Cuculionidae) is considered one of the most important insect pests for banana cultivation²⁸. It is found throughout tropical and subtropical areas where banana, plantain, abaca (*Musa textilis*) and other Musaceae are cultivated ²⁹.
- The adult weevil is black in color and measures 10-15 millimeters; it is free-living, although it is more commonly found among foliage sheaths, on the ground at the plant's base or associated with crop residues ³⁰.
- **Symptoms:** Wright, cited by Ajanel (2003), determined that putrefaction can occur in completely perforated rhizomes that have been reduced to a blackened mass of tissue, while leaves die prematurely. Infested plants have a pale yellowish-green color and soft foliage. Young sprouts are frequently withered and their development is deficient.
- **Damage:** The weevil borer reduces yields due to smaller size and inferior quality of bunches, as well as delayed maturation and shortened useful life of plantations due to the poor budding quality. Perforations caused by larvae of this insect can be utilized by other organisms as an entryway, mainly by the screwworm *Castniomera humboldti* (Lepidoptera; Castaniidae) or by microorganisms such as *Ralstonia solanacearum* and *Fusarium oxysporum* (Ajanel, 2003). The presence of rot caused by bacteria of the *Erwinia* sp. genus in the corms was directly proportional to corm damage by weevils³¹.
- **Favored by:** Weevils are active at night and are very susceptible to desiccation; thus they prefer humid conditions and avoid light (Gold and Messiaen, 2000). Weevils are attracted to host plant volatile substances emitted by recently cut corms. Furthermore, they can feed on decomposing vegetal material. Corms left on the ground in the plantation are visited by the insect at night and eggs are laid before corms are planted, causing the loss of recently planted material³².

²⁶ Source: Gold and Messiaen, 2000

²⁷ Source: Pasapera, 2013

²⁸ Cubillo and Guzmán, 2003

²⁹ Cubillo, 2013

³⁰ Gold and Messiaen, 2000

³¹ Cubillo and Guzmán, 2003

³² Cubillo, 2013



Weevil borer damage in the corm. (Source: Alarcón and Jiménez, 2012.)



Adult Weevil borer parasitized by *Beauveria bassiana*. (Source: Ramírez and Torres, 2016)

- **Prevention**

- Use vigorous and healthy seed (uninfested) in good conditions (Ajanel, 2003).
- Submerge vegetative seeds or corms in water at 52-55°C for 15-27 minutes. These baths are very effective for eliminating nematodes, but will only kill one-third of weevil borer larvae (Gold and Messiaen, 2000).
- Whenever possible, new planting areas should be free of Musaceae residues and the presence of the insect (Cubillo, 2013).
- Carry out adequate weed control.
- Maintenance of well drained soils.
- Opportune dedaughtering.
- Maintain adequate plant nutrition. Alarcón and Jiménez (2012) recommend correcting boron and potassium deficiencies.
- Maintain an adequate propping system.
- Adequate management of the irrigation system.
- Adequate management of other pests and diseases.
- Do not leave the bent pseudostem after harvesting, i.e. a hanging pseudostem end after the harvest (Pasapera, 2013).
- To maintain low weevil populations, old rhizomes should be dug up and removed, as well as waste and other vegetative materials where weevils can reproduce. Remove buds and corms regularly. When harvesting the bunch, the pseudostem should be cut close to the ground (Ajanel, 2003).



Mechanical Control:

- Use of traps made from pseudostems or corms, that function as food attractors, can be employed at high densities (25-50 traps/ha). Insects are collected manually from these traps (Cubillo, 2013).
- a high number of pheromone traps can be used to manage reduction of the *C. sordidus* adult population and 6 to 25 traps/ha can be set. This method can capture up to 18 times more than pseudostem traps (Cubillo, 2013).
- **Biological control:** Insect larvae have the following predators: *Plaesius javanus*, *Hololepta quadridentata* (Coleoptera: Histeridae) and *Dactylosternum hydrophiloides* (Coleoptera: Hydrophilidae), the ants: *Pheidole megacephala*, *P. guineense*, *Azteca* sp. and *Tetramorium guineense* (Hymenoptera: Formicidae) (Cubillo, 2013; Gold and Messiaen, 2000). Additionally, nematodes from the families Heterorhadtidae (*Heterorhabditis* spp.) and Steinernematidae (*Steinernema* spp.), attack both adult and larval weevils in the field, (Cubillo, 2013; Gold and Messiaen, 2000). Yet cost and efficacy of these nematodes allow their use only where weevil borers are found in high population densities, currently limiting extensive use. Entomopathogenic fungi such as *Beauveria bassiana* (Balsamo) and *Metarhizium anisopliae* (Merch) are sources for controlling this insect (Cubillo, 2013). Under laboratory and field conditions, some strains of *B. bassiana* can cause a greater than 60% mortality (Cubillo, 2013). Other reported larval and egg predators are *Euborellia annulipes* Lucas (Dermaptera: Carcinophoridae) y *Labia borelli* Burr (Dermaptera: Labiidae), *Ontophagus* sp. (Coleoptera: Scarabaeidae) and *Eutochia* sp. (Coleoptera: Tenebrionidae) (Navas, 2011). Chemical combat includes the use of vegetal extracts with insecticidal properties, such as neem (*Azadirachta indica* A. Juss), which contains insecticidal compounds such as phytoalexins. Musabyimana, cited by Navas (2011), determined that powder from neem seeds at 60 to 100 gr/plant at planting time and later at four-month intervals for a three-year period, was effective in combatting weevils, causing an interference in locating the host by producing repellence, reduced oviposition, anti-fedant and growth inhibition in larvae. Gold and Messiaen (2000) mention that immersion of sprouts in a 20% solution of *A. indica* during planting protects the young plants from lesions, reducing oviposition through the repellent effect on weevils.
- **Threshold:** There is no unified criterion regarding a threshold for action; however, Alarcón and Jiménez (2012), indicate that 20 to 25 traps per hectare are placed, then checked two to three days later after being installed and afterwards on a weekly basis, for no more than four weeks. During these revisions, trapped insects are collected and counted. If the average number of insects per trap is greater than 5, massive trapping should be applied to lower the population; a biological insecticide or in extreme cases, a chemical insecticide should be applied.
- **Sampling:** If sampling lesions in the corm or rhizome, management measures are recommended when there is an average of > 15 lesions(Cubillo, 2013).



Nematodes



Lesions caused by *R. similis* in banana roots. (Source: Guzmán, 2011.)



Lesions caused by *P. coffeae* in banana roots. (Source: Soto, 2008.)



Superficial lesions caused by *H. multicinctus* in banana roots. Source: Coyne and Kidane, 2019.

General Information

Nematodes are somewhat transparent, filiform animals with an unsegmented body that is covered by a hyaline cuticle, which has stripes or other marks; they have a round transversal cross-section, with a mouth but no extremities or other appendages (Guzmán, 2011; Agrios, 2005).

There are 146 species of nematodes reported in Musaceae, distributed in 43 genera. Of the total of nematodes, 10% correspond to phytoparasitic species representing an important factor for reduction in many crops.

According to Araya, cited by Salazar, et al., 2012, the most devastating and widely disseminated phytonematodes are the migratory endoparasites: *Radopholus similis*, *Pratylenchus coffeae*, and the semi-endoparasite *Helicotylenchus multicinctus*. *R. similis* (a borer nematode) is the most important in banana crops. Thus, in this study we will focus on the measures for managing and/or controlling *R. similis*, which are also applicable to the other species of nematodes that attack bananas.

- **Symptoms:** According to the mode of action of the different species, the symptoms vary from most severe, which is uprooting the plant, to the less obvious, such as prolonged production cycles (Morales, 2014). Bayer, cited by Sierra (1993), states that when the nematode populations exceed certain levels, symptoms appear in the aerial part, such as yellowing, wilting, which is especially strong at critical times, due to deficient water absorption; with reduced stalk diameter and reduction in the number and size of the leaves; delayed growth of the daughters, reduced size and weight of the bunches, plantation degeneration and the need to re-establish or renovate in just a few years, loss of anchorage and possible plant falls.
- **Damage: López,** cited by Sierra (1993), mentions several types of damage produced by nematodes: they invade the root system, destroying it; they reduce the anchorage, causing plants to fall with a consequent loss of the bunch; they drain the strength of the crop and cause nutritional deficiencies; they are the entry way for numerous diseases caused by microorganisms; they cause fertilizer waste as well as destroying the plants' defense mechanisms by interfering with their enzymatic system.
- *R. similis* is the most abundant and the main phytoparasite species constituting between 82 and 97% of the nematode population in roots and corms (Guzmán, 2011); and when this phytonematode isn't controlled, it reduces the bunch weight and, yield is reduced (t ha⁻¹) due to the effect of uprooting, between 60 and 52% in first and second harvest, respectively. But yield reduction may go as high as 80% (Guzmán, 2011).



