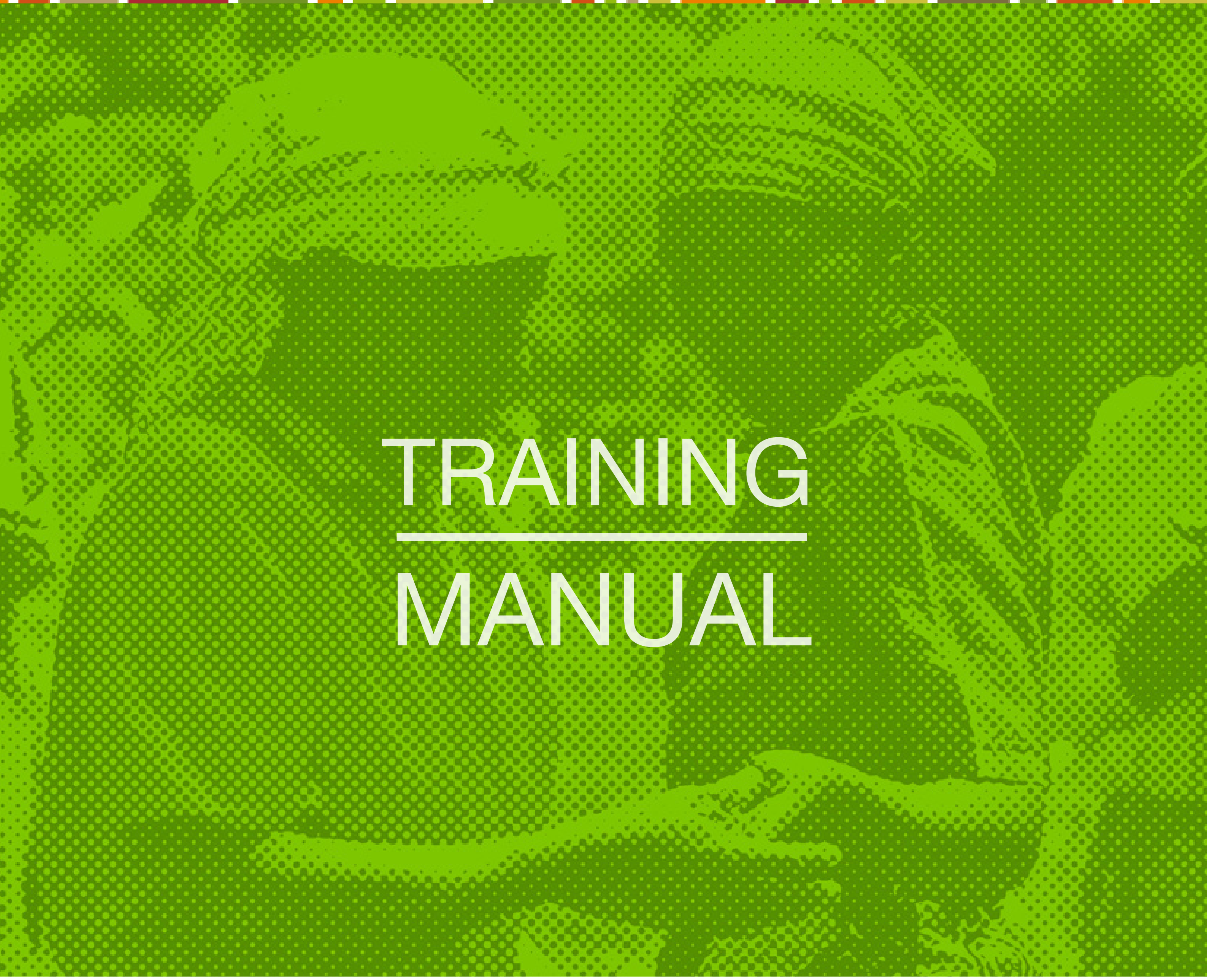

TRAINING MANUAL

- AGRICULTURAL PRODUCTION AND PROCESSING -

INTEGRATED MANAGEMENT OF BIOAGRESSORS

COLEACP

This training manual was produced and designed by the Training, Information and Communication services of COLEACP. This publication was written by Bruno Schiffers with the collaboration of Gilles Delhove for chapter 3 and Henri Wainwright for chapter 4.

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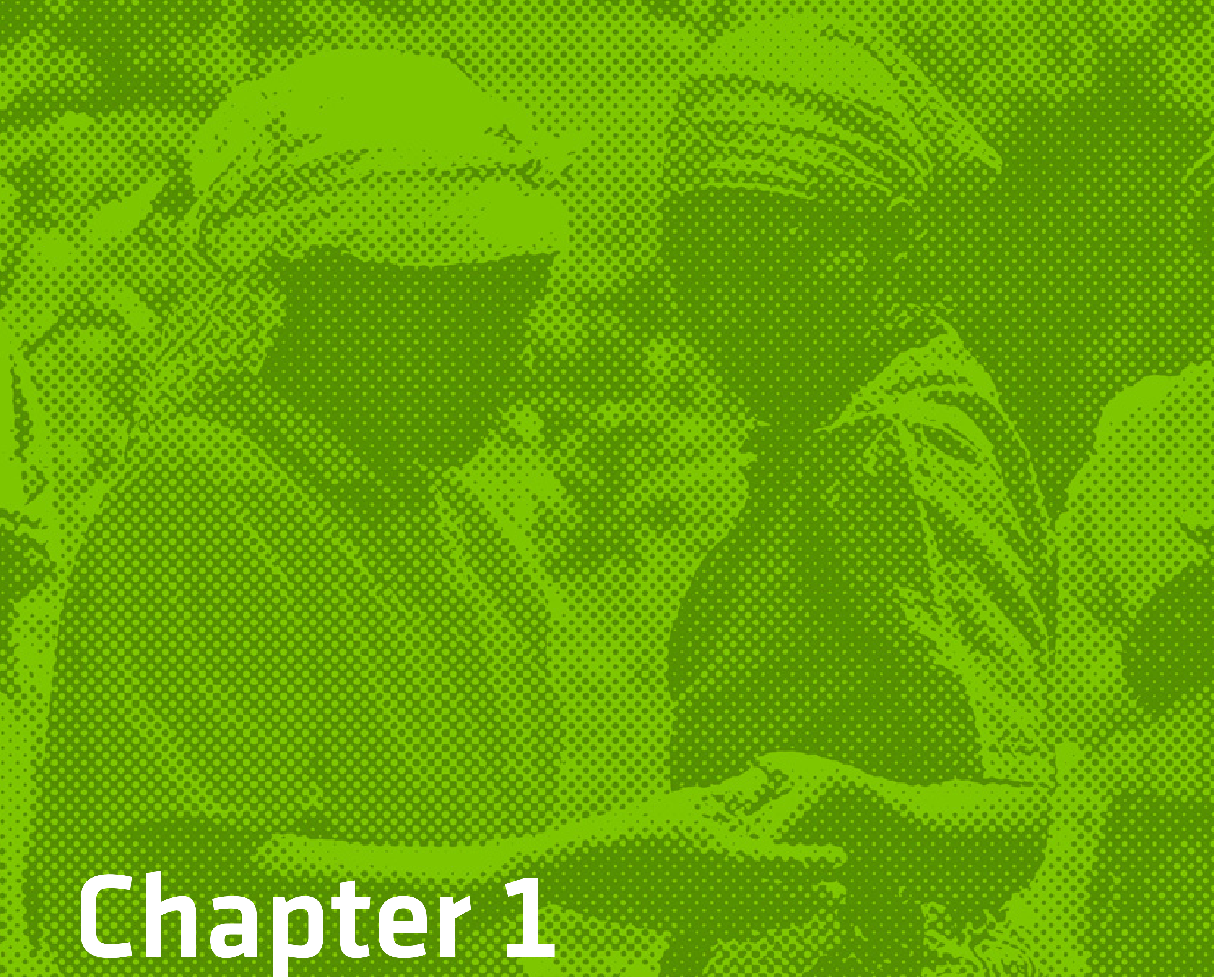
Integrated management of bioagressors



Chapter 1

Introduction: from chemical control to integrated crop management

1.1. Chemical control at a crossroads

1.1.1. The impact of changes in traditional practices

In Africa and other countries in the southern hemisphere, many farmers still practise **subsistence farming**, and the vast majority of producers of fruit and market garden produce cultivate their crops on very small plots of land, often for just a few weeks or a few months of the year. Generally, although the know-how acquired by these farmers has been passed down from one generation to the next, these producers have **only limited agricultural knowledge and technical resources at their disposal**.

Where they are mostly mixed (crops and animals), family-based, small-holdings, farmers tend not to apply large amounts of pesticides and fertilisers. Against this backdrop, despite the climatic conditions, which are often unfavourable for plant growth but conducive to pest and disease proliferation (heat and humidity), the farmers have nonetheless **developed effective production systems**. They have learned to make the most of their environment and have utilised the natural resources available to them (botanical insecticides, plants that act as beneficial insect refuges, and various minerals, ashes and smokes that reduce insect attack) to manage the pests and diseases that affect their crops and disrupt their food supplies. The hardiness of numerous local varieties, which often give poor yields but are well adapted, and the considerable natural biodiversity of the environment combined with non-intensive cultivation methods (minimal cultivation, cover crops and crop rotation), have enabled them to keep both disease- and pest-related pressures within tolerable limits.

The situation is entirely different in the **case of horticultural cash crops**, which are an important agricultural activity for rural communities as well as for urban and peri-urban populations in Tropical Africa. The production of fresh fruit and vegetables intended for local and export markets has become a significant source of income for many small-scale producers. **Producers have gradually integrated the use of inputs (fertilisers and pesticides) into their agricultural practices, abandoned their traditional varieties and slowly but surely relinquished their traditional production and protection methods** in order to protect their harvests, increase production, improve the quality of their produce and boost their income.

The horticultural exporting sector in ACP (African, Caribbean and Pacific) states is still characterised today by a large number of small- and medium-sized operations. As a general rule, in this situation, it is **neither beneficial nor appropriate** to completely replace traditional methods by chemical control because the latter is not always within the farmer's grasp. In fact, farmers do not usually have an opportunity to put chemical control to good use because they have limited information on this topic and do not generally have sufficient funds to purchase adequate (effective and authorised for use on the crop in question) plant protection products or the high-quality equipment for safe and effective application to their crops.

The recommended equipment and products are often **not sold locally** or else are **difficult to obtain**. Furthermore, product presentation (e.g. no labels or labels in an incomprehensible language, defective packaging), poor quality of the formulations, unsuitable pack sizes and the lack of protective equipment, training and information for farmers make the use of pesticides a random, costly procedure fraught with health and environmental hazards.

At the present time, most small-scale horticultural producers unfortunately resort to the routine use of synthetic pesticides, sometimes comprising highly complex blends of various products, without knowing anything about their properties. As vegetables are **short-cycle crops, which are consumed fresh** or after having undergone minor processing, the risks incurred through the excessive, uncontrolled use of inputs (pesticides/fertilisers) are all too real and have been the subject of expert debates that have highlighted the following issues:

- the presence in harvested produce of residues at concentrations that are harmful to consumer health ;
- contamination of ground and surface waters;
- destruction of beneficial organisms and natural enemies and, as a general rule, a loss of biodiversity;
- adverse effect on the health of operators, and that of their families, following repeated exposure;
- frequent accidents (inadvertent poisoning);
- development of resistance by the pests and diseases that are to be eradicated;
- emergence of new and hitherto unnoticed pests and diseases;
- a reduction in soil fertility.

These risks are compounded by the **increased dependency** on chemicals by the producers who are faced with the need to purchase inputs (pesticides/fertilisers), and the **loss of income** when the use of such products is not off-set by an increased yield and/or healthier harvested crops and improved plant protection.

Although export production represents only a small portion of small-scale horticultural production in ACP states, it is nevertheless strategic because it represents the only income source for many family businesses. Europe is by far the main export market for the ACP fresh fruit and vegetable sector. The relative importance of these exports on the countries' economies obviously varies considerably: over thirty ACP states regularly export fruit and vegetables to Europe. For these countries, the horticultural export sector represents a **substantial economic and social asset**, especially in view of the jobs it creates and the income it generates in rural settings where poverty and unemployment pose particularly serious problems.

Today, faced with rising European demands in terms of food safety and animal and plant health measures, coupled with the increasing commercial requirements of large-scale retailers, ACP producers have no choice but to **correct their practices** in order to supply compliant products [e.g. compliance with MRLs and other standards] and safeguard their market share. Moreover, consideration of only the "health"-related aspects of their production methods will no longer suffice because the market is gradually imposing criteria focusing on environmentally friendly approaches, the protection of biodiversity and the adoption of ethical production methods; in short, **the role of chemical control in crop production systems is clearly being questioned**.