Banana plant uprooted with severe damage from *R. similis*.
(Source: Licona and Mldonado, n.d.)

- **Favored by:** The nematodes are concentrated primarily within the first 50 cm of depth. Their mobility is minimal, some of them being able to travel a few centimetres throughout their lifetime, so that their diffusion operates by external means, such as agricultural machinery, irrigation water, humans and animals, among others. They move more rapidly when the soil is wet (Sierra, 1993).

Prevention:

- Use clean nematode-free planting material. Submersion of seed or corms in 52-55 °C water for 15-27 minutes is recommended. These baths are very efficient for eliminating nematodes (Gold and Messiaen, 2000).
- Whenever possible, use plants sourced from in vitro tissue cultures (Sarah et al., 1996).
- Before establishing a crop, try solarization; that is, treating the soil with heat from solar radiation. Sun exposure of "peeled" material for two weeks may further reduce nematode populations. However, this technique should not be used on small suckers, since they are quite fragile and need to be replanted rapidly (Sarah et al., 1996).
- Optimal soil preparation should be carried out before planting, for better growth and development of root systems in loose soils. This will result in greater amounts and longer roots, as opposed to what will happen in heavy and compacted soils.
- Constant incorporation of well-processed organic conditioners, such as chicken manure, coffee pulp, vermicompost, bokashi, ash, swine manure, etc., will promote root health and vigor in Musaceae crops, enabling them to better compete against nematodes.
- Apply a balanced fertilization to the plants.
- Provide adequate water layers through the irrigation system according to banana crop requirements.
- Application of banana or plantain rachis leachates can reduce phytoparasitic nematode populations, but their mechanism of action is still unclear (Salazar et al., 2012)
- Land where Musaceae plants have been grown should be left unplanted (fallow) for six months or more, up to two years, so it can rest. Sarah et al., 1996, has indicated that nematode populations can be reduced to imperceptible levels after a single year of remaining fallow, using non-hosting crops such as *Chromolaena odorata* (Asteraceae), which is very efficient in Africa, and *Panicum maximum* (Poaceae) in Queensland (Australia) (Coyne and Kidane 2019). In the Cote d'Ivoire, rotation with pineapple (*Ananas comosus*) contributed to reduction of *R. similis* populations (Coyne and Kidane, 2019) and rotation with sugar cane (*Saccharum officinarum*) was somewhat successful in Central America (Coyne and Kidane, 2019).



- **Mechanical Control:** Considering that *R. similis* survives in infected corms and roots, remove external layers of “peeled” rhizomes to eliminate infected tissue and reduce nematode populations; furthermore, this practice allows for inspection of white tissue, in order to detect the presence of weevils. Sanitary cleansing of corms by “peeling” should be carried out outside the fields and severely damaged necrotic corms should be discarded. Only clean corms should be used for planting (Guzmán, 2011).
- **Biological control:** The most commonly used entomopathogenic fungi against *R. similis* in banana crops are probably those based on the *Purpureocillium lilacinus* (formerly known as *Paecilomyces lilacinus*). There are several commercially available products and formulations. The fungus attacks eggs, juveniles and adults. Results vary depending on conditions, however, in general they exert a good level of control and are financially viable. It has been demonstrated that banana root invasion by *R. similis* is inhibited by entomopathogenic bacteria like *Bacillus* species, such as *B. firmus* and *B. subtilis*, as well as *Pseudomonas fluorescens* (Coyne and Kidane, 2019). *Pasteuria* spp., which are nematode parasitic bacteria, differ with respect to their range of hosts and their pathogenicity towards nematodes. It has been found that *Pasteuria penetrans* is an *R. similis* parasite (Coyne and Kidane, 2019) but this species has not been fully developed as agent against this pest. Diverse trials have been carried out on use and inoculation of endophytic fungi (*Trichoderma* spp. and *Fusarium* spp.) in greenhouse vitroplants with promising results. According to Meneses (2003) and Morales (2014), the endophytic fungi *Trichoderma* spp. and *Fusarium* spp. cause 75% to 100% reductions of *R. similis* populations. Improved results were obtained by combining both species of bacteria. Furthermore, the plants developed greater radicular weight and superior growth when free of nematodes. Lastly, growth promoting effects in plants caused by arbuscular mycorrhizal fungi not only provide potential benefits for banana, but they have also been shown to reduce infection and damage by *R. similis* (Coyne and Kidane, 2019). Total *R. similis* density decreased by 60% and root necrosis by 56% in arbuscular mycorrhizal fungi- colonized banana seedlings under greenhouse conditions (Coyne and Kidane, 2019). However, as has been repeatedly seen when evaluating and applying biological control agents, reactions can be fairly specific depending on the host cultivar and control agent species or strains (Coyne and Kidane, 2019). With respect to chemical control with natural products, neem (*Azadirachta indica*) formulations stand out for providing good management of banana nematodes (Coyne and Kidane, 2019). It has been shown that sesame-based products, essential oil mixtures containing sesame or garlic, furfuraldehydes and *Myrothecium verrucaria*-based products are very toxic for nematodes and can provide a very promising *R. similis* reduction.



- **Threshold:** The threshold triggering nematicide application will depend on local parameters, such as climate and soil conditions and pathotype aggressivity. For this exercise to be worthwhile, verification should be based on precise nematode counts. Nematodes should be extracted from vegetative material and surrounding soil, using approved protocols (Coyne and Kidane, 2019). In the North coast of Guatemala, the following are the defined critical levels or action thresholds:
 - Functional root weight under 50 gr/plant.
 - Dead root percentage greater than 10%.
 - Nematode populations between 30,000 and 40,000 *R similis*/100 gr roots.
 - Uprooting greater than 3 plants/ha/week.
 - Bunch weight reduction greater than 10%/6-month period.

In other Central American (including Costa Rica) and South American countries, a population level of 10,000 specimens/100 gr roots is used.



7.2 Common diseases in banana

Black Sigatoka (*Mycosphaerella fijiensis*)



Early ripening of the fruit in transit due to problems with Black Sigatoka. ³³



General Information

Black sigatoka is caused by a fungus (*Mycosphaerella fijiensis*) that attacks bananas and plantains. It is present throughout the tropics. Dissemination is carried out by wind, water and human carriers. This is a polycyclic disease that will always be present in a permanent crop. Reproduction is by asexual (conidia) and sexual (ascospores) means.

- **Symptoms:** The fungus mainly attacks the leaves and it is characterized by a great number of streaks and spots, particularly noted on the underside of the leaves. All stages of the disease will be found in a plantation; initial symptoms are virtually imperceptible streaks that will develop towards later stages with symptoms of necrosis and burning of the foliar area.
- **Damage:** This is the most destructive of foliar diseases and the one with the greatest economic crops losses in banana. Without control measures, losses can reach up to 50% of the yield and up to 100% of production due to quality issues for export. Costs for managing this disease are high – between 15 and 18% of total production costs.
- **Predisposing conditions:** High temperature, high levels of precipitation, high humidity, poor drainage, poor nutrition
- **Prevention:** Preventive actions are focused on constant monitoring and appropriate management of cultural practices:
 - Adequate nutritional level in the plantation; elements such as silicon, copper, calcium, boron and zinc contribute towards reducing severity of the disease ³⁶.
 - Promote ideal moisture conditions in the soil (avoid excessive accumulation, such as puddling).
 - Adequate weed management or control to prevent greater moisture accumulation.
 - Avoid unnecessary loss of leaves due to other causes or practices (protective defoliation, deflowering, bagging, harvesting); should be avoided as much as possible.

³³ Source: Taken from personal files 2019

³⁶ Guzmán & Paladines, n.d



A banana plant without functional leaves due to poor black sigatoka management.³⁴



A banana plant that is ready for harvest and has lost all its foliage due to poor black sigatoka management.³⁵

- Application of a mixture or 10% solution of urea on leaves with sigatoka that are on the ground, thus accelerating vegetal matter decomposition and reducing the inoculum.

- **Mechanical Control**

- Trimming, consisting of cutting off the apical portion of the leaf.
- Surgery, a practice that only eliminates the affected area of the leaf.
- Delamination, whereby a longitudinal half of the leaf is removed because of high infection of the foliar area.
- At a minimum, a weekly sanitary or sigatoka defoliation needs to be carried out in order to prevent accumulation of necrotic tissue affected by the sigatoka fungus; if necessary, two defoliation cycles per week should be executed.

- **Biological control:** Strains QST 713, FZB24, MBI600 and D747 of *Bacillus amyloliquefaciens* (sin. *B. subtilis*) or *Melaleuca alternifolia* (FRAC, 2018)

- **Threshold:**

- Position of streak in leaf 8 (HJE)
- Position of late spot in leaf 12 (HJMT)
- Number of leaves to flowering or parturition 12
- Number of leaves to harvest 6 leaves
- 5. Severity of the disease greater than 1

³⁴ Source: Ronny Mancilla, 2019

³⁵ Source: Ronny Mancilla, 2019.



Moko or bacterial wilt (*Ralstonia solanacearum*)



External Moko symptoms. (Source: Taken from Dita, 2020.)



Premature ripening from Moko in a banana bunch. (Source: Personal files, 2001.)

General Information

This important banana disease is caused by the bacteria *Ralstonia solanacearum* race 2, which is a natural soil inhabitant. Triploid bananas are attacked by at least four race 2 types: D or distortion, B or Bananas, SFR (Semi-Fluid Round) and H.

- **Symptoms:** Because this is a systemic disease, symptoms may appear at any phenological stage of the crop and all organs of the plant, from the roots to the bunch, may be infected and may exhibit symptoms. External symptoms consist of plant wilting and yellowing, younger leaves dry up and break without falling from the plant and the cigar leaf suffers necrosis. Suckers and regrowth from diseased plants may remain small, twisted and blackened. Leaf edges dry up and an intense yellow streak follows. Deformed bunches and fingers, some fruit ripens prematurely, and fingers split open when the bunch is very developed. The male bud dries up, followed by the stem until the entire bunch dries up (Alarcón y Jiménez, 2012).
- **Damage:** Moko is one the major diseases attacking banana crops and can cause great economic losses if not adequately managed. Moko destroys the bunch and prevents the plant from completing its vegetative cycle. (Martínez y García, 2004, cited por Álvarez et al., 2013).
- **Predisposing Conditions:** This bacteria are transmitted or disseminated by infested tools used in crop practices, vector insects, transport of crop residues or infected materials and infested soil, contact of diseased plant roots with healthy plants caused by nematode populations moving from one plant to another, and by planting in infested areas. The bacteria can disseminate by water runoff in canals, rivers and streams, by machinery, host weeds and, in general, any mobile medium introduced by humans (Alarcón and Jiménez, 2012; Álvarez et al., 2013).
- **Prevention:** Available prevention mechanisms are the use of clean seeds; worker and visitor footwear and tool disinfection at the time of defoliation; removal of host vegetation³⁷ and signage at the affected sites (Mesa and Triviño, 2007, cited by Álvarez et al., 2013).
- **Mechanical Control:** Eradication of plants with disease symptoms. Eradication of Moko cases consists of eliminating the sick and all neighboring plants in an 18-foot (5.5 meter) radius. Each diseased plant

³⁷ The following are the carrier weeds of the variant causing crop damage:

Heliconia latispatha, *H. caribae*, *H. acuminata*, *H. imbricata*, *H. bihai*, *Brassica campestris*, *Datura stramonium*, *Solanum caripense*, *Solanum nigrum*, *Cyphomandra betacea*, *Lycopersicon sculentum*, *Photomorpe peltata* & *Physalis anguata*.



Internal Moko symptoms (Source: Dita, 2020.)

within an 18-foot radius will cause a new case, thus new plants within an 18-foot radius must be removed.

- **Non-chemical Control:** Arenas et al., 2004, cited by Álvarez et al., 2013, determined that the *R. solanacearum* bacterial population could be reduced by 84.7% by adding French marigold flowers (*Tagetes patula*) to the soil. Furthermore, pathogenic bacteria in the soil were significantly reduced after applying other sources, such as a 58.2% control with liquid fertilizer (composed of 2.7% total nitrogen, 1.7% phosphorus, 5% potassium, 12% fulvic acids, and 5% humic substances); a 50.8% reduction after adding Calfos and 31.6% with banana stalk compost lixiviate.
- **Threshold:** The appearance of a single plant requires eradication. Quarantine should be set when 5 or more cases in a single cable appear within a 6-month period or less.



Fusarium (*Fusarium oxysporum* f.s. *cubense* race 4) (TR4)

Dita et al. (2017) indicate that Fusarium wilt in Musaceae (also known as Panama disease due to its early 20th century impact in this region) is caused by the fungus *Fusarium oxysporum* f. sp. *cubense* (Foc). This is the most destructive disease in Musaceae (the family including bananas and plantains) and it is considered among the ten most significant diseases in the history of agriculture. In the Americas, race 1 triggered an epidemic that impacted the banana export industry, which is based on the Gros Michel variety, and caused the destruction by United Fruit of more than 379,000 hectares just in Central America (May and Plaza, 1958; Stover, 1972) with an economic impact of approximately US \$2,300 million in the 50s and 60s. Substitution of 'Gros Michel' with resistant clones of the Cavendish subgroup, currently representing almost all export bananas planted in the Americas, was the only solution to this problem.

For a long time, Cavendish subgroup clones were affected by the pathogen solely under conditions of nutritional stress and low temperature, such as those seen in bananas grown in subtropical regions. However, at the beginning of the 90s, a new race was reported in Southeast Asia, known as tropical race 4 (R4T), which severely attacks Cavendish subgroup varieties under tropical conditions. The rapid dissemination of this race and its pathogenic capacity are a serious threat for the Latin American and Caribbean banana industry. An additional factor to consider is that Foc R4T can affect other important varieties for food security and income generation aside from Cavendish group varieties, among which can be the following: plantains (AAB), Bluggoe cooking bananas (ABB), Gros Michel (AAA), Prata (AAB) and Manzano (AAB). Considering the above precedent, Foc R4T entering Colombia in 2019 evidently places the remaining American continent in jeopardy; a menace that could impact food security in the region.

In Southeast Asia, vast areas planted with Cavendish subgroup varieties have been affected by Foc R4T, causing multi-million losses. Damages are not only associated with losses from diseased plants but also with the cost of necessary management measures and technological changes which implementation has been required for disease impact minimization.

Exclusion (preventing entry) is the best option for avoiding the impact from Foc R4T in Musaceae production in a given country. Once this pest invades an area, severe phytosanitary measures must be implemented to forestall pathogen movement from infected to uninfected areas. These strict measures are costly and require trained personnel for pest recognition and management.

Fusarium wilt symptoms

The term and concept of race has been used to classify *F. oxysporum* f. sp. *cubense* strains after the 1950s (Stover, 1962). Foc races have been named based on pathogenicity of the different reference varieties under field conditions. Four Foc pathogenic races have been described (Stover y Waite, 1960; Stover, 1962; Moore et al., 1993; Su et al., 1998).

Race 1 attacks Gros Michel (AAA), Manzano (Silk, AAB), Pome (AAB) and Latundan clones; race 2 affects Bluggoe and other ABB genome clones; race 3, which was previously described (Stover, 1962; Waite y Stover, 1960) attacks heliconia (*Heliconia* spp.); and race 4 is pathogenic for Cavendish and all susceptible cultivars to races 1 and 2 (Dita et al., 2017).

Fusarium wilt typical symptoms result from severe water stress caused by clogging of the xylem and from the combination of pathogenic activities such as mycelia accumulation, toxin production, and/or host defense responses, including tylose and gum production and crushing of vessels due to associated parenchymatous cell growth (Beckman, 1990; Xiao et al., 2013).

The different Foc races cause similar symptoms in Musaceae; thus, races cannot be differentiated based on symptomatology (Stover, 1962; Ploetz, 1990; Ploetz y Pegg, 2000).

The disease is characterized by two types of external symptoms: the yellow leaf "syndrome" and the green leaf "syndrome" (Stover, 1962; Pérez-Vicente, 2004).

Yellow leaf "syndrome": this is the most classic and distinctive external symptom of Fusarium wilt in bananas. Early on in the infection process, is characterized by yellowing of the edges



of older leaves (this symptom can be initially confused with potassium deficiency, particularly under dry or cold conditions). Leaf yellowing progresses from older to younger leaves. Eventually, the petiole bends and leaves collapse or, most commonly, leaves buckle towards the central vein and hang around the pseudostem, forming a skirt of dead leaves.

Green leaf “syndrome”: As opposed to the yellow leaf syndrome, in some clones leaves of affected plants will predominantly remain green until petioles bend and leaves collapse.

In general, younger leaves are the last to show symptoms and frequently will remain erect, giving the plant a “spiky” appearance. An infected plant will continue growing and emerging leaves are usually paler than healthy leaves. The blade in emerging leaves may be markedly reduced, wrinkled, and distorted. Longitudinal cracks may develop in the pseudostem. There is no evidence of symptoms in the fruit.

Internal symptoms are characterized by vascular coloring that starts with yellowing of root and corm vascular tissue, progressing to form a yellow, red, or dun continuously colored vascular bundle in the pseudostem, which is typical for the disease. In very susceptible clones, colored bundles on leaf petioles can be seen.