Rather than consider these changes as disruptive and negative for the ACP horticultural sector, which provides a living for millions of people in rural settings, these market trends should ideally be put to good use to challenge the drift away from traditional practices, rekindling interest in traditional control techniques, questioning the use of chemical control and reworking production methods within the context of the sustainable farming framework. **Integrated crop management** and **organic production methods** open up real market opportunities for ACP producers.

1.1.2. The essential change in crop protection

Generally, in other parts of the world, although chemical crop protection is usually effective, it no longer provides a satisfactory solution. This is not only because of the threat to sustainability of agricultural ecosystems (loss of biological diversity, degradation of the physico-chemical quality of the environment) but also in view of its increasingly limited efficacy as shown by pest resistance, changes in natural enemy populations and the early stages of a serious environmental imbalance (water pollution and contamination of the soil and air).

These concerns are further heightened by the increasingly stringent requirements and restrictions for authorising the marketing of active substances, in the light of recent changes in European Directive 91/414/EEC,[1] calling into question the economic profitability of developing new groups of active substances. Furthermore, the immediate consequence of the revision process applied to older active substances, and of their mass withdrawal, means less choice for the producer and even the total absence of any chemical control method. At the same time, the adoption on 01 September 2008 of Regulation (EC) No. 396/2005[2] harmonising EU MRLs, exposed ACP producers to greater risk of exceeding the authorised MRL level by using unauthorised products or products withdrawn from Europe.

Crop protection currently **stands at a crossroads** and includes the following options:

- Promoting 'good plant protection practice' relying on positive advances in chemical control technology, thanks to development of new and more environmentally friendly chemicals and relying on the generally acknowledged ease with which most chemical treatments can be applied. Some continue to advocate only the use of chemicals, considering a change in mentalities and habits or a change in practices as too radical and deem the cost of other control methods (**rational control**) to be excessive.
- Others prefer the transgenic route (e.g. incorporation of the 'Bt' gene in cotton or maize) as a long-term alternative to chemical control, despite its current critics (**use of Genetically Modified Organisms**).
- Finally, others stress the merits of preventive and integrated measures to reduce the risk of outbreaks of pest populations, as part of the development of strategies which take into account the environment, cultivation practices and local socio-economic constraints, calling on, as required and in order of priority, various

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1 Council Directive dated 15 July 1991, concerning the launch of plant protection products (*OJEC*, L 230 of 19 August 1991).

2 Regulation (EC) No. 396/2005 of the European Parliament and Council dated 23 February 2005 concerning maximum permissible limits for pesticide residues found in or on foodstuffs and animal fodder of plant and animal origin, and modifying Council Directive 91/414/EEC (*OJEU* of 16 March 2005). The first draft of appendices II, III and IV were published in Commission Regulation (EC) No. 149/2008 dated 29 January 2008. These appendices were amended by Commission Regulation (EC) No. 839/2008 of 31 July 2008 published in the *OJEU* of 30 August 2008 and which took effect on 1 September 2008.

techniques for managing the risk posed by pests and diseases (**integrated pest management**).

Moreover, in an increasingly competitive international market place, intensive methods of cultivation with a high rate of input (pesticide/fertiliser) use may result in an economic stalemate. A significant reduction in input quantities should be attempted in order to cut production costs without jeopardising yield. Small-scale producers experiencing the gradual withdrawal of subsidies will have to resort to more traditional management methods using fewer pesticides.

These technical, regulatory and economic considerations all argue in favour of crop protection geared towards **a more ecological approach** such as integrated protection. This change thus prioritises the **balanced and sustainable functioning of agricultural ecosystems.**

1.2. The various crop management concepts

1.2.1. Sustainable farming

Sustainable farming is the application to agriculture of the principles of sustainable development as recognised by the international community in Rio de Janeiro in June 1992. This is a crop management system aimed at ensuring the **ongoing production** of food, wood and fibres in accordance with ecological, economic and social limitations that safeguard continued production over time.

Sustainable farming is aimed at improving the 'sustainability' of the system by generating more wealth and jobs per production unit on a fairer and more ethical basis. Its principles are based on recognition of the fact that natural resources are finite and should be used wisely in order to ensure lasting economic **profitability** and **social** well being, while striking an **ecological** balance at the same time (the three pillars of sustainable development).

Sustainable farming does not lead to certification. At the present time, in terms of an environmental approach to agriculture, only rational and organic farming are actually "recognised" by the authorities.

1.2.2. Rational farming

Rational farming is a method of agricultural production aimed at greater respect for the environment by the operators. This concept, which, on the whole, is supported by pesticide manufacturers and retailers, is based on '*authoritative literature'*,[3] which integrates economic with social and ecological aspects (using only the required input dose, when and where necessary). This type of authoritative literature is compiled through collaboration by the ministries for agriculture and the environment, the world of agriculture (trade unions, development, co-operation and trade organisations etc.), processors, retailers and, to a lesser extent, by environmental and consumer associations. It comprises requirements relating to the environment, control of hygiene risks, health and safety at work, and animal welfare. The control of farms and certification (by Independent Certifying Organisations – ICO) is allocated to producers who comply with the principles of rational farming.

Authoritative literature relating to rational farming attempts to boost the positive impact of agricultural practices on the environment and to reduce the negative effects without challenging economic profitability. The 'environmental issues' of production methods are rational as part of a comprehensive approach to operations. In a given area (small agricultural region, watershed, etc.), key issues must be identified, relating to factors such as:

- erosion;

[3] Rational Farming authoritative literature, Ministry of Agriculture and Fisheries (France) – 8 January 2002.

- flooding;
- water pollution due to nitrates;
- water pollution due to phosphates;
- water pollution due to plant protection products;
- quantitative management of water resources;
- noxious olfactory aspects;
- biodiversity;
- the landscape.

From this, one can analyse the situation of the smallholding in relation to the local factors and identify and target, where necessary, essential practices to be developed. This concept is, therefore, only a vague commitment to ‘good practice’ compliance. It is not, in any way, binding and does not challenge intensive farming methods. Those who oppose this concept in fact believe that, of the 97 listed measures, 43 merely comply with regulatory requirements (e.g. ‘*Use only products for which a marketing authorisation has been granted’*).

1.2.3. Organic farming

Organic farming can be considered as one of the approaches to sustainable farming, the difference being that so-called “organic” production implies an inspection and product certification in accordance with **Regulation (EC) No. 834/2007**[4] describing the production principles and specific control regulations. The regulation applies to unprocessed agricultural crop products, as well as livestock and unprocessed livestock produce.

The fundamental rule of organic farming is respect for natural ecosystems. It aims to:

- preserve the natural balance of soil and plants;
- promote recycling;
- strike a balance in terms of organic matter;
- select animal and plant species adapted to natural conditions;
- fully respect the landscape and uncultivated areas;
- preserve biodiversity.

Organic farming is consequently a specific agricultural production system, which excludes the use of synthetic fertilisers and pesticides as well as genetically modified organisms. Appendix II of the organic farming regulation gives precise details on soil improvements, the fertilisers or plant protection products that can be used and their stringent application methods. Only a few substances of animal or plant origin (e.g. azadirachtin from neem, beeswax, tobacco extracts, plant oils etc.) and certain micro-organisms (*Bt*, granulosis virus etc.) can be applied. Mineral-based phytosanitary products (containing Copper, Sulphur and sulfo-calcium spray) can only be applied to crops if the producer can confirm that they are essential. As for some chemicals (e.g. pyrethrins, pheromones and spinosad etc.) listed in Appendix II, they are reserved for trapping and eradicating pests.

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[4] (EC) Regulation 834/2007 concerning organic production methods for agricultural products and the impact on agricultural products and foodstuffs, *OJEU* of 20 July 2007.

Farmers who practise this type of farming use, for example, crop rotation, green manure, composting, **biological control** or mechanical weeding in order to maintain soil productivity and to control pests and diseases. This is a system that manages overall production by promoting the agricultural ecosystem, biodiversity, the biological activities of the soil and biological cycles.

As the organic production method is recognised as a specific approach to production and packaging, the ensuing produce must be labelled in a specific way. Several international recognition "labels" for this type of farming have been defined, including the ***AB Label*.** AB Label specifications do not focus solely on product quality but also on respect for the environment.

European Organic Agriculture logo July 2010

AB Label

1.2.4. Integrated crop management

The concepts and strategies developed within the sustainable farming framework have advanced towards the integrated concept of '**conservation of water, biomass and soil fertility**'.

The term '**Integrated Crop Management – ICM'** is directly derived from the '**integrated pest management**' concepts of the IOBC (International Organisation for the Biological Control and Management of Noxious Animals and Plants). This is a concept that not only relates to plant protection but **all cultivation practices *per se***.

Unlike Organic Farming, there are no official **specifications** for integrated crop management.

Integrated crop management differs from rational farming, being based solely on the optimisation of traditional production methods. In rational farming, farmers treat soils/crops only when necessary, at the right time and with the appropriate dose. In integrated crop management, the use of alternative techniques such as biological control, or the establishment of ecological compensation areas can be just as effective from an agricultural standpoint and more environmentally friendly. Integrated crop management also differs from organic agriculture in that it does not abandon chemical methods when they do not pose scientifically proven problems for food safety and the environment. As its name suggests, integrated crop management "integrates" all of these aspects. Only the best solution for the environment, consumer and producer is applied.

Integrated crop management allows producers:

- to **manage and make a profit from** their crops via integrated pest management, considering the environment as their ally;
- to introduce a **more stringent management approach** to the enterprise and to make wiser choices in terms of control methods in order to rationalise, reduce and replace pesticides and thus to lower associated risks;
- to utilise the IPM process as an **indispensible marketing factor** in promoting their products.

1.3. Steps towards integrated crop management

1.3.1. To develop more environmentally friendly cultivation and plant protection methods

Various forms of action can be taken by producers to improve their practices along the lines of integrated crop management:

1) To adopt a planned approach to crop nutrition and plant protection, which assumes:

- thorough knowledge of the plot of land, the variety cultivated, plant requirements at various growth stages and anticipated plant protection risks (taking into account previous crops, adjacent crops, surroundings, methods of control, the products used and the region);
- the existence of historical data and experience (water and mineral requirements, a description of effective plant protection methods);
- reliable tools to assist in the decision-making processes (relating to irrigation, crop nutrition, plant protection treatments etc.) based on:
    - regular, simple plant observations and, as regards the plot, knowledge of the conditions under which diseases, pests and biological agents (introduced or occurring naturally) develop, and the use of models to reflect the development of these pests and diseases;
    - scouting, monitoring (e.g. trapping) and early warning systems;
    - rapid diagnostic analyses (disease detection kits; analyses of the soil, leaves, water, nutrient solutions, substrate etc.);
- the use of well-calibrated and well-maintained equipment for application.

2) To control and reduce inputs, residues and effluents by using and effectively managing:

- genetic options (tolerant or resistant varieties and root stocks);
- the protection of biodiversity and the introduction of natural enemies;
- the precise rate of plant protection products (including the correct calculation of dose rate, equipment calibration and control, training in application techniques);
- the use of irrigation and fertilisers in response to crop requirements;
- the possibility of localised treatments (use of baits and traps, spot treatments in a crop/ on trees in an orchard, chemically treating seeds rather than the whole field, application of herbicides in bands or strips rather than the overall field etc.);
- the use of cultivation techniques (size, barriers like insect nets, stripping leaves, harrowing, false seed beds etc.) to limit weeds, pests and diseases;
- liquid (e.g. bottom of tank) and solid effluent (e.g. packaging).

3) Recycling or treating crop residues, off-types, waste and effluent:

- rapid burial of waste or crop residues before they become breeding grounds for pests or diseases, or attempt to recycle them (e.g. composting);
- optimum utilisation of crops which are out of specification (off-types) – too big or small (e.g. for animal fodder, biomass, search for new markets);
- recycling or rational disposal of inedible crop waste without polluting the soils or ground water (composting, incorporation in the soil);
- recycling of nutrient solutions used in irrigation;
- avoidance of the use of plastic (mulch, covers, drums, etc.) by using natural materials that can be degraded or recycled more easily;
- selection of easily destructible, recyclable packaging (wood, paper and cardboard boxes).

4) Turn towards sustainable farming:

- reconstitute a farm plan to limit the noxious effects of the elements (erosion, wind and rain), by positioning the plots and installing hedges, windbreaks, ditches, anti-erosion barriers, retention basins, channels and grassed banks etc.;
- improve soil structure by adopting good practices and appropriate agricultural techniques: soil improvements conducive to striking a balance in soil floral/fauna, liming, rotation, type of soil cultivation etc.;
- priority use of natural control methods (soil solarisation, introduction of natural enemies, nets and traps etc.) and the introduction of traps and antagonist plants in plant rotation cycles (e.g. *Tagetes*) or non-pest-host plants (e.g. cereals in horticultural crops) to reduce soil pest build up and the need for sterilisation;
- taking economic constraints into account, to adopt rotations, cultivation and plant protection practices which reduce the development, resurgence or resistance of diseases, pests and weeds.