In some cases, Fusarium wilt caused by Foc has been confused with Moko bacterial wilt caused by *Ralstonia solanacearum* race 2. The following criteria can be used to differentiate between these two diseases:

- In Fusarium wilt, symptoms progress from older to younger leaves. In bacterial wilt or Moko, symptoms usually progress from younger to older leaves;
- In bacterial wilt, young suckers emerging from the rhizome are distorted and rotten and can die. In Fusarium wilt, young and growing suckers show no symptoms.
- In Moko, bacterial exudation is seen in all tissues when cut (roots, pseudostem, stem, flowers and rhizome, etc.). In Fusarium wilt, there is no exudation.
- In Moko, there is internal necrosis and rotting in the fruit, while in Fusarium wilt, no symptoms are apparent in the fruit. (Dita et al., 2017).

Prevention

Action lines to prevent entry of the pathogens in the farms (exclusion):

Foc R4T can remain in the soil for several decades, even if bananas are not grown. Currently there are no known effective measures for eradication from contaminated soil (Ploetz 2018, cited by Guzmán et al., 2018). Countries that are still free from this pathogenic race can continue being so with joint efforts for exclusion of the pathogen. Implementation of basic prevention measures in farms such as the following, can substantially contribute to reducing entry and dissemination risk:

- Farm biosafety
- Use of disease-free planting material
- Management of biotic factors favoring the disease, such as weevil and nematode attacks
- Management of soil abiotic factors, pH, nutrition [P, Ca, Zn & N], silicon, use of N sources that increase NO₃ and reduce NH₄, calcium, since whitewashing increases soil suppressiveness and reduces chlamydospore germination (Höper et al., 1995; Peng et al., 1999); iron, as reducing availability increases soil suppressiveness (Scher y Baker, 1982) and reduces chlamydospore germination (Peng et al., 1999), adequate drainage network maintenance.
- Soil health-oriented fertilization (organic matter + beneficial microorganisms that suppress the pathogen and/or promote plant growth, etc.), compost, green fertilizers.
- Acid soils (pH <5.0) are more favorable for the disease; pH over 5.6 is less optimum for the fungus.



- At present, no tolerant and/or resistant varieties or hybrids are available in the market that provide adequate quality fruit which is acceptable for marketing. In Taiwan, GCTV 119 and GCTV 218 somaclones with partial resistance are used; however, these are reinfected over time.
- Crop rotation with non-hosting plants for Foc R4T, although this practice is not possible in commercial plantations.
- Use of cover crops (Dita, 2020).
- Keeping an updated registry of all persons entering the farm.
- Restricting non-authorized persons from entering the farm and not allowing entry of people that have been in countries with Foc R4T in the last three months.
- If for some reason it is strictly necessary that a person such as indicated above should enter the farm, he or she should comply with a biosafety protocol, including: use of farm-provided footwear, clean clothing and refrain from introducing tools or equipment that has been previously used in countries having Foc R4T, all of which should nevertheless be disinfected beforehand. All tools should be provided by the farm.
- Farm vulnerable boundaries and main entrance should be protected with fences or defenses to ensure people move solely through safe areas.
- At principal entry points in the farm (including the packing plant), use of footbaths for shoe disinfection should be mandatory and these should be kept clean and in good condition. Additionally, establishing sites for vehicle disinfection (fire baths) and sanitation tunnels are highly recommended.
- Before entering a farm, visitors should change their footwear for farm-provided rubber high-leg boots, which have been duly cleaned and disinfected and are preferably not black in color.
- Workers should be trained in prevention methods for the disease. Instruction should include mandatory tool disinfection before going to the files and periodically during the workday. Disinfection of both blade and handle of tools should be considered, as well as other utensils such as sheaths, files, ropes and strings, stakes, among others. Tools should be exclusively used on the farm; therefore, removing them from the farm should be prohibited unless such a practice is duly authorized and biosafety measures have been taken.
- Workers should be trained and informed about the disease's symptoms. They should be instructed to inform farm administrators if any plant with symptoms similar to Foc R4T is detected and what procedure should be followed. Workers should never cut down a suspicious plant.
- Any type of machinery or agricultural equipment to be used in the plantation should be thoroughly washed and disinfected before entering or leaving the farm.
- Disinfectants with proven efficacy against the pathogen should be used to disinfect tools, machinery and agricultural equipment and in footbaths (Taken from Guzmán et al., 2018).



Type of disinfectant	Recommended dose (mg/L) ¹ Residual effect up to seven days	
	For use in tool disinfection	For use in footbaths and agricultural equipment disinfection
Quaternary ammonium	2,000	4,000
Iodophor	2,000	4,000
Glutaraldehyde	1,000	3,000

¹/ Doses recommended for their efficacy in eliminating chlamydospores, based on studies carried out by CORBANA on Foc race 1, with high inoculum concentrations, soil and organic matter. Source: Guzmán et al., 2018.

Monitoring

This activity is carried out solely and exclusively in countries and/or farms having Foc R4T in order to characterize Foc R4T incidence in infected areas (Dita et al., 2017). However, each farm should have technical staff that has been trained in Foc R4T symptoms so plants with symptoms similar to this disease are promptly detected (suspicious plants). Such plants must be isolated and confined to prevent the risk of dissemination of the fungus and Ministry of Agriculture authorities in each country should be immediately notified so the confirmatory molecular diagnosis can be executed.

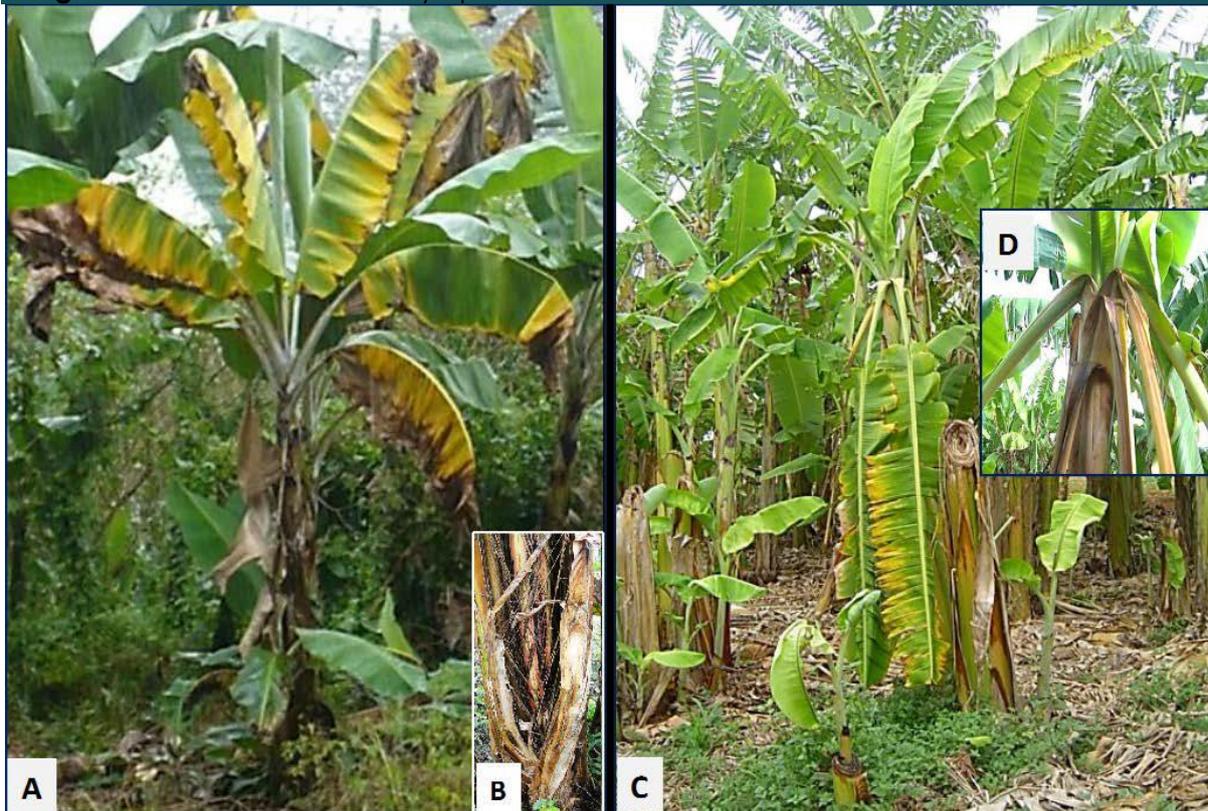
Control and intervention

Just like monitoring, control activities are carried out solely and exclusively in countries and/or farms having Foc R4T, in order to contain, suppress and eradicate detected Foc R4T cases (Dita et al., 2017).

For further information on monitoring, control and intervention, the OIRSA document is recommended as the basis for a contingency plan when facing a tropical race 4 (Foc R4T) outbreak. This very complete text includes all legal, technical, and scientific guidelines for Foc R4T management, with exclusion, suppression, and eradication measures. The document was prepared and is frequently updated by professionals who are experts on this disease. It is available at: https://www.oirsa.org/contenido/2018/Sanidad_Vegetal/Manuales_OIRSA_2015-2018/Plan_conting_FOC_R4T_2017-V2-Final-FEB18-2017.pdf



Image 1: Fusarium wilt external symptoms in banana.

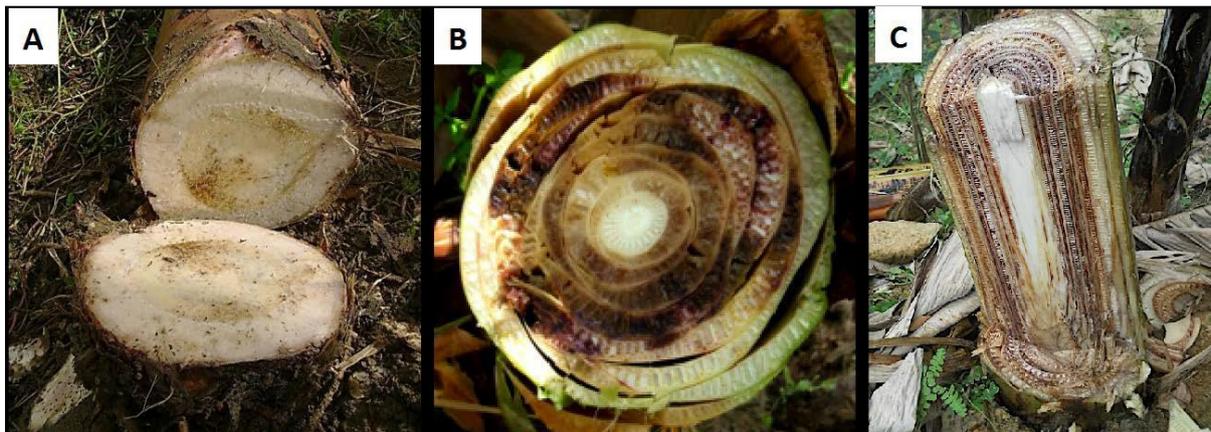


- A.** Plant with generalized chlorosis on the leaves ("Yellow leaf syndrome") at an advanced disease stage.
- B.** Cracks at the pseudostem base.
- C.** Plant affected by Fusarium wilt with green leaves ("Green leaf syndrome").
- D.** Detailed view of leaves breaking off at the petiole base.

(Source: taken from Dita et al., 2017)

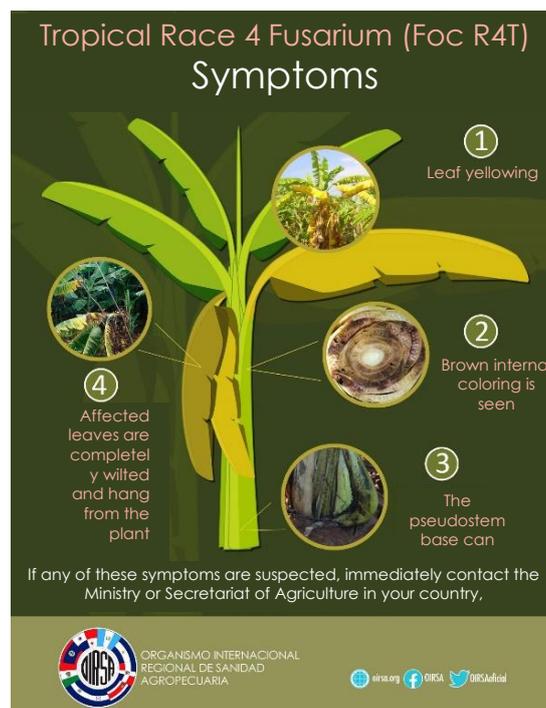


Image 2: Fusarium wilt internal symptoms in banana.



- A.** Cross section of the corm (rhizome) showing tissue necrosis.
- B.** Cross section of the pseudostem, showing advanced vascular tissue necrosis.
- C.** Longitudinal section of the pseudostem, showing vascular bundle necrosis.

Image 3: Infograph of Foc R4T Symptoms



Source: Infograph from OIRSA 2019 Foc R4T Course



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7.3 Natural enemies of banana (*Musa AAA*) pests and diseases.

Mealybugs/ *Planococcus citri* Riss/ *Dysmicoccus brevipes* Cokerell /*Pesudococcus jackbeardsleyi* Gimpel and Miller/*Pesudococcus elisae* Borchsenius/ *Ferrisa virgata* Cokerell.



Cryptolaemus montrouzieri adult³⁸



Cycloneda spp. adult preying on an aphid³⁹



Chrysopa spp. adult⁴⁰

Mealybugs

- **Mealybugs** have a large number of natural enemies, unfortunately the blanket application of pesticides affects the populations of these biocontrol agents. We will focus on the natural enemies considered to be of most importance.
- **Predators:** two coccinellids, *Cryptolaemus montrouzieri* and *Cycloneda* spp. and a neuropter (*Chrysopa* spp.) (Cubillo 2013).
- *Cryptolaemus montrouzieri* is a polyphagous species. The small larvae, and the adults, prefer to feed on mealybug eggs while the older larvae have a preference for all mealybugs life stage .
- *Cycloneda* spp.: is a polyphagous species, voracious predators of soft-bodied insects such as aphids, mealybugs, mites, coccids, and immature stage of lepidoptera and Homoptera, they also feed on honeydew and flower nectar. They are density dependent and therefore are able to switch from one area to another where the prey is more abundant. They prefer the underside of leaves, almost always close to a colony of aphids or other pests. It is a very efficient insect predator and a biological control agent thanks to its voracity, functional response and numerical response. Its pupa has the amazing ability to “bite” potential prey⁴³.

Lacewings

- *Chrysopa* spp.: The voracity of the larvae makes them one of the most favored biological control agents in agricultural crops.⁴⁴
- Larvae of all species and adults of some genera are predators and feed on a wide variety of phytophagous insects such as mealybugs, aphids, whiteflies, and other soft-bodied insects found on the foliage. For this reason, some species are currently being mass produced and released in the field for the biological control of agricultural pests⁴⁵.

³⁸ Source: controlbiologico.info - Cochinillas

³⁹ Source: Google Image Search

⁴⁰ Source: https://upload.wikimedia.org/wikipedia/commons/thumb/9/99/Chrysopa_perla01.jpg/250px-Chrysopa_perla01.jpg.

⁴³ EcuRed 2020

⁴⁴ Oswald et al., cited by Valencia et al. 2006

⁴⁵ New, Adams & Penny, Hunter, Arredondo, cited by Valencia et al., 2006.



Chrysoperla spp. larva preying on an aphid⁴¹



Allotropa musae adult⁴²

- Chrysoperla spp.: from the same family as Chrysopa spp. Chrysoperla spp.
- Its larvae has been observed preying on more than seventy different species of insects belonging to five separate orders. Most of the prey belong to the Homoptera order (sucking pests including mealybugs).
- Adults are not predators but feed on pollen and sugary substances. However, they have also been identified in agricultural crops attacking various species of aphids, spider mites, thrips, whiteflies, caterpillar eggs, leaf miners, psyllas, small moths and caterpillars, beetle larvae. They are also considered important predators of mealybugs in greenhouses.
- **Predators** of mealybugs are Hemerobius sp., Sympherobius maculipennis, Sympherobius sp. (Neuroptera: Sympherobiidae), Scymnus nitidus, Hyperaspis funesta (Coleoptera: Coccinellidae).⁴⁶
- **Parasitoids**: of the Encyrtidae families (ex. *Anagyrus spp.*, *Acerophagus spp.* and *Leptomastix spp.*), *Platygasteridae* (ex. *Allotropa spp.*)⁴⁷
- *Allotropa musae* is a parasitoid not commercially-available. Described for the first time in 2004, it parasitizes the first-growth stages of the pest and is most frequently found on petioles and leaves.⁴⁸

⁴¹ Source: https://upload.wikimedia.org/wikipedia/commons/thumb/e/ee/Chrysoperla_camea_larva02.jpg/220px-Chrysoperla_camea_larva02.jpg.

⁴² Source: Hernández 2011.

⁴⁶ New, Adams & Penny, Hunter, Arredondo, cited by Valencia et al., 2006

⁴⁷ Hernández, 2011; Waterhouse, cited by Cubillo 2013

⁴⁸ Hernández, 2011; Waterhouse, cited by Cubillo 2013



Scales/ Diaspis boisduvalli Signoret/Aspidiotus destructor Signoret/Chrysomphalus aonidium Linn.