1.3.2. Implementation of a weed, disease and pest integrated management system

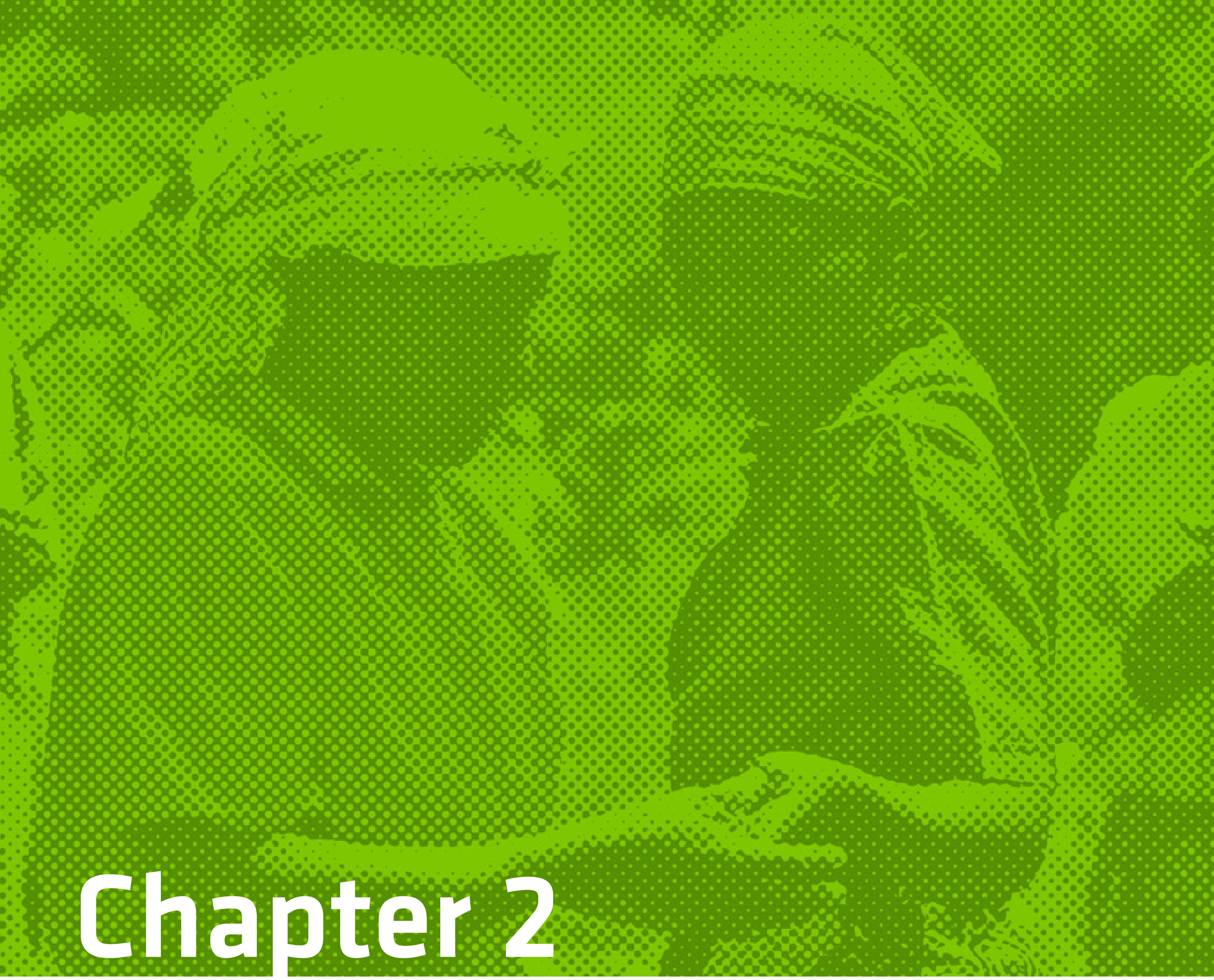
In integrated crop management, plant protection control is based on '**integrated**' **pest management** (or IPM). The transition to this agro-environmental control approach by the producers who usually adopt chemical control methods, must comprise several stages.

The time taken by the producer to **analyse their practices** and **evaluate their production site** ensures the long-term success of this conversion process. In order to justify their decisions, the producer must, be capable of correctly evaluating the plant protection risks according to the stage of development and variety of the crop, environmental conditions conducive to crop growth, the abundance of both noxious and beneficial organisms in the plots and the surrounding areas, and the impact of their cultivation and plant protection practices on the development of crop enemies and that of beneficials.

The following table lists the **key stages** in the implementation of an integrated disease and pest management system within the more general integrated crop management framework. When converting to IPM the farmers should begin with the first stage and progress to stage three as illustrated in the following table.

Agro-environmental practices	Actions to be taking during the:		
	First stage	**Second stage**	**Third stage**
Study of the site and environmental conditions	Identification of environmental risks (erosion, water pollution, etc.)	Soil improvement in the plot (organization of the plots, plantation of hedgerows, introduction of weeding mechanisms etc.)	Adaptation of the ecosystem: use of resources aimed at making the ecosystem favourable for beneficial organisms and plants but difficult for crop pests to tolerate
Analysis of cultivation practices	Identification of practices posing environmental risks	Adoption of environmentally friendly cultivation practices (ploughing, direct sowing, split nitrogen application etc.)	
Monitoring of fields and evaluation of the general situation	Field visit and diagnosis of natural enemies observed (once or twice a week)	Continuous monitoring of fields and pests using recognised techniques for each crop	
Identification of pests and their natural enemies	Precise identification of pests	Identification of pests and their natural enemies	Identification of natural enemies and primary and secondary pests
Use of intervention thresholds	Use of a pesticide or any other control technique		
	At the right time (no threshold)	At the right time and justified by the use of intervention thresholds	
Integration of various control methods	Seldom	Often	Almost always
	Use of mainly synthetic Pesticides that are of low persistence to natural enemies	Use of synthetic pesticides that are compatible with natural enemies and alternative methods	Mainly use of alterative methods

<table>
<tr><td rowspan="6">Pesticide management</td><td>Appropriate choice of pesticides applied. Compliance with dose rates and application deadlines before harvesting. Keeping a register.</td><td>Rotation of groups of chemicals (according to the mode of action of the pesticides). Restricted use</td><td>Choice of selective pesticides to protect natural enemies and compliance with certain application periods</td></tr>
<tr><td>Equipment calibration and regulation</td><td colspan="2">Use of pesticide application techniques aimed at reducing the quantities used and optimising treatment</td></tr>
<tr><td>Storage in a locked, specially designated area.</td><td colspan="2">Adoption of hygiene measures. Keeping pesticide stocks to a minimum.</td></tr>
<tr><td>Application under favourable weather conditions.</td><td colspan="2">Use of nozzles to reduce pesticide drift</td></tr>
<tr><td colspan="3">Use of appropriate PPE
(depending on toxicity and work being carried out)</td></tr>
<tr><td colspan="3">Triple rinsing and disposal of pesticide containers
in a safe and environmentally friendly manner.</td></tr>
<tr><td>Training</td><td colspan="3">Recognition of enemies and natural enemies.
GPP (Good Phytosanitary Practice) and GAP training.
Personal hygiene training.</td></tr>
</table>



Chapter 2

Principles of biological and integrated control

2.1. Biological control

2.1.1. Definition

The protection of crops against harmful organisms involved the use of various cultivation and biological methods well before the advent of chemical products. Fallow land and crop rotation practices, amongst others, bear testimony to traditional, often empirical know-how, reducing the incidence of organisms harmful to cultivated plants by interrupting their reproduction cycles. Awareness of the limitations of chemical control processes, which, at one time, were considered likely to resolve all plant protection problems on their own, has refueled interest in biological control. Since then, the International Organization for Biological Control (**IOBC**) has played a crucial role in steering changes in plant protection towards biological solutions.

'Biological Control' (or 'biocontrol') is a method that involves the eradication of a pest, through its natural enemies, or a disease, by promoting its antagonists. Biological control is primarily directed against pests (insects, mites and nematodes). Predators, parasitoids or infectious agents (entomophagous fungi and viruses) are considered natural enemies of crop pests, limiting the frequency and severity of pest proliferation. This is the **recommended** control method in **organic agriculture**.

Definition from the IOBC: "the use of **living organisms** (unlike a '**biopesticide**', which refers to both living organisms and inert substances of biological origin, or so-called "biocompatible" plant protection products, living or inert active substances, which may or may not be of biological origin used in integrated control) (parasitoids, predators, pathogens, antagonists or competitors) to prevent or reduce the damage caused to crops by pests or diseases".

Despite numerous successes, the validity of the biological control method is, however, under debate today not only in terms of success rate, which is deemed by some to be inadequate, but also given the biological risks involved in handling parasitic organisms.

2.1.2. Principles and implementation strategies

Biological control methods used to eradicate organisms harmful to crops use the **natural regulation mechanisms** of populations of insects, mites, nematodes and rodents, etc. This regulation is the achieved by striking a balance between the 'biotic potential' of living organisms (the driving force behind their development) and the natural resistance to their development by their environment. In crops, given the loss of biodiversity in particular, **natural regulation factors have, in general, become inadequate in terms of their efficacy and ability** to handle pest proliferation single-handedly.

Beneficial organisms have demographic characteristics related to those of their "host" populations: They depend on the density reached by populations of the target organism (insect, disease, weeds).

Competition, predation and **parasitism by these natural enemies** are the principal biotic factors that **control the stability of pest and disease populations** by exerting a crucial influence on their development.

When the populations of natural enemies and pests are balanced, the natural enemies **that are active at low density** play a crucial role in regulating the final larval stages of their hosts and preventing proliferation. This means, however, that populations of natural enemies are generally **insufficient in number** to ensure the immediate regulation of host populations which suddenly increase following a disruption in the initial balance.

Faced with this invasion of pests, the populations of which increase rapidly, man tends to intervene by using the most effective methods available and those that will have an immediate effect: generally pesticides are the method of choice. However, if **non-selective products** are used, that also target natural enemies, then the risk is that the last of the natural enemies will be killed and the pests will continue to increase (**'boomerang effect'**).

Intervention strategies exist in diverse, albeit complementary, forms:

- ❑ **Maintaining and developing the role of indigenous natural enemies**

The development of intensive agricultural practices (e.g. monoculture) is not generally conducive to these controlling mechanisms as they tend to reduce the farm's biological diversity. To maintain natural ecosystems, **rational management of fragmented land holdings** must be introduced in order to preserve sheltered areas where the populations of natural enemies (hedges, field insectaries, weeds, nectar producing plants) can be maintained. It is necessary to limit the use of unfavorable practices (e.g. removal of hedges, suppression of fallow land, ploughing etc.), along with plant protection treatments with non-selective products on refuge zones, at the time of flowering, etc.

- ❑ **Voluntary introduction of exotic natural enemies**

This technique is used to correct 'errors' arising from the unintentional introduction of pests into a crop without the accompanying natural enemies that would usually combat fluctuations in the populations of such pests. Intentional introductions of exotic natural enemies in such circumstances can, however, trigger unintentional effects due to the lack of specificity of action. This type of application is most suited to **perennial crops** due to the long-term benefit of the naturalized predators. **Interest** in this technique is **considerably limited given the extent of the risk** of ecological niches being occupied by the new colonizing species and, by definition, of reducing the original biological diversity. An example of this problem was the introduction of the cane toad in Australia to control cane beetle, but the toad then went onto reduce the population of many other insects and in turn the indigenous population of other toads and frogs declined.

- ❑ **Augmentation by mass release of natural enemies**

This strategy is based on the introduction of large quantities of natural enemies (inundative) at the desired time and location, where biological treatment replaces traditional chemical treatments. The recent development of mass rearing techniques for natural enemies (e.g. mass rearing of *Trichogramma* on host eggs) has promoted the application of this strategy.