Aphytis sp. adult⁴⁹



Pentilia spp. adult⁵⁰



Insect parasitized by *Beauveria bassiana*⁵¹

- **Parasitoids:** Hymenoptera of the Aphelinadae family such as *Aphytis* sp., *Coccobius* sp., and the Encyrtidae family, for example *Plagiomerus* sp.⁵²
- *Aphytis* sp.: are ectoparasitoids which place an egg under the shield of scales and mealybugs, depositing it on the body of the victim after having paralyzed them. In addition, a large part of *Diaspis* die directly when the parasite pierces them with its ovipositor, aiming to feed on the fluids that arise from the wound they have just caused. This predatory action (nutritional bites) constitutes a very important step in the field for *Diaspis* control.
- **Predators:** predatory ladybugs *Cryptolaemus montrouzieri*, *Pentilia* spp. and *Delphastus* spp. (Coleoptera: Coccinellidae) and lacewings *Chrysoperla* sp. and *Ceraeochrysa* spp.⁵³
- **Entomopathogens:** *Beauveria bassiana*: Capable of infecting more than 200 species of insects. It is powdery in appearance, cottony white or creamy yellowish in color.
- The spores of the fungus land on the insect's cuticle, germinate and penetrate the cuticle and the fungus penetrates the insect soft tissues. Once inside the insect, the fungus branches its structures and colonizes the host cavities. Then it starts producing a toxin called Beauvericin that helps to break down the host's immune system, which facilitates the invasion of all tissues by the fungus. After the death of the insect, the fungus multiplies its infective units (hyphae) which grow simultaneously, and ultimately invade all the insect tissues and become resistant to decomposition, apparently due to the antibiotics secreted by the fungus.⁵⁴

⁴⁹ Source: <http://gipcitricos.ivia.es/wp-content/uploads/2010/07/A.-melinus-1-206x155.jpg>.

⁵⁰ Source: Google Image Search

⁵¹ Source: Google Image Search

⁵² Cubillo 2013; Solano 2019

⁵³ Guillén et al., Guillén and Laprade, cited by Solano 2019; Cubillo 2013

⁵⁴ INTAGRI 2020



Banana weevil / *Cosmopolites sordidus* Germar.



***Plaesius javanus* adult⁵⁵**



Tetramorium guineense adult⁵⁶



Black weevil adult (*C. sordidus*) parasitized by *Beauveria bassiana*⁵⁷

- The insect larvae have the following **predators**: *Plaesius javanus*, *Hololepta quadridentata* (Coleoptera: Histeridae) and *Dactylosternum hydrophiloides* (Coleoptera: Hydrophilidae), ants: *Pheidole megacephala*, *P. guineense*, *Azteca* sp. and *Tetramorium guineense* (Hymenoptera: Formicidae).⁵⁸
- *Plaesius javanus*: is considered a native to Southeast Asia, specifically the islands that comprise Indonesia such as Java and Sumatra. *P. javanus* was introduced to numerous countries in Asia, Africa and the Americas. It was released in the wild in 29 countries or islands, and it has become established in 12 (41.4%): Cook (Islands), Fiji, Guam, Jamaica, Marianas (Islands), Mexico, New Caledonia, Puerto Rico, Samoa, Tahiti, Tonga and Trinidad. *P. javanus* can consume up to eight fully developed larvae of *C. sordidus* per day.⁵⁹
- Based on laboratory tests, *P. javanus* larvae and adults attacked 75-88% of the larvae and 38-53% of *C. sordidus* pupae placed in tunnels made artificially in plant parts⁶⁰. However, attempts to introduce these natural enemies into other banana regions were largely unsuccessful. Research on endemic predators (beetles and earwigs) in Africa suggests only a limited potential for control under field conditions⁶¹.
- *Tetramorium guineense*: ants are capable of locating and preying on some *C. sordidus* larvae⁶².

⁵⁵ Source: Google Image Search

⁵⁶ Source: Google Image Search

⁵⁷ Source: Ramirez y Torres 2016.

⁵⁸ Sirjusingh et al. and Sponagel et al., cited by Cubillo 2013; Gold and Messiaen 2000

⁵⁹ Jepson, cited by Arredondo and Rodríguez 2015

⁶⁰ Arredondo and Rodríguez 2015

⁶¹ Gold and Messiaen 2000

⁶² Castañeda 2016



- **The entomopathogenic nematodes (EPNs)**, *Steinernema* spp. and *Heterorhabditis* spp., attack both adult weevils and larvae in the field (Gold and Messiaen 2000). The diversity of isolated strains presents a wide range of hosts. The ability of EPNs to eliminate pest insects in 24-48 hours, as well as the development of commercial formulations, make them an alternative for controlling *C. sordidus* in banana plantations⁶³. However, since EPNs can be affected by environmental conditions, such as temperature, solar radiation (UV rays) and soil characteristics like acidity, organic matter and texture⁽⁶⁴⁾, strategies are needed to improve their survival in the field, such as the use of different encapsulation methods⁶⁵ or strain isolation adapted to the agricultural ecosystem conditions.
- **Entomopathogenic fungi:** *Cordyceps bassiana*, *Beauveria bassiana* Bals and *Metarhizium anisopliae* Metch are bio control agents of the insect⁶⁶. *B. Bassiana* is an entomopathogenic fungus currently used in general applications within the crop, placed in traps; this method renders the best infection and control results⁶⁷.
- Other reported larval and egg predators are *Euborellia annulipes* Lucas (Dermaptera: Carcinophoridae) and *Labia borelli* Burr (Dermaptera: Labiidae)⁶⁸, *Ontophagus* sp. (Coleoptera: Scarabaeidae)⁶⁹, *Eutochia* sp., (Coleoptera: Tenebrionidae),⁷⁰.

⁶³ Kaya; Hiltbold, cited by Vidaurre et al., 2020

⁶⁴ Bedding; Andaló et al., cited by Viaduarre et al., 2020

⁶⁵ Peters; Bogantes, Flores, Castellón, and Uribe, cited by Vidaurre et al., 2020

⁶⁶ Contreras, Carballo cited by Cubillo 2013; Maharaj & Khan; González et al., cited by Vidaurre et al., 2020

⁶⁷ Navas 2011

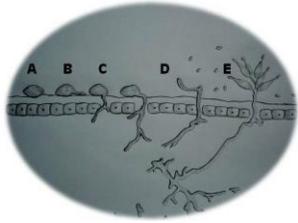
⁶⁸ Koppenhöfer, Tinzaara et al., cited by Navas 2011

⁶⁹ Cubillo et al., Ríos et al., cited by Navas 2011

⁷⁰ Castrillo, cited by Navas 2011



**Nematodes/ Radopholus similis (Cobb) Thorne/Pratylenchus coffeae Sher & Allen/Helicotylenchus multicinctus Cobb /H. dihyteria Cobb/
Meloidogyne incognita (Kofoid and White) Chitwood/ Meloidogyne javanica (Treub) Chitwood,**



- a) conidia adhesion to the nematode,
- b) conidia germination, c) penetration,
- d) fungus colonization nematode body,
- e) external growth and conidia production⁷¹



Antibiosis action of the endophytic fungus about the nematode.⁷²

- *Meloidogyne javanica* (Treub) Chitwood, fungus parasitizes nematode eggs, adults and cysts. It can also affect mobile nematodes found outside the roots. In this way, it can infect the nematode in any of these stages, causing death or preventing the nematode from completing its life cycle, thereby reducing populations in the field ⁷³.
- *Bacillus* species, such as *B. firmus* and *B. subtilis*, and strains of *Pseudomonas fluorescens* bacterium have been shown to inhibit the invasion of banana roots by *R. similis* ⁷⁴.
- Trials on the use and inoculation of endophytic fungi (*Trichoderma* spp. and *Fusarium* spp.) in *in vitro* plants at greenhouse level have shown really promising results. Meneses (2003) and Morales (2014) showed that the endophytic fungi *Trichoderma* spp. and *Fusarium* spp. reduced the *R. similis* populations from 75 to 100%, and obtained better results by combining both.

⁷¹ Source: Monzón et al., 2009.

⁷² Source: Meneses 2003.

⁷³ Monzón et al., 2009

⁷⁴ Aalten et al.; Mendoza and Sikora, cited by Coyne and Kidane 2019



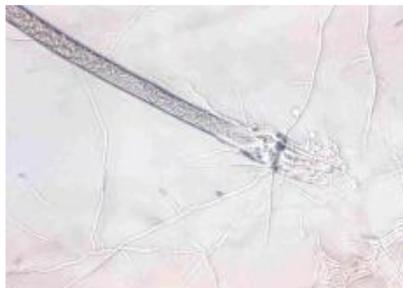
Weeds/Various genera and species.



Example of biological control in other crops. Symptoms of disease caused by *Fusarium oxysporum* FOXY 2 on *Striga hermonthica* (right) stems and control (left).⁷⁵

There are no known practical use references for biological control against specific banana and plantain weeds, but these crops will possibly benefit once current research identifies predators or pathogens for *Chromolaena odorata*, *Mikania micrantha* H.B.K. control and that of other weeds⁷⁶.

The biological control of weeds utilizes natural enemies that feed on the plant, including but not limited to insects, mites and nematodes, or they can also be controlled by diseases caused by fungi⁷⁷.



Antibiosis action of the endophytic fungus about the nematode.⁷⁸

Meloidogyne javanica (Treub) Chitwood, fungus parasitizes nematode eggs, adults and cysts. It can also affect mobile nematodes found outside the roots. In this way, it can infect the nematode in any of these stages, causing death or preventing the nematode from completing its life cycle, thereby reducing populations in the field⁷⁹.

Bacillus species, such as *B. firmus* and *B. subtilis*, and strains of *Pseudomonas fluorescens* bacterium have been shown to inhibit the invasion of banana roots by *R. similis*⁸⁰.

Trials on the use and inoculation of endophytic fungi (*Trichoderma* spp. and *Fusarium* spp.) in *in vitro* plants at greenhouse level have shown really promising results. Meneses (2003) and Morales (2014) showed that the endophytic fungi *Trichoderma* spp. and *Fusarium* spp. reduced the *R. similis* populations from 75 to 100%, and obtained better results by combining both.

⁷⁵ Source: Elzein y Kroschel 2004

⁷⁶ Terry 1996

⁷⁷ FAO 2004

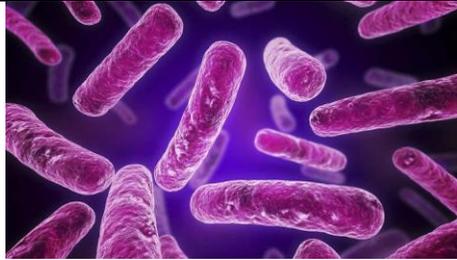
⁷⁸ Source: Meneses 2003.

⁷⁹ Monzón et al., 2009

⁸⁰ Aalten et al.; Mendoza and Sikora, cited by Coyne and Kidane 2019



Black Sigatoka *Mycosphaerella fijiensis* Morelet.



*Bacillus subtilis*⁸¹

- *Bacillus subtilis* QST-713 (sin. *B. amyloliquefaciens*): Biofungicide of protective and contact action. Lipopeptides, substances resulting from bacteria fermentation, destroy fungal structures' cell membranes (shattering the germ tube and mycelium of the fungus). It also creates an inhibition zone in the leaf, preventing pathogen attack and stopping pathogen growth competing for nutrients and space on the leaf's surface. It attacks target organisms exclusively, making it safe for fish, pollinators, and other beneficial organisms. Due to its natural origin, this product is harmless for human beings, and it has no use restriction in relation to the number of applications, it also helps to reduce the crop's chemical load⁸².



*Bacillus pumilus*⁸³

- *Bacillus pumilus* QST-2808: Biofungicide of protective and contact action. It inhibits the fungus by producing an amino sugar that interrupts cell metabolism and destroys the cell walls of the host. It also creates an inhibition zone on the plant surface, preventing the fungi from setting, stopping growth by nutrients and space competition on the leaf surface. It attacks target organisms exclusively, making it safe for fish, pollinators, and other beneficial organisms. Due to its natural origin, this product is harmless for human beings and it has no use restriction in relation to the number of applications, it also helps to reduce the crop's chemical load ⁸⁴.
- Other biocontrol agents under investigation are: bacteria: *Paenibacillus* spp., *Serratia* spp. and *Streptomyces* spp.; fungi: *Trichoderma* spp. and *Rhizophagus irregularis*. ⁸⁵.

⁸¹ Source: Google Image Search

⁸² Bayer, 2018; Guzmán, 2012; Guzmán et al., 2019

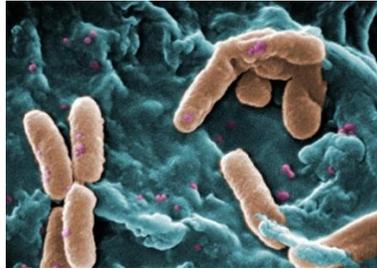
⁸³ Source: Google Image Search

⁸⁴ Bayer, 2018; Guzmán, 2012; Guzmán et al., 2019

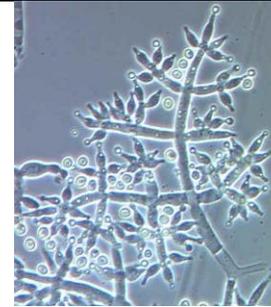
⁸⁵ Guzmán, 2012; Guzmán, et al. 2019



Black Sigatoka *Mycosphaerella fijiensis* Morelet.



Pseudomonas spp.⁸⁶



Trichoderma spp.⁸⁷

There are currently no commercially available biocontrol agents against Moko bacteria. Biocontrol agents under investigation are: Small populations of *Ralstonia solanacearum* race 2 (Smith), which were observed in banana plants (*Musa* AAB Simmonds)⁸⁸ and antagonist bacteria⁸⁹.

⁸⁶ Source: Google Image Search

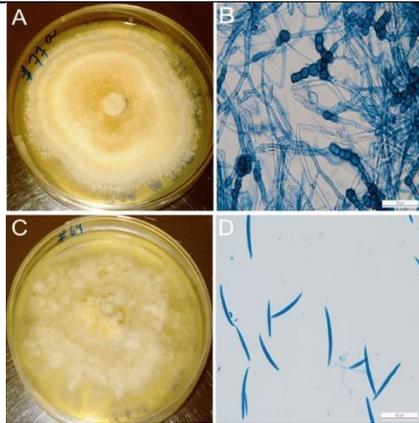
⁸⁷ Source: Google Image Search

⁸⁸ Alexopoulos and Mims, cited by Ceballos et al., 2014

⁸⁹ Guzmán et al., 2019

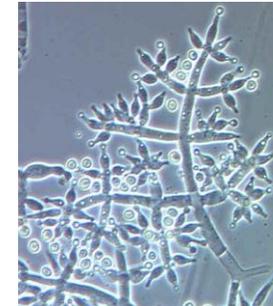


TR4 *Fusarium* banana wilt or banana fusariosis (*Fusarium oxysporum* f. Sp. cubense) – Foc .



Fusarium spp fungus growth in PDA medium (A and C). Chlamydospores of *Fusarium* spp (B). *Fusarium* spp spores (D)⁹⁰

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Trichoderma spp.⁹²

- There are currently no biocontrol agents in commercial use aimed at controlling TR4 (Foc).
- The perennial nature of the banana plant and the need for long-term efficacy of such controls are rarely considered when developing management strategies for this disease. Much of the literature on this topic reveals the results of short-term in-vitro or greenhouse studies with no indication that they have proven to be useful in the field.
- For example, although many biological control studies have been conducted, none of the published results indicates it would be helpful because of field cost effectiveness ⁹³.
- Biocontrol agents under investigation: There is experimental evidence that *Trichoderma* spp., non-pathogenic *Fusarium oxysporum* and some species of bacteria have potential for the biological control of TR4. However, this evidence has been obtained in studies carried out in vitro and in greenhouses⁹⁴. Scientific literature indicates that some soils are carriers of non-pathogenic isolates of *Fusarium* spp. or belonging to another special form, and act as suppressants to pathogenic strains ⁹⁵.