Examples include:

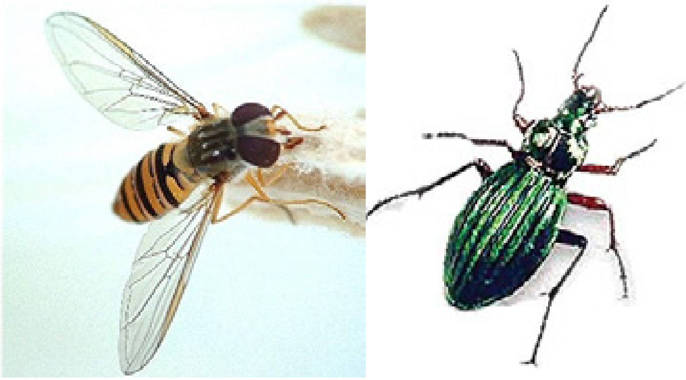
- the breeding followed by the distribution of **ladybirds** to limit the spread of a Seychelles scale that invested lemon trees;
- The use of *Phytoseiulus persimilis* to control red spider mite in many crops;
- Hymenoptera release to combat the Olive Fly;
- **Trichogramma** used to combat the European Corn Borer – *Ostrinia nubilalis* which is a moth. The advantage of these natural enemies is that they are oophagous (egg-eating); they therefore destroy the European Corn Borer from the outset, before it has time to do any damage. The technique is based on the annual release of 200,000 to 400,000 parasites per hectare. For application, the Trichogramma are released within parasitized eggs of *Ephestia kuehniella* (Mediterranean Flour Moth). They are packed in small, biodegradable, pierced cardboard capsules soaked with paraffin oil, which protect the predators against inclement weather and facilitates product handling. The procedure must be repeated annually when the pests are laying their eggs.

The availability and release of natural enemies on mass allows biological control to be applied to annual crops – a technique that previously has not been used in crop protection. A key component of the success of any mass release of biological control agents in the tropics has been that sufficient are released to gain control and this may require low cost production systems.

2.1.3. Which auxiliary organisms?

The term ‘natural enemies’ covers a wide range of living organisms that differ because of the various biological roles they play within the same ecological niche. Natural enemies include predators, parasites and parasite-specific diseases.

Weed scientists are interested in biocontrol agents that are specific in action and protect the crop from any unintentional effects: phytophagous (plant-eating) insects, pathogens and even herbivorous fish have been used to limit the development of water hyacinth, which has invaded numerous stretches of water in Africa. Plant pathologists work on competitor micro-organisms that prevent infection by and proliferation of phytopathogenic species (e.g. yeasts colonising the surface of apples intended for storage, which prevent the formation of *Penicilium expansum*). Entomologists make particular use of the diversity of predators and parasites as biocontrol agents (**insects and mites**, see tables overleaf).



Beneficial insects (aerial or soil insects): The Syrphid Fly and Ground Beetle

In order to ensure the specific mode of action of the mass produced natural enemies used in biological control, the so-called specialist species are generally preferred to general species. This is why **predators** are used less frequently than **parasitoids**, for instance, even if there are exceptions to the rule such as ladybirds (predators, but most of the species only eat aphids) and *Phytoseiulus persimilis*.

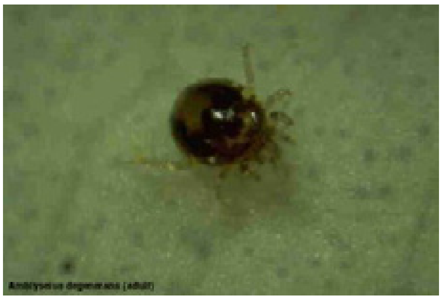
Arthropods suitable for biological control	
Predator insects	
Coleoptera	*Coccinella, Adalia, Adonia, Propylea, Harmonia,*
Coccinellidae	*Scymnus, Chilocorus, Stethorus*
	Oligota, Tachyporus, Staphylinus
Staphylinidae	*Agonum, Harpalus, Bembidion, Poecilus, Platisma*
Carabidae	
Heteroptera	*Orius, Anthocoris*
Anthocoridae	*Deraeocoris, Phytocoris, Malacocoris, Pilophorus,*
Miridae	*Campyloma, Heterotoma, Atractotomus*
	Himacerus, Nabis
Nabidae	
Nevroptera	*Chrysopa*
Chrysopidae	*Hemerobius, Micromus*
Hemerobidae	*Conwentzia*
Cogniopterygidae	
Diptera	*Syrphus, Episyrphus, Epistrophe, Scaeva*
Syrphidae	*Leucopsis*
Chamaemyiidae	*Aphidoletes*
Cecidomyiidae	

Parasitoid insects	
Diptera	
Tachinidae	*Pales, Agria, Phryxe*
Hymenoptera	
Ichneumonidae	*Itoplectis, Ephialtes*
Brachonidae	*Macrocentrus, Apanteles*
Aphidiidae	*Aphidius, Trioxys, Praon*
Trichogrammatidae	*Trichogramma*
Encyrtidae	*Encryrtus, Ageniaspis*
Aphelinidae	*Aphelinus, Encarsia, Aphitis*
Pteromalidae	*Eupteromalus, Asaphes*
Eulophidae	*Eulophus, Tetrastichus*
Mites	
Gamasida	
Phytoseiidae	*Typhlodromus, Amblyseius, Phytoseiulus, Neoseiulus*
Actinedida	
Anystidae	*Anystis*
Stigmaeidae	*Zetzellia*
Trombidiidae	*Trombidium, Allothrombium*

A few examples of biological control applications

The Trichogramma spp. parasitoid

The *Trichogramma* spp. parasitoid is used in over 52 hectares of cotton plants in the Gorgan Province in North Iran to control cotton pests. The result appears to be better than that obtained with traditional pesticides.



The use of a predator mite (Amblyseius degenerans) against thrips.

Amblyseius degenerans is a predator mite that stings its prey and sucks the contents. It readily settles in flowers, feeding on pollen in the absence of prey. It is supplied in a tube containing vermiculite and can be applied to prevent thrip infestation in flowers.

	***Biological control in cassava to combat the Mononychellus tanajoa mite*** Biological control to eradicate the *Mononychellus tanajoa* mite by predator mites (*Typhlodromus aripo*) in 18 African countries producing cassava: 60% decrease in pest mite populations.

2.2. Principles of integrated pest management

2.2.1. Definitions

'**Integrated control**' or better still, '**Integrated Pest Management**' (IPM) is used to manage, in an environmentally friendly manner, the damage caused to crops by 'pests'. The term pest is a general term and refers to animal pests, diseases and weeds. IPM is characterized by control of crop pests that takes into account the relationships between the pest and its natural enemies, the plant and its environment, and the local socio-economic context (part of the world, local industry or even a specific business).

More than thirty years after the expansion of this concept, there is still no universally accepted definition of IPM. For some, this is part of a wide-scale approach, leading towards 'chemical free' agriculture (school of 'Pest Management'). For others, however, e.g. CROP LIFE, it is simply a **crop protection system** ensuring a more rational and environmentally friendly use of pesticides (school of 'Pesticide Management').

Definition of Directive 91/414/EEC

Integrated pest management is the integrated application of a combination of biological, biotechnological, chemical, physical, cultivation and or plant selection measures in which the use of chemical plant protection products is limited to that strictly necessary in order to keep pests below the threshold for economically unacceptable damage.

This is a **decisional process**, which seeks to prevent pest infestation by means of several **combined strategies** geared towards **long-term control.**

IPM is aimed at **containing damage** due to pests **below economically damaging levels within the local production context**, by opting for the prevention of the infestation. IPM prioritizes appropriate cultivation techniques to enhance biodiversity, judicious selection of genetically strong varieties and the use of biological control agents before resorting to using pesticides. Pesticides will, however, be used but only if no other solution is available or economically viable, and only if the risk to the consumer, environment and biodiversity or the onset of resistance does not outweigh the anticipated "benefit" (improved hygiene quality and/or increased production).

By reducing the dependency of producers on pesticides, IPM can also **cut production costs and significantly reduce the 'residue' risk at the same time.**

IPM has led, by extension, to the principle of '**Integrated Crop Management**', which is characterized by the implementation of agricultural practices that result in the production of quality crops through the optimal use of natural resources and regulating mechanisms to replace the use of polluting inputs. This approach also ensures sustainable agricultural production (thanks to the preservation of soil fertility, maintenance of quality and the diversity of the environment), whilst complying with economic profitability requirements at the same time.

The 'Good Agricultural Practice Code' is an essential ally for IPM. In accordance with European legislation, each Member State must establish a code of practice for approval by the European Commission. It contains a wealth of information, technical data and recommendations to help farmers preserve the environment more effectively.

2.2.2. Implementation programme

An **IPM** programme may include awareness raising, producer training, proper waste management, structural adjustment, crop preservation, recourse to biological, genetic, physical and mechanical control techniques and, finally, pesticide application.

In practice, implementation of an IPM programme will comprise:

- selection of **phytogenetic resources** (crops and varieties adapted to ecological conditions or resistant or tolerant to certain diseases and insects, etc.), with or without GMO, depending on the "schools of thought" or even the type of resistance introduced;
- **rejection of prophylactic,** pre-determined, treatments in favor of interventions based on **observations**:
- **monitoring changes** in pest and natural enemy populations in the crop (visual inspection, trapping);
- considering population levels in order to decide on a procedure (**tolerance threshold, damage threshold, intervention threshold**);
- the use of **a range of methods** (cultivation, biological and biotechnological, etc.) **adapted in line with economic and ecological requirements** to keep enemy populations at acceptable levels.

Compliance with the threshold concept, based on an estimated population level, **rejects the aim of totally eradicating pests**, emphasizing at the same time the importance of **striking a balance** through the beneficial role of natural enemies.

The strategy is based, on the one hand, on the principle of integrating various control methods (the techniques are selected for their minimal environmental impact) and, on the other hand, on a **specific decision-making process** allowing the producer to **evaluate** the **actual risks** for each plot of land so that they can decide how and when to intervene.

The development of an IPM programme will involve a **systematic approach comprising several stages:**

1. **to identify and recognize** crop pests and natural enemies;
2. **to assess** the context: to systematically detect the presence of crop pests and evaluate the overall situation (environmental conditions, abundance of pest and beneficial organisms, condition of the plants and their stage of development, level of plant resistance or tolerance, harvesting date, and quality and regulatory requirements);[1]
3. **to use intervention thresholds** (to keep damage caused by pests below an unacceptable economic damage threshold, whilst promoting their natural enemies);
4. **to adapt the ecosystem** by making it conducive for the development of beneficial organisms but unattractive to pests;
5. **to combine** (preventive or curative) control **methods** in an integrated crop protection system;
6. **to evaluate the actions** taken in terms of their adequacy, impact on man and the environment, and their efficacy.

2.2.3. The 16 'Basic Principles' of an IPM strategy[2]

These basic principles do not focus solely on the management of pests but also highlight **all the environmental factors** that influence crop development. The acquisition of healthy propagation material and healthy crops is the foundation stone of any IPM strategy.

Adoption of these 16 principles by the producer will enable them to:

- efficiently protect their crops and harvest;
- comply more easily with sanitary and phytosanitary (SPS) quality standards, especially the maximum permissible limits for pesticide residues (MRLs);
- boost their income/hectare through reducing use of inputs (fertilizers and pesticides).

Good crop hygiene management implies the adoption of the following **16 basic principles**:

1 The level of infestation 'tolerance' may be **equal to zero** when this is a quarantine organism and the harvested products must be exported.

2 Adapted from A. Youdeowei, *Guide 1 – Integrated control principles: obtaining healthy crops*, Wageningen, CTA, 2004.

Principle 1

To obtain healthy seeds or plant material (cuttings and plants)

Implementation
To obtain certified seeds from licensed seed distributors or official organisations.
To use the seeds of healthy fruits and plants from the previous crop.
To carry out germination tests prior to sowing.
To consult the Hortivar database (FAO)

Risks

Non-compliant variety
Transfer of pathogens or pests
Presence of residues on harvesting (treated seeds)
GMO seeds

Anticipated results
Quality seeds form the basis of strong, healthy horticultural produce: "*Good seeds lead to good harvests*".

The resistant or tolerant varieties are not susceptible to certain diseases (e.g. Fusarium in tomatoes or cucurbitaceae).

Principle 2

Choose fertile soils and locations suitable for cropping

Implementation
Select soils with good natural drainage, suitable for cultivation. Check the soil history. Identify the plots.
Always plant in weed-free fields.

Risks

Contaminated soil
Excess nitrogen
Soil pathogens
Soil erosion

Anticipated results

Crops need a minimum amount of soil management and water to develop and compete effectively with weeds.

Principle 3

Adopt good nursery practices and comply with hygiene requirements

Implementation
Set up nurseries in pest- and disease-free soil to promote the development of the young plants.
Cover the soil with a mulch (e.g. neem leaves or dried grass).
Take cuttings only of the selected material free from pests/diseases and comply with hygiene requirements.
Analyze the soil where planting will occur.

Risks

Transfer of pests in plant material, soil and work tools

Anticipated results
After planting out in the field, the young, hardy plants will develop into robust plants.