⁹⁰ Source: Google Image Search

⁹¹ Source: Google Image Search

⁹² Source: Google Image Search

⁹³ Ploetz, 2019

⁹⁴ Dita et al., 2017

⁹⁵ Amir & Alabouvette, cited by López and Castaño 2019



- Endophytic fungi volatile compounds isolated from *Musa* spp. have shown a highly significant inhibitory effect on Foc⁽⁹⁶⁾.
- Regarding other microorganisms, it has been documented that *B. subtilis* inhibits mycelial growth, colonizes plant tissues, reduces vascular discoloration and the incidence of the disease⁹⁷
- Studies have shown that:
 - *Serratia marcescens* can act as an inducer of enzymes production involved in the defense of banana plants, suppressing the incidence of the disease.⁹⁸
 - *Streptomyces griseus* affects the development of Foc, by inhibiting spores formation and degradation of fungus cell wall.⁹⁹
 - *Streptomyces violaceusniger* G10 inhibits mycelial growth and prevents conidia
- Endophytic fungi volatile compounds isolated from *Musa* spp. have shown a highly significant inhibitory effect on Foc¹⁰⁰.
- Regarding other microorganisms, it has been documented that *B. subtilis* inhibits mycelial growth, colonizes plant tissues, reduces vascular discoloration and the incidence of the disease¹⁰¹

⁹⁶ Ting et al., cited by López and Castaño 2019

⁹⁷ Sun et al., cited by López and Castaño 2019

⁹⁸ Ting et al., cited by López and Castaño 2019

⁹⁹ Zacky & Ting, cited by López and Chestnut 2019

¹⁰⁰ Ting et al., cited by López and Castaño 2019

¹⁰¹ Sun et al., cited by López and Castaño 2019



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8 IPM RESOURCES

IPM apps

"Pesticides and Alternatives" app: <https://www.rainforest-alliance.org/articles/app-for-integrated-pest-management>

You can download it free from the GooglePlay or iTunes app Store in English, Portuguese, or Spanish. Once it's downloaded, it can run offline so you can access it wherever you are. This app will provide you information about pesticides and its alternatives by country

Other resources on safe use pesticide handling, storage and transport of pesticides

FAO. 2008. Guidance on **Management Options for Empty Pesticide Containers**: http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/Containers08.pdf

CropLife guidelines for **container Management**: <https://croplife.org/crop-protection/stewardship/container-management/>

Template of the minimum type of information to be recorded for the IPM strategy:

Monitoring and recording data is a very important component of the IPM strategy to be able to know if there is success or whether you need to make any type of update or change in the strategy.

It will also help you in the annual update of the strategy. As a minimum - **record and keep the following information about each pest**:

1. Name of pest (local name, scientific name)
2. Time and location of occurrence:
3. Main natural enemies:
4. Threshold and sampling method:
5. Management:
 - Preventive measures
 - Control measures
 - o Non-chemical
 - o Chemical



9 EXAMPLES OF NATURAL ENEMIES

Example illustration	Beneficial organism	Pest controlled (prey or host)
Predators		
	<p>Ladybugs (Coccinellidae) larva and adult (several species)</p>	<p>aphids are the preferred prey, but will also eat mealy bugs, spider mites and other soft bodied pests and their eggs</p>
	<p>Delphibug (<i>Delphastus catalinae</i>)</p>	<p>Feeds on whitefly at all stages</p>
	<p>Adult (above) and larvae (below) and adult of Mealybug Destroyer (<i>Cryptolaemus montouzieri</i>). The larva resembles mealybugs and can be easily confused</p>	<p>Feeds on mealybugs and aphids</p>
	<p>Caterpillar of the Apefly butterfly (<i>Spalgis epeus</i>), which resembles its prey, the mealybug</p>	<p>Mealybugs</p>



	<p>Larvae and adults of the Predatory beetle (<i>Rhyzobius lophantae</i>)</p>	<p>Feeds on armored scales</p>
	<p>Larvae and adult of Vedalia beetle (<i>Rodolia cardinalis</i>)</p>	<p>Feeds on Cottony cushion scale, Citrus mealy bug</p>
	<p>Green Lacewing larvae (<i>Chrysoperla ssp</i>)</p>	<p>Aphids, mites and other insects</p>
	<p>Nymphs and adults of Predatory mite (family: Phytoseiidae)</p>	<p>Feeds on spider mites, whiteflies, thrips larvae, fly larvae, psyllid nymphs</p>
	<p>Gall midge larvae (<i>Feltiella ssp</i>)</p> <p>The adult can be easily mistaken for a small mosquito</p>	<p>Feeds on spider mites, aphids,</p>

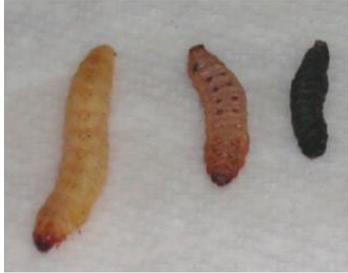


	<p>Adult of Predatory Bug (<i>Macrolophus ssp</i>)</p>	<p>Adult: preferred prey is whitefly, but will also prey on aphids, moth eggs and small caterpillars (incl. larvae of leaf miners), psyllid nymphs, nymph feeds on spider mites</p>
	<p>Adult of Predatory bug (<i>Orius ssp</i>)</p>	<p>Feeds on thrips nymphs and adult, aphids</p>
	<p>nymphs and adult of Praying Mantis</p>	<p>Feeds on grasshoppers, crickets, bees, wasps and flies</p>
	<p>Adult (above) and Larvae (below) of Hoverflies (several genera)</p>	<p>Feeds on aphids (adults feed on pollen and nectar)</p>



Parasitoids		
	<p>Parasitic wasp (several genera)</p>	<p>Parasitises whitefly larvae, aphids, mealybug nymphs, eggs and larvae of butterflies and moths, eggs of bugs, psyllid nymphs</p>
<p>Tiny <i>Trichogramma</i> wasp on fruit worm egg</p>	<p>Trichogramma wasp adult (several <i>Trichogramma</i> sp.)</p>	<p>More than 200 pest species, including cutworms, armyworms, fruit worms and many moth and butterfly eggs</p>
	<p>Braconid wasps adults (several species)</p>	<p>Parasitizes a broad range of pests (lepidoptera, coleoptera etc)</p>
	<p>Adult <i>Diglyphus isaea</i> wasp</p>	<p>leaf miner larvae</p>



Pathogens		
 <p>Healthy <i>Galleria mellonella</i> (waxworm) (left), infected with <i>Steinernerma carpocapsae</i> (middle), and infected with <i>Steinernema glaseri</i> (right)</p>	<p>Entomopatogenic nematode (<i>Steinernerma</i> ssp)</p>	<p>Kills thrips pupae, fly larvae, soil-dwelling caterpillars, and a large number of other insects</p>
 <p>Healthy grub (left) and grub infected with <i>Heterorhabditis bacteriophora</i> (right)</p>	<p>Entomopatogenic nematode (<i>Heterorhabditis bacteriophora</i>)</p>	<p>Infects soil-dwelling larvae of beetles, borers and weevils</p>
	<p>Entomopatogenic fungus <i>Metarhizium anisopliae</i></p>	<p>Infects and kills chafers, grubs, locusts, termites, leafhoppers, aphids, thrips, whitefly, weevils and ticks.</p> <p>Entomopathogenic Fungi should be used in a temperature range of 12 to 32 degrees Celsius and targeted to the pest.</p>
 <p>Whiteflies killed by <i>L. muscarium</i></p>	<p>Entomopatogenic fungus <i>Lecanicillium muscarium</i></p>	<p>Infects whitefly larvae, sometimes also pupa and adult.</p> <p>Entomopathogenic Fungi should be used in a temperature range of 12 to 32 degrees Celsius and targeted to the pest.</p>
	<p>Entomopatogenic Fungi <i>Beauveria bassiana</i> and <i>Isaria fumosorosea</i></p>	<p>Infect whitefly larvae, thrips.</p> <p>Entomopathogenic Fungi should be used in a temperature range of 12 to 32 degrees Celsius and targeted to the pest.</p>



 <p>Caterpillar killed by <i>Bacillus thuringiensis</i></p>	<p>Entomopathogenic bacteria <i>Bacillus thuringiensis</i></p>	<p>Larvae of several moths and butterflies</p>
 <p>Root infected by nematodes</p> <p>Root treated with <i>B. subtilis</i></p>	<p>Entomopathogenic bacteria <i>Bacillus subtilis</i> and <i>B. licheniformis</i></p>	<p>Infects and kills nematodes (several species)</p>

Predators – here are some more. Also birds, owls and bats are important predators. Spiders are some of the best predators (because of their numbers & species).



9.1 Other natural enemies

Assassin bugs



This adult assassin bug (*Zelus renardii*) is a common predator. It impales insects with its piercing mouthparts and injects a paralyzing venom.



The forelegs of this spined assassin bug (*Sinea diadema*) are thickened and have sharp barbs (raptorial forelegs) for holding prey. This polyphagous predator is widely distributed throughout the

LENGTH

Spined assassin bug



Adult leafhopper assassin bug



Egg cluster



Nymph



Damselflies

Damselflies (suborder Zygoptera)

Damselflies, typically being smaller than dragonflies, are sometimes confused with newly moulted dragonflies. However, once a dragonfly moults, it is already fully grown. There are other distinctions: 1. most damselflies hold their wings at rest together above the torso or held slightly open above, whereas most dragonflies at rest hold their wings perpendicular to their body, horizontally or occasionally slightly down and forward. 2. Also, the back wing of the dragonfly broadens near the base, while the back wing of the damselfly is similar to the front wing. 3. The eyes on a damselfly are apart; in most dragonflies the eyes touch.



Birds





Owls



Bats

- Bats are among your best friends.
- A single bat in an evening of feeding will consume its own weight in insects, mostly small flying insects and mosquitoes.
- In one day a small bat will eat 1500 to 2000 small insects & 10 to 15 larger ones (like beetles,).

Spiders