Principle 4

Use spacers and devices suitable for planting

Implementation
Plant in lines, leaving a suitable space between the plants to prevent overcrowding.
Intercropping is usually carried out in lines, alternate lines or strips.
Sow or plant across the slope.
Follow the soil contours to reduce erosion.

Risks

Creating conditions conducive to pest development

Anticipated results
Overcrowding will hamper crop development and lead to disease through the creation of a humid environment.
Planting in lines saves seeds and facilitates agricultural procedures such as weeding and harvesting. Intercropping reduces insect pressure and guarantees yields.

Principle 5

Plant the crops to coincide their growth period with a low incidence of pests and diseases

Implementation
Schedule planting so as to avoid periods of high pest and disease pressure in the field. Co-ordinate regional planting dates to prevent the passage of pests from one crop to the next and to maintain a seasonal rest period.

Risks

Need to treat the soil extensively at the start of cultivation. Risk of residues on harvesting.

Anticipated results
The crop escapes periods of high pest and disease incidence during their growth and development. The pest development cycle is interrupted. The pest populations do not have enough time to proliferate extensively.

Principle 6

Practice crop rotation

Implementation
Plant in succession those crops that do not have the same common pests (e.g. rotation of cereals and root crops and tubers with vegetables or pulses).
Plant cover plants during fallow periods.

Risks

Development of other pests and diseases causing more damage (alternate damage)

Anticipated results
Crop rotation prevents the proliferation of diseases and terminal pests (e.g. nematodes or pathogens). The cover plants enrich the soils, smother weeds and reduce erosion.

Principle 7

Adopt good soil conservation practices

Implementation
Recover the soil with mulch and improve the soil with compost or organic fertilizer.
If needed, correct the nutrient balance with mineral fertilizers to enrich less fertile soils.
Apply fertilizer in split applications, especially nitrogenous fertilizers, in order to satisfy crop requirements more effectively and avoid leaching.

Risks

Excess nitrates contaminating the soil and water courses

Heavy metals in uncontrolled compost

Anticipated results

Poor soils are enriched to stimulate the growth and development of healthy crops and to boost yields. Increase soil organic matter. Efficient and effective use of fertilizers.

Principle 8

Adopt suitable water management practices

Implementation
Plant in soils with a good natural drainage.
Construct drainage channels to eliminate excess water and prepare water collection basins to ensure adequate water conservation.
In the case of irrigated crops, irrigate the plants regularly but only as required.

Risks

Contaminated water (nitrates, pesticides, heavy metals, substances that are pathogenic to both man and plants)

Anticipated results
Crop growth and development are not compromised by a lack of water. Moreover, the plants will not wilt or be water logged. Fewer fungal diseases especially in the root zone.

Principle 9

Weed regularly

Implementation
Plant the crop in weed-free fields. To prevent the production of weed seeds, hoe within three weeks of planting and superficially weed by hand until the crop has covered the ground. Pull out the first Striga plants before flowering and before seeds develop.

Risks

A mixture of plants and weeds seeds on harvesting. Transmission of (viral) diseases and pests from the weeds to the crops.

Anticipated results
Saves labor. Less damage to the crop roots. Competition between the crop and weeds is eliminated. The weeds cannot produce seeds. Parasitic weeds cannot become established in the fields. Easier to harvest.

Principle 10

Regularly inspect the crops by monitoring and scouting

Implementation
Inspect the fields every week to monitor crop growth and development, and follow the growth of natural enemy populations.
Quickly detect the appearance of pests, diseases and weeds.
Decide on the agricultural measures to be taken.

Anticipated results
Regular field inspections will highlight any problems and allow IPM procedures to be implemented in order to prevent worsening damage and thus significant losses in terms of yield.
Healthy harvest with few treatments.

Risks

Development of pests.
Need to treat, triggering the presence of residues.
Quarantine organisms present.

Principle 11

Keep the fields clean

Implementation
Remove the residues from the previous crop.
Pull out and destroy crops presenting symptoms of disease at the start of the vegetative cycle.
Following harvesting, remove crop residues (rake and use as fodder for livestock, or bury).

Anticipated results
These measures prevent the proliferation of pests and diseases and their passage from one crop to the next.

Pests and diseases cannot proliferate/develop over the entire small-holding. Healthy harvest with few treatments.

Risks

Development of pests.
Need to treat more often, thus triggering pesticide residues on the crop.

Principle 12

Effectively control pests and diseases

Implementation
Adopt a strategy to prevent pest build-up and preserve natural enemy populations. Give priority to control measures that are less harmful to man, the crop and the environment. Opt for mechanical or natural methods. Apply a suitable product if required, as directed and in accordance with Good Agricultural Practices (recommended dose, stage, length of time to harvesting, maximum number of treatments, authorized formulation and volume/hectare).

Anticipated results
The problems of pests and diseases are confined, allowing increased, sustainable production with minimal input (costly fertilizers/pesticides hazardous for the environment).

Risks

Presence of pesticide residues.
Use of unauthorised products.
Non-compliance with GAP.
Plant phytotoxicity.

Principle 13

Boost the population of natural enemies

Implementation
Adopt practices that create conditions that are environmentally conducive to the reproduction of natural enemies (hedges, weeded sections, fallow land, pest-specific control products).
Apply mulch to stimulate the reproduction of natural enemies.

Risks

Inadequate efficacy or delayed effect of natural enemies.

Anticipated results
Pest populations are effectively and naturally controlled by significant populations of natural enemies. Natural pest control is not harmful to man or the environment.

Principle 14

Reduce chemical pesticide application to a minimum

Implementation
Avoid the routine and regular application of pesticides. If this approach is essential, treat only with compatible pesticides.
Opt for alternative methods and products.
Always analyze the agricultural ecosystem before taking a treatment decision.

Risks

Residues > MRL in cases of repeated, systematic treatments.
Development of resistance.

Anticipated results
When used sparingly, compatible chemical pesticides allow natural enemy populations (predator ants, spiders, mantis and ladybirds, for instance) to develop to the detriment of pests.
Less resistance amongst pests. No residues.

Principle 15

Adopt good harvesting practices

Implementation
Harvest the crops as soon as they reach maturity; do not injure, tear, break or cause any other form of damage to the harvested produce.
Adopt good hygiene practices on harvesting.
Do not harvest and store the fruit and vegetables with direct exposure to sunlight. Keep the packaging unit clean.

Risks

Products contaminated by pathogens. Injuries.

Anticipated results
Clean, undamaged produce, which will keep more easily because it has no point of access for pests or pathogens. Freshly harvested produce stored at a low temperature will keep for longer. Comply with hygiene standards.

Principle 16

Use clean, high-quality storage equipment

Implementation
Always keep the warehouses clean and well ventilated. Only store whole products. Keep the harvested produce in hermetically sealed locations to protect against pests. Treat only those batches with a long shelf life and when authorized (e.g.: seeds and tubers).

Risks

Development of diseases and mould during storage: presence of mycotoxins.
Loss of quality.

Anticipated results
The quality of stored produce is maintained during the storage period. The stored produce is less exposed to attack from pests and pathogens. Economic use of pesticides recommended to treat produce during storage.

2.3. Disease and pest management measures to be integrated

The FAO clearly identifies IPM as a system for controlling populations of pests according to economic criteria by using the **integration** of many techniques - instead of a simple addition of all techniques – recognized as ‘regulating factors’ (initial preventive measures followed by intervention).

‘Integrated protection’ is no longer based on a control concept but adopts the procedure for **managing populations** of pests and beneficial organisms. It assumes that **preventive measures** have been taken in the right place and at the right time to reduce the extent of plant protection risks. It demands the integration of cultivation, genetic, biological and biotechnical methods. Experience has shown that the success of such integration implies the adoption of a **specific programme based on the unique situation of each producer**.

2.3.1. Prophylactic measures

The selection of preventive measures assumes prior knowledge of the behavior of pests in their ecological context.

❑ **Use of healthy seeds, plants, suckers or tubers**

For many crops, the **seeds** are used as propagation material. They may be contaminated (both internally and externally) by fungi, bacteria, viruses or nematodes. These pests will develop with plant germination and growth. The producer must therefore check that only seeds of known origin and duly certified (produced under good hygiene conditions under constant monitoring and plant health checked prior to delivery) are used. Seeds that are certified as **produced by an authorized organization** have the added advantage of guaranteeing compliance with the variety and its characteristics (guaranteed absence of seeds of GMO plants!) for better germination and improved production potential. The seeds can be treated by fumigation or coating. They are often treated against pathogenic soil fungi responsible for ‘damping off’ (e.g. *Pythium*, *Rhizoctonia*), against certain soil insects (e.g. grubs, wireworms) and even against aerial insects (aphids and gall midges).

Treated seeds can help to control cut worm

For a small number of crops, it is not the seed that is the starting point but **sections of the cultivated plant** (vegetative reproduction). For instance, potatoes are cultivated from tubers, bananas from suckers and cassava from cuttings. With this type of reproduction, **some pests and diseases** can develop during the first season and be transmitted to the following crop.

For instance, if the tubers of plants infected with the Potato Leaf Roll Virus (PLRV) were used to produce or reproduce potatoes, then the new plants would also be infected. Another example is where African Cassava Mosaic virus is transmitted by cassava cuttings. Similarly, the Cassava Mealybug can be transmitted to a new crop by infested cuttings. Therefore healthy cuttings, plants, suckers and tubers etc. should always be used for reproduction in order to prevent the transfer of disease and pests.

The producer must regularly inspect their plants, especially in the **nurseries**. They can identify those plants that do not have any symptoms of disease or have not been attacked by insects (e.g. aphids) and which can be used for cultivation purposes.

At the end of the season, they can also use a marker such as a plastic band or post, which they can use to identify healthy plants in a crop that can be used to collect propagation material for the following crop (e.g. collect the seeds,[3] cuttings or suckers). If all the plants are infested, they cannot be used for reproduction. It is better to obtain healthy cuttings or tubers from another location or even from an official seed production organization and/or certified plants.

❑ Implementation of rational crop rotation

Crop diversification involves practicing several types of cultivation method in order to reduce the risk of total loss on harvesting. It can easily be combined with the practice of rotation. **Crop rotation** limits the development not only of diseases and pests, but also of weeds, because it breaks the pests' life cycle. Conversely, the successive cultivation, year after year, of a susceptible crop in the same plot of land promotes pest development. When possible, it is, therefore, preferable to practice crop rotation because:

- diseases and pests are more or less closely related with one crop, but may have no effect on plants belonging to a different family, even if the inoculum is present;

3 Except for hybrid varieties.

- alternating various crop cycles (soil preparation, sowing, harvesting, burying of residues at different dates from one year to the next) avoids the selection and proliferation of a certain type of weed, especially annual weeds;
- the incorporation of green fertilizer in crop rotations will keep the soils fertile: e.g. young sorghum plants used as green manure.

Problems with **nematodes** may, for instance, arise without crop rotation. Root knot nematodes (*Meloidogyne* sp.) thrive in the soil of tomato plants and remain on the roots after harvesting. If, the following year, tomato plants are recultivated, the nematodes, which usually have a high proliferation capacity, may pose a very serious problem. The same problem will arise if a plant susceptible to Meloidogyne (root knot nematode), e.g. green beans, is cultivated after the tomato. Conversely, if this is replaced by a plant that is not attacked by Meloidogyne, the nematode populations will decrease (e.g. the cultivation of sorghum or cereals after tomatoes will decrease Meloidogyne populations in the soil).

'**Previous crops**' can have advantages and disadvantages in a crop rotation (the value of the previous crop should not be considered solely from the plant protection perspective: it can effect soil structure, the residual soil nutrients and the level of organic matter, for example, and therefore must also be taken into account when selecting crops for rotation).

In the **case of the green bean**, certain previous crops must be avoided (see Table below) such as those which leave behind a significant mass of plant residues, or maize, if any residues remain of the herbicide, atrazine, which is toxic to the bean and other pulses such as the pea. A rather long rotation cycle or else a prolonged fallow period are recommended in the interests of plant protection and, in particular, to prevent "damping off" due to *Rhizoctonia solani*.

Example of previous crops for cultivation of the Green Bean		
Previous crops to be avoided	**Unfavorable previous crops**	**Recommended previous crops**
Beans, Peas Potatoes African eggplant, Aubergine Melon, Cucumber, Zucchini, Water Melon Okra	Peanut Pepper, Celery, Lettuce Carrot Onion, Garlic, Shallot	Cereals, the residues of which are not buried (maize, sorghum and millet) Cabbage, Turnip Roselle (Hibiscus flower) Beetroot Cassava Sweet Potato Strawberry Plant

The '**COLEACP Crop Protocols**' list the effect of previous cultivations for each crop in tabular form and advise the producer on choices… but the producer's decision is also based on economic considerations!

2.3.2. Choice of resistant species or root stock

The use of **resistant** or tolerant species and/or **varieties** in horticultural crops is an important strategy and there are increasing numbers of varieties resistant or tolerant to diseases – varieties of lettuce resistant to downy mildew, varieties of melon resistant to aphids, powdery mildew and Fusarium, etc.

Wild species of plants and primary cultivars have been used extensively for the **wealth of resistant genes** they contain. Typical examples include: wild carrot *Daucus capillifolius*, used to introduce resistance to the carrot fly in cultivated lines; or resistance to the root knot nematode *Meloidogyne arenaria* in tomatoes, (*Lycopersicon esculatum*) introduced from the wild species, *L. hirsutum*. **This explains the major importance of preserving biodiversity and wild species -** genuine "gene banks" to be protected!

'Monogenic' (or 'vertical') resistance runs the risk of being swiftly distorted by the appearance of new virulent races of pest. Non-specific (or 'horizontal') resistance, which is supposedly longer lasting, is therefore preferable. Furthermore, the level of resistance has occasionally been seen to be linked to pest pressure (e.g. carrot fly, cabbage fly etc.). In the majority of cases, breeders are not able to produce total resistance but, rather, partial resistance. This is especially true since various mechanisms are involved in the acquisition of resistance, (e.g. in the case of the onion, resistance to *Thrips tabaci* is acquired by modifying the position of the leaves).

The use of varieties with **partial resistance** to insect pests therefore obliges producers to implement a protection strategy taking into account those areas at greater risk and the biology of the pest.

Grafting can control soil pests by grafting a susceptible cultivated variety to a **resistant root stock variety**: grafting of eggplants onto tomatoes, and zucchinis onto squash to eliminate soil fungi, root stock resistant to the nematodes found in tomatoes, cucumbers, water melons or eggplants etc. This technique has been carried out on several species of cucurbitaceae and solanaceae, and produces a high level of resistance to certain diseases and/or soil pests. Historically this has been an important method of control and interest in grafting as a crop protection technique has been revived, particularly for melons, tomatoes and eggplants.

The characteristics of cultivars and root stock that can be used in ACP countries are listed on the **FAO Hortivar site** (visit the Hortivar project Website (FAO): www.fao.org/hortivar/) and in commercial **variety catalogues**.

Hortivar is an FAO database providing information on the **performance and resistance of horticultural varieties** in relation to agro-ecological conditions, cultivation practices and the occurrence of pests, diseases and production schedules. Hortivar covers six horticultural categories: fruits, vegetables, roots and tubers, ornamental plants, fungi, herbs and condiments.

This approach is, however, **limited in practice because importers** and distributors want a certain fruit or vegetable, or even a specific variety or product, or because **they need to**

have special characteristic (e.g. melons that withstand transport). Producers often have only a theoretical choice between the varieties and are obliged to cultivate certain varieties in order to have access to the markets.

2.3.3. Adoption of beneficial cultivation techniques

Good cultivation practices prevent the development of diseases, pests or weeds. The **procedure** (ploughing, weeding, ridging, tying, localized thinning, adjusting planting density, increased ventilation of greenhouses, etc.), by promoting the elimination of weeds, crop residues and/or increasing plant ventilation, reduces the incidence of attacks by certain pests and of certain fungal, bacterial or fungal diseases. Pruning, stubble ploughing and elimination of residues from the previous crop, etc. reduce the inoculums and thus the level of the attacks.

Producers can be advised to **integrate the following practices into their crop protocol**:

❑ **Ploughing**

One advantage of ploughing is its **direct effect on the number of pests** present in the field. Ploughing can, in fact, unearth many pupae and grasshopper eggs found in the soil, expose them to the heat of the sun and to predators (birds, insects, ants and beetles, etc.). This will reduce the populations of pests which may infest the new crop. Furthermore, ploughing buries a large number of weeds. This is beneficial to the crop seedlings during their development as they do not have to compete with the weeds for water, light and soil nutrients.

In loose soil, plants can anchor their roots more easily and at greater depth. Consequently, the plants develop more quickly and become more robust. They are thus less susceptible to pests and diseases.

Ploughing should, however, **be adapted according to the sensitivity of the soil to** wind or water erosion (structure of the soil, O.M. content, distribution and intensity of rainfall etc.).

❑ **Adapting the sowing date**

The choice of **sowing date** is a cultivation practice that is often recommended in order to avoid attacks from certain pests. Plants are more susceptible to attacks from insects when they are still young. Many insect populations are still very low at the start of the growing season.

The advantage of **early sowing** is that the plants are already big and strong when the insect populations start to increase. This helps to limit damage (e.g. the Sorghum Shoot Fly, which attacks young sorghum plants that are particularly susceptible during the four weeks following emergence; young peanut plants, which are more susceptible to aphids than older plants; control of millet ergot because early sowing helps to reduce the initial infection). If dry sowing is carried out (very early approach), the seeds have to be treated to protect those buried in the soil against termites and ants.

Conversely, **late sowing** is sometimes recommended to prevent or limit the formation of mould on the seeds (seeds reach maturity after the rain has stopped). In the case of late sowing, care should be taken not to leave the soil bare, in order to stop erosion. Changing the sowing time can only be used where there are distinct seasons (wet and dry, or warm and then cold).

❑ Changing the density of the vegetation

With dense sowing, the plants quickly cover the soil if their germinative energy is good. This can prevent weeds from developing. Some plants are attacked by aphids to a less extent in the presence of dense sowing. However, dense sowing can **increase the humidity** in the mass of vegetation. This can promote the development of certain fungal diseases. For instance, anthracnose and mildew will develop more easily if humidity is high. Early removal of the leaves reduces Botrytis (grey mould) attacks on grapes by 60%. During the cultivation of protected horticultural crops, a slightly lower density of salad vegetables and the use of ventilated greenhouses will reduce the risk of Bremia (downy mildew). Dense vegetation can, however, also promote the development of **entomopathogenic fungi** (EPFs) which can eradicate many pests.

The general recommendation is to **sow or plant in lines**. Sowing in lines makes it easier to keep a uniform distance between the plants. Furthermore, this method of sowing facilitates weeding and other types of agricultural practices (inspection, harvesting, treatments etc.).

❑ Weeding

Weeding is an effective method of **controlling weeds**. The time at which weeding is carried out is very important. Initial weeding is easier and more effective if carried out shortly after emergence. The procedure must be repeated when the weeds start to grow back. Moreover, weeding loosens the soil, and facilitates the infiltration of water and the root development of cultivated plants.

❑ Inter-cropping

Intercropping involves the cultivation of two or more crops at the same time in the same field. This practice is very often used by farmers in Africa. The various types of associations have given rise to different terms such as: ‘mixed cultivation’, ‘intercropping’, ‘associated crop cultivation’ and ‘cultivation under cover’ and to meet objectives that can vary considerably and include: reduction in pest pressure, less competition from weeds, maintenance of soil structure, reduction of erosion etc.

Risk reduction is one advantage of intercropping because many pests proliferate and diseases spread more readily in a single crop than amongst mixed cropping. In a single crop, the spread of insects is easier and faster. In combined crops, the insects need far more time to look for host plants, e.g. as in the case of the Spotted Stalk Borers. The attacks by Spotted Stalk Borers on intercrops of maize and cowpea are less serious. Many studies have highlighted the effect of intercropping in reducing cabbage fly and cabbage aphid (*Brevicoryne brassicae*) populations on cabbage plants, or the level of leek blight. The efficacy of this method is, however, complex: for instance intercropping can occasionally boost the effect of the pests.

Another advantage of intercropping is that **the soil is used more effectively.** A mixture of different crops generally provides better soil coverage, which, in turn, reduces the invasion of weeds. In cases where a cereal is combined with a pulse, the latter helps to fertilize the cereal (nitrogen intake). In addition, different crops grown together can ideally use different soil layers or have different nutrient requirements. As a general rule, the yield per hectare is said to be higher in the case of intercrops than when crops are grown separately.

However, in the case of more intensive crops, such as production for exportation, inter-cropping presents several disadvantages: a more complex harvest, risk of harvested produce being contaminated by foreign plants, hindrance to mechanical work and the application of chemical treatments etc. It is, therefore, seldom used in such situations.

- ❑ **Avoid the excessive use of fertilizers**

Avoiding the excessive use of fertilizer (especially the application of **nitrogen**) will limit the susceptibility of plants to diseases. For instance sap feeders like aphids and mites will multiply faster when the sap is high in nitrogen. Conversely, a lack of certain (trace) elements will render plants susceptible to pest and disease attack.

- ❑ **Roguing (removal of) diseased or infested plants**

This method is especially important when a pest or disease is detected that can spread rapidly in a field (diseases, root knot nematodes, mites and plants infected with a virus). To control millet mildew, for instance, all plants showing symptoms of the disease should be destroyed within 30 days of emergence as they will not contribute to yield but represent a source of infection for healthy plants. In the case of mite infestation along field borders, it is often more economical to destroy the infested area of the plot rather than treat it, especially if harvesting is approaching or is already underway (risk of residues exceeding the MRL). The infected plants should be destroyed by **burying deep in the soil** or, better still by **incineration**.

- ❑ **Destroy previous crop residues**

The **residues of plants (stems and roots) or even fruits** remaining in the fields and orchards after harvesting often contain pests or are diseased, thus presenting a **source of infestation** for the next crop. In fact, many of these pests can survive during the dry season and infest the next crop. This is why the destruction of harvest residues is often recommended.

For example, **root knot nematodes** found in the roots, or spotted stalk borers that survive in harvest residues. The number of surviving insects can be reduced as soon as possible in a variety of ways:

- burn the stems and the stubble;
- bury the stems and stubble deeply in the soil;
- make a compost with the harvest residues;
- use the stems and stubble as animal fodder.

Some farmers do not want to destroy the old stems because they want to use them as building materials or to make fences. In this case, the stems should be dried by laying them out flat on the soil, in thin layers, and exposing them to sunlight for a few weeks. The heat of the sun and soil can kill a large number of insects within the stems.

In **orchards of mango trees**, failure to collect and destroy mango fly-infested fruit that drops and remains in the soil, promotes pest development: the larvae leave the fruit and the pupae form in the first few cm of soil. It is therefore advisable to:

- collect the fallen **fruit** every day;
- swiftly remove these fruits from the orchard and destroy them;
- bury them in a pit between 40 and 60 cm deep and cover with earth or quicklime;
- collect them in a leak-proof plastic bag or frame, and expose them to sunlight;
- immerse them in a drum filled with water or incinerate them in a pit or drum.

❑ **Spread mulch on and between the lines of crops**

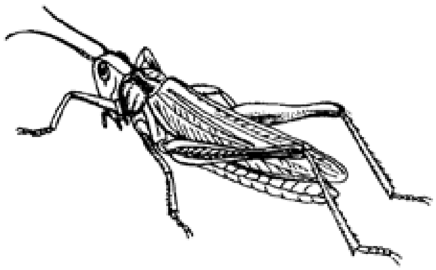
Mulching is a practice that involves covering the soil around the cultivated plants with straw, well-rotted manure or other organic material (e.g. peanut shells obtained by decortication). This considerably reduces the growth of weeds and improves the surface layer of the soil.

Mulching (with straw) of leek crops is currently practiced in Belgium in order to limit contamination by mildew. Mulching (with black polyethylene, 35 µm thick) effectively controls *Rhizoctonia solani*. Mulching can reduce white fly populations and thus delay (but not prevent) the viruses that they spread. Mulching is also recommended for reducing thrip populations.

Additionally, mulching saves water – this is a considerable bonus when cultivating manually irrigated market garden crops, and also protects the soil from erosion. It can be routinely recommended for horticultural crops (tomatoes, okra, cucumbers and lettuce etc.) as well as fruit trees.

2.3.4. Improving barriers

A **ploughed strip** should preferably be left around fields. These should **not contain any crops** or weeds. The strip will act as a **barrier for insects** that migrate from the uncultivated areas to the fields. A ploughed strip can thus protect crops against **armyworms** that migrate from other crops. However, this approach involves a great deal of work (ploughing and weeding) for the producer over an area of land that will not produce any yield. Most producers do not, therefore, readily agree to this practice. It should be recommended, therefore, when an invasion seems likely (e.g. when the adjacent crop plots are heavily infested).



To reduce the invasion of **bands of grasshopper larvae** and make a barrier against these pests, trenches can be hollowed out between the field and the approaching grasshoppers. If the larvae are very young and not very mobile, they will fall into these trenches as they approach the field. It only remains for the larvae trapped in these pits to be buried or destroyed by fire. This technique is used in Chad.

2.3.5. The preservation of beneficial fauna

The preservation of hedges and embankments combined with natural vegetation in the areas at the edge of the field, promotes the presence of beneficial organisms (insects, birds and reptiles) in close proximity to the plot. The appropriate choice of soil cover also promotes the presence of certain natural enemies.

2.3.6. Local application of plant protection products

❑ **Poisoned bait**

The use of bait, i.e. a mixture of a substance that attracts insects and an insecticide to kill them, is recommended in order to control certain insects. Baits basically comprising bran and sugar (or even molasses) mixed with 0.5 to 1.5% insecticidal active substance are often employed. The mixture thus obtained is then distributed in small quantities throughout the field, near the threatened host plants. Insects attracted by the bait die from poisoning. The use of baits is recommended to control insects such as cicada, mole crickets, myriapods, cutworms and grasshoppers.

The Dow Agrosciences Company produces SUCCESS APPAT®, a CS (concentrated suspension) formulation containing 0.24 g/L of **spinosad**, an insecticide authorized for organic production within the European Union, **and an incorporated food bait,** which can be used in localized treatments in mango tree orchards.[4]

The impact on natural enemies is very low with these type of treatments and there are fewer risks for operators.

❑ **Attractive traps (with pheromones)**

The traps contain pheromones, i.e. reconstituted sex hormones, which attract the males or females of only the species to be controlled. The trap does not, therefore, destroy the various beneficial insects within the perimeter.

[4] See the **COLEACP/CTA Brochure** - *How to combat the mango fly*, Collection of CTA Practical Guides, No. 14 (available on the COLEACP website or in the COLEACP Tool Box).

The pheromone is contained in a small capsule, which releases into the atmosphere.

The capsule is placed on a sticky, glued, (cardboard) base within a delta trap. It must be replaced every 4 weeks together with the glued (cardboard) base. Attracted by the pheromone, the males (in the case where a female lure is used) will remain glued to the base of the trap. Pheromone traps may be used for monitoring population development, to better target control measures, or, in large numbers, to effect control themselves by reducing the numbers of insects in the plot.

In the case of the mango fly, populations of the male *Bactrocera invadens* flies can be reduced in mango orchards by capturing the flies using '**parapheromone**' traps.[5] Used on a large-scale and in high numbers, they can also halt population development at the start of the season. The technique involves laying, at the start of the season, plates saturated with a specific attractant and treated with a contact insecticide. The traps must be placed in the orchard at least one month before the fruit starts to attract insects. It is also advisable to place these traps in orchards where other susceptible fruit trees are growing (e.g. citrus orchard).

[5] See the **COLEACP/CTA Brochure** – *How to combat the mango fly*, Collection of CTA Practical Guides, No. 14 (available on the COLEACP website or in the COLEACP Tool Box).

2.4. Biocontrol products

2.4.1. What are the expected responses of biopesticides?

To reduce the application of plant protection products (‘pesticides’), and in particular the herbicides widely used in recent years in all communes for the weeding of public spaces (such as park paths, cemeteries, playgrounds...), New active substances are subject to authorization and new products, derived from the environment and based on natural control mechanisms, are gradually appearing on the market.

The expectation of both researchers and regulatory authorities, industry and the public, of bio-control products is in line: to obtain effective protection or weed control of crops without the disadvantages associated with the use of majority of the synthetic products currently used, which is why they are often referred to as ‘alternative products’.

Indeed, while the effectiveness of synthetic pesticides is no more to be demonstrated than their ease of use, intensive and recurrent use on crops, in green spaces or in private homes, has resulted in numerous undesirable effects and Hidden costs for health, water purification or the loss of value of ecosystem services provided by auxiliaries and pollinators. All stakeholders in crop protection, including farmers and firms, are now putting a lot of hope in biopesticides. Moreover, if they are indeed new technical solutions, their implementation does not fundamentally call into question either intervention strategies or schemes to combat pests. It is more a matter of substituting chemicals for products from the natural environment than of modifying cropping practices in depth, as suggested by organic farming or agroecology.

The expected benefits of the development of bio-control products are many: to reduce the risk for the operator who will apply less toxic plant protection products, to offer farmers – as well as individuals – technical solutions that will be as efficient but more selective: Auxiliary insects or pollinators for better respect for biodiversity, protect natural resources and in particular water, provide an alternative to chemicals to avoid resistance to pests, dispose of products that can be used in organic farming, avoid residues of Products, or to provide an adapted response to uses in non-agricultural areas.

However, what is ‘natural’ is not necessarily synonymous with ‘safe for man or his environment’. Many natural substances or organisms (toxins, alkaloids, viruses, bacteria...) can have real negative effects for the man and the exposed animals. It is therefore legitimate to examine, first of all, the nature of these bio-control products and then on the risks that could be linked to their use in crop protection.

2.4.2. Should we talk about bio-control products or biopesticides?

Bio-control products or biopesticides are commonly referred to as commercial products which use natural mechanisms for the control of pests (insects or harmful mites, weeds, pathogenic fungi or bacteria, slugs, phytophagous nematodes, etc.).). They are therefore not ‘organic products’ or products that can be used automatically in organic farming (the latter are the subject of a precise positive list).[6]

As research in this field is very active, the number of these products is constantly increasing and diversifying in recent years, making it difficult for the legislator to try to classify these products, which is necessary to determine the legislation applicable to those products. How to classify, for example, pieces of yeast walls like cerevisane? As defined by the regulations, they are neither substances nor micro-organisms (as they are not complete) nor extracts.

If we do this exercise, we can nevertheless classify these bio-control products into five categories:

1. **The macro-organisms**
2. **Products based on micro-organisms**
3. **Chemical mediators**
4. **Natural substances**
5. **Elicitors**

We will further develop each of these five categories of bio-control products. However, a distinction will be made between macro-organisms and the four other categories of products, which may be referred to as ‘biopesticides’ (even though European legislation does not define the term biopesticide). Biopesticides are a subgroup of products derived from natural materials within plant protection products.

This distinction is based on the European regulations governing the placing on the market of plant protection products (broadly, 'pesticides for agricultural use'). Until now, macro-organisms are not covered by Regulation (EC) No. 1107/2009,[7] unlike all products based on the other four categories which must be regarded as 'plant protection products' and which, Therefore, will be evaluated according to the same procedures, using the same methods and on the same criteria, as all synthetic pesticides.

It can be seen immediately that all plant protection products (including biopesticides), whether ‘natural’ or ‘synthetic’, will be considered and evaluated in the same way as soon as they claim to be effective in protecting crops (at large). What matters to the legislator is the claim of a biological effect (e.g. insecticide, acaricide, fungicide, herbicide, regulator, repellent, attractant etc.). Article 2 of Regulation (EC) No. 1107/2009 clearly states that it applies to ‘substances (defined as chemical elements and their compounds as they occur naturally or as they are Produced by industry), including micro-organisms, with a general or specific action on pests or on plants, parts of plants or plant products', all referred to as' active substances'.

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6 This is Annex II to Regulation (EC) No. 889/2008 laying down detailed rules for the application of Regulation (EC) No. 834/2007 on organic production. It should be noted that, if various active substances classified as biopesticides are found, more restrictive conditions for their use in organic production are also detailed in a table in Annex II (available on fytoweb.be/en).

7 Regulation (EC) No. 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant-protection products on the market and repealing Council Directives 79/117 / EEC and 91/414 / EEC. This regulation instead refers to bio-control agents (Article 3/8) to 'non-chemical methods', *i.e.* ‘chemical substitution methods for chemical pesticides Phytosanitary protection and pest control, based on biological control’ (they therefore belong to the recommended methods for integrated pest management within the meaning of Directive 2009/128 / EC).

It is important to understand that only products that have been previously authorized can be used as crop protection products. These are the only products, pesticides as biopesticides, whose toxicity and risks have been evaluated scientifically. This does not mean that these products are safe. However, if they have received an authorization for use, this means that the risk was considered acceptable for health and the environment under the conditions required for their use. In addition, they are also products whose efficacy as a plant protection product has been officially demonstrated. It is therefore hazardous to venture to use other 'natural products' whose effects and the absence of toxicity cannot be guaranteed!

2.4.3. What are these products used for bio-control?

❑ **The macro-organisms**

As we have said, under the legislation, macro-organisms are a special case among bio-control products. These organisms, naturally present in the medium, are reproduced and dispersed as such (without modification). They may be predatory insects (such as ladybugs) or parasitoids (such as some micro-hymenopterans), predatory mites, entomophagous nematodes or even vertebrates such as certain fish used to limit the growth of algae or invasive aquatic plants.

Several species of nematodes (*Steinermatidae* and *Heterorhabditidae*) are parasites of insects. Infection is most often from eggs deposited on the leaves of plants. The eggs hatch and the larvae penetrate the host through the natural orifices and even the cuticle. Either they release the bacteria that quickly kill the host or, in the fourth stage, they leave the host by tissue perforation. It follows the death of the insect. Although nematodes are good biological control agents, their use in the dry zone is limited by abiotic factors, particularly UV.

For this category, the term 'biocontrol agents' refers to 'Biocontrol Agents' (BCA). The consequences of the unfortunate introduction of bio-control agents in a given area are now well known and documented (the case of the Asiatic ladybird *Harmonia axyridis*, an ally that has become invasive). The release of an exotic macro-organ is no longer regarded with such a favorable eye as in the past. The use of exogenous organisms has become rare since their entry into the territory of an EU Member State and their introduction into the environment must be subject to prior examination.

However, for macro-organisms, the evaluation and decision of their introduction remain the responsibility of the Member State. And, unless working in a perfectly confined and controlled environment, a pest risk analysis (PRA[8]), including a study of the potential impact on the biodiversity of the environment, will be required before any authorization of use.

❑ **The micro-organisms**

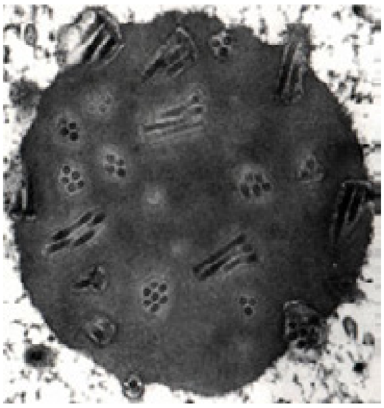
The micro-organisms that are used in plant protection products are all isolated from the natural environment (e.g. from infected insects or soil) and produced by various techniques now well-controlled for the multiplication of microbes on a scale (Usually

[8] PRA or Pest Risk Analysis. This is an approach that has been codified in an FAO/IPPC standard.

fermenters). They are presented in various forms (suspensions, granules or powders for use with or without dispersion in the water of the sprayer).

These are products made from either **viruses** (e.g. Betabaculovirus responsible for granulosis of apple moth, *Cydia pomonella*), bacteria (e.g. *Bacillus thuringiensis* or *Bt*), fungi (e.g. *Paecilomyces fumosoroseus*, *Trichoderma*, *Beauveria bassiana*...) or mycorrhizal agents (e.g. soil aerobic bacteria *Rhizobium etli*).

- ***The Baculoviruses***



The **baculovirus** family (insect-specific virus that is harmless to man) is considered to be the most promising group in terms of microbiological control procedures, especially in view of the fact that is harmless to both man and vertebrates.

A certain number of caterpillars are susceptible to the **granulosis viruses** (type of Baculovirus found in the Lepidoptera).

The viral infection of caterpillars occurs via the ingestion of viral particles when biting. Once ingested, the baculoviruses will bind to the microvilli of the epithelial cells in the ventriculi of insects susceptible to this micro-organism.

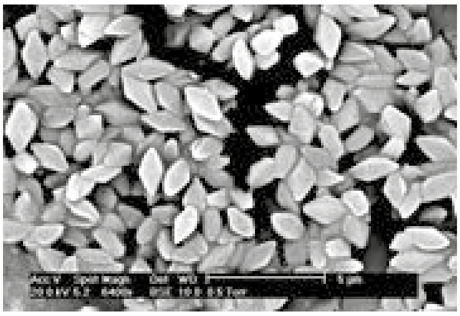
The insect does not die immediately. The caterpillar becomes infected during the feeding stage – the period during which it carries out exploratory bites. The granules are dissolved and released in the body of the caterpillar. They are carried throughout the body and embed into the new cell nuclei. The caterpillar's behavior does not alter initially. The caterpillar then stops feeding and loses its mobility. In the final stage, the caterpillar becomes deliquescent. Applications must coincide with the hatching of the young larvae. It is, therefore, advisable to monitor migration using sex pheromone traps and to follow plant protection warnings. Only the larval forms of the insects are, in fact, susceptible to viruses. The adults can, however, be passive carriers or transmit the disease to their offspring.

The main characteristics of viral bio-insecticides are specificity, high virulence, rapidity of action and a reasonable level of persistence in the environment. Viral persistence is, however, affected by UV rays. In a certain number of cases, the length of time between ingestion and death is considered too long and substantial crop damage may still occur.

A typical example of the use of baculoviruses includes 'Carpovirusine', a biological insecticide to eradicate Carpocapsa in apple and pear trees (*Cydia pomonella,* codling moth – a tortrix moth). Green caterpillars of the cabbage looper (*Trichoplusia ni*) can also be eradicated using a spray prepared from caterpillars infected by viral diseases present in the field. These infected caterpillars can easily be detected in the field because they initially turn whitish in color and become inactive after having been infected. They tend to migrate upwards in the plant. They can then be found hanging on the underside of the leaves. Finally, they turn black and are filled with an oozing liquid.[9]

[9] See the process for the preparation of *Baculovirus* suspensions appended.

➢ ***Products containing* Bacillus thuringiensis**



Insecticides containing the spores and toxins of ***Bacillus thuringiensis*** (abbreviated to *Bt*) – a sporulant bacillus – are available. *Bt* is present in virtually all soils, water, air and plant foliage. The *Bt* bacterium is capable of synthetizing and excreting **crystals that are toxic to certain insects**. These crystals are formed from a combination of several proteins representing almost 30% of the dry weight at the end of sporogenesis.

Only these proteins are insecticidal to Lepidoptera, Coleoptera and/or Diptera. They act by destroying the cells of the ventricles (mid gut) of the insect larva affected by these toxins, leading to the death of the insect. Compared to chemical insecticides, **they have the advantage of not killing natural enemies** (although this point is currently debated). Moreover, these products are **non-toxic** for users and consumers.

Some of these strains are specific to Lepidoptera (Kurstaki), some to Diptera (Israelensis) and others to Coleoptera (Tenebrionis). In order for it to be effective, the bacterium or toxin must be ingested by the insect.

Related to its specificity of action, the intensive use of *Bt* may lead to pest resistance. Such cases have already been described for the Diamondback Moth (*Plutella xylostella*). On the other hand, as for contact insecticides, the use of *Bt* on tomato plants predicates on observation of Lepidoptera caterpillars by trapping. In fact, once the caterpillars are inside the fruit, the efficacy of *Bt* is considerably reduced.

➢ ***Entomopathogenic fungi***

Entomopathogenic (insect killing) fungi have the specific feature of infecting insects through the skin. The infectious hypha penetrates and colonize tissues, causing the death of the host. The corpse becomes « mummified » with evidence of sporulation on the surface of the insect's body under favorable conditions. Only one mummy is needed to produce a local focus of infection. Entomopathogenic fungi are divided into different orders and types. The most common include the Entomophthorals (Zygomycete fungi associated with the Homopteran Aphididae and Cicadidae), and Deuteromycetes (*Beauveria, Hirsutella, Metarhizium, Nomuraea, Paecilomyces, Verticillium, Tolypocladium* etc.).

Entomopathogenic fungi are tricky to use under agronomic conditions due to technological production problems, the susceptibility of the micro-organisms to environmental conditions and the difficulties of becoming established in the plots of land.

A few nematophagous fungi should also be highlighted, such as *Arthrobotrys* (Deuteromycetes), which capture phytophagous nematodes thanks to specific organs in the shape of loops, rings and buds coated with adhesive lectins and then parasitize them, or the Hirsutella genus with conidial adhesion, Paecilomyces and Verticillium.

Infectious spore of Beauveria bassiana

Soil fungi of the ***Trichoderma*** genus are potential natural enemies ('**antagonists**') controlling numerous phytoparasitic fungi: For example, *Trichoderma virens* is approved in the United States for managing *Rhizotocnia solani* and *Pythium ultimum* in horticultural crops. Rhizospheric bacteria belonging to different genuses (*Pseudomonas, Enterobacter, Serratia* etc.) ensure the protection of roots whilst *Pasteuria penetrans* has proved effective against attacks from phytophagous nematodes. Some strains of *Fusarium oxysporum* are antagonists of parasitic strains of the same species (forming '**suppressive soils**'). Yeasts are used to protect apples stored in refrigerators.

Finally, beneficial fungi for farmers include **endomycorrhiza**, which play an important role in the mineral nutrition of plants and in protecting against certain root pathogens. Under controlled conditions, for instance, tomatoes colonized by *Glomus mosseae* have a high level of protection against *Phytophthora parasitica*.

Antagonist fungi, entomopathogens and endomycorrhiza are exposed to the effects of **cultivation practices**, some of which have a negative impact on their development: fertilisers with high phosphate content and the application of fungicides trigger a low mycorrhization rate. Within the integrated crop management framework, it is essential to take into consideration the relationships between the micro-organisms in the soil, the crop and the organic matter.

❑ Chemical mediators

Certain volatile organic compounds (VOCs) present or released in the natural environment act as 'chemical messengers'. Pheromones are known (chemicals comparable to hormones, emitted by most animals and some plants, and act as messengers between individuals of the same species), kairomones (which allow, for example, predators or parasites to detect their prey or host at a great distance), repellents (e.g. garlic pulp...) or attractants (e.g. di-ammonium phosphate or attractant ITAB used for olive fly).

The best known use of these compounds is that of sex pheromones which have been studied, isolated, identified for several species, and then synthesized to attract male or female insects in traps. This technique is appreciated for the monitoring of grain silos or orchards, or it allows the fight against certain butterflies by sexual confusion.

❑ Natural substances

By definition, any substance present 'as is' in nature could be classified in this category. However, according to the legislation, both substances originating from a natural source material and substances obtained by chemical synthesis may be used, but which, in their molecular structure, are strictly identical to the substances found in the Nature (they are referred to as 'identical products'). This category includes all substances derived from living organisms, irrespective of whether they belong to the plant or animal kingdom (prokaryotes, unicellular eukaryotes and fungi). Paradoxically therefore, a toxin produced by GMO bacteria in fermenters can be classified as 'natural substance'!

The nature and composition of these 'natural substances' are very varied, as they are of vegetable, animal, microbial or even mineral origin. Several of these substances are classified as eleven 'basic substances' (still a category!) Which have been recognized to date for their efficacy, albeit partial, and therefore legally permitted to be used, the conditions of use are respected. The basic substances are products that are already marketed for other purposes, such as food, but can also be used for crop protection. These include: vinegar, sucrose, fructose, horsetail, willow bark, chitosan hydrochloride (chitosan), diammonium phosphate, lecithins, whey, calcium hydroxide and sodium hydrogencarbonate (or sodium bicarbonate).

If the natural or base substance is not on the positive list, it means that its effects on the environment or on the user are not known. And even if they are 'natural' products, that does not mean they are harmless. Obviously, the dose and the mode of application also play a part, which is why this information is also included in the positive list. When these substances are used in a different way, for example, at a higher dose, they may pose a health or environmental hazard. List all their properties here is impossible, but the fact that these substances act on living organisms should encourage caution in their use.

➢ *Natural substances of plant origin*

Natural substances of plant origin can be of several types:

- substances extracted from plants and purified (e.g. pyrethrins, nicotine, sugar etc.);
- unpurified aqueous extracts (e.g. horsetail decoctions – *Equisetum arvense*), herbal teas, willow, garlic, chili infusions etc.) or extracts in a solvent (e.g. azadirachtin extracted by methanol);
- vegetable oils (e.g. neem oil, rapeseed oil etc.);
- essential oils (e.g. citrus fruits and many other plants);
- plant powders or parts of plants (e.g. willow bark, ground leaves, bulbs).

A large number of plants possess pesticide properties. **Local flora**, whether cultivated or spontaneous, provide many opportunities for plant protection management.

Neem (*Azadirachta indica* or Indian lilac), a tree found to varying degrees throughout Africa, is a well-known example. All the parts of this tree, but the seeds in particular, contain an active substance (azadirachtin) which can be used as an insecticide and which is effective against a large number of insects such as the cotton boll worm (*Helicoverpa armigera*) in tomatoes, the diamond-back moth (*Plutella xylostella*) in cabbage, ladybird (*Henosepilachna elaterii*) in cucurbitaceae, thrips and aphids.

Other plant products possessing insecticidal properties include pyrethrins, rotenone (Derris extract), chili pepper, garlic, turmeric or **tobacco**, the extracts of which are particularly effective against aphids and thrips (see Appendices).

Spectrum of action of some plant products						
Plants	Thrips	Caterpillars	Aphids	Moths	Whiteflies	Mites
Garlic	▪		▪		▪	▪
Annona		▪	▪			
Turmeric		▪				▪
Derris	▪	▪	▪	▪		
Meal			▪			▪
Neem	▪	▪	▪	▪		▪
Nere	▪		▪	▪	▪	
Pepper			▪			
Pyrethrin	▪	▪		▪	▪	▪
Tobacco	▪	▪	▪	▪	▪	

The **leaves** of certain plants (e.g. neem) and **vegetable oils** are to a certain extent effective in the control of insects found in **stored produce**. When used appropriately, they have a protective effect. Fresh branches of the *Boscia* (Capparidaceae) shrub are used to cover millet or sorghum stores in traditional granaries in Chad, in Senegal etc.

Neem (Indian lilac) seeds

Leaves and fruits of Boscia sp.

The following vegetable oils were tested and used successfully on stored foodstuffs: peanut, coconut, safflower, mustard, castor bean, cotton, soya, neem and maize. Sunflower oil is not always effective. The oily coating hampers the reproduction of adult insects that can no longer lay their eggs in the seed. External larvae cannot enter the seed because of the layer of viscous oil. The oil can also destroy insects' eggs. The layer of oil prevents gaseous exchanges if the egg is already present inside or on the surface of the seed. Larvae inside the egg or seed perish because of a lack of air. The product can be bagged after treatment. The protective effect lasts for at least 3 months and often up to 6 months, depending on the type of oil used and the prevailing conditions. As the oil can have a negative effect on the germination power of the grains, those to be used as seeds should not be treated.

Furthermore, many other plants possess **insecticidal** (basil, carrot, lemon grass, citrus bark, eucalyptus, onion, tagetes and even tomato leaves), **fungicidal** (garlic, tumbleweed, bitter cassava, onion, papaya tree, chili and castor bean etc.), and **nematocidal** (crotalaria, Persian lilac, castor bean, tagetes etc.) properties. Their efficacy depends on the plant organ used (seeds, bark, leaves, stems, bulbs, etc.) and the time at which the latter were collected.

'**Rustic preparations**' (see examples appended) are produced by: maceration in cold water (vegetable manure), infusion in hot water, extraction by exerting heavy pressure or by stamping the plant material to extract the juice or oil etc. Solid residues (oilcakes) are also used (e.g. solid neem residues incorporated in the soil to control nematodes; castor bean cakes) moist or dry. They are used in the preparation of baits to control insects, rodents and birds.

➢ ***Natural substances of animal origin***

Natural substances of animal origin are:

- solid substances (e.g. chitosan, tallow etc.);
- liquid substances (e.g. whey or whey, which has fungicidal properties against powdery mildew);
- volatile substances (pheromones, kairomones).

➢ ***Natural substances derived from micro-organisms***

Natural substances derived from microorganisms may be:

- unprocessed purified substances (e.g. spinosad);
- purified and processed substances (e.g. spinetoram);
- microbial toxins (e.g., *Bacillus thuringiensis* toxin, *Bt*);
- pieces of strain walls of microorganisms (e.g. pieces of Saccharomyces cerevisiae wall: LAS117 or cerevisane).

➢ ***Natural mineral substances***

Natural mineral substances may be:

- powders (to be powdered or dispersed in water) (e.g. sulfur);
- suspensions (to be sprayed) (e.g. clays such as kaolin, talc etc.);
- soluble (pour or spray) products (e.g. baking soda, which is fungicidal for scab or powdery mildew, calcium hydroxide, an effective fungicide against cankers of apple and pear trees).

The plants can be sprinkled with wood ash to control certain insects in vegetable crops such as okra, pepper, chili and some cucurbits. Wood ash is particularly effective in combating aphids. It also brings nutrient minerals to the crop. The timing of the ash spread depends on the degree of moisture in the leaves: they should not be too dry (the ash does not adhere) or be too wet (the ash could accumulate in the water droplets and cause Lesions on the leaves). To avoid these disadvantages, spreading is done early in the morning or at night, at sunset.

Wood ash, and certain minerals, such as fine sand, laterite powder, lime, are also used for the protection of stored foodstuffs. These minerals fill the space between seeds, thus preventing the movement and spread of insects in the stored product.

❑ **Elicitors (or defense inducers)**

These are substances that stimulate the natural defenses of plants and the production of defensive substances (including phytoalexins, PR proteins, etc.) by mimicking molecules belonging to pathogens (fungi or bacteria). These bio-control products (referred to as PDSs or plant defense stimulators) may be derived from living organisms, such as chitin from fungi or crustacean shells, or oligogalacturonides derived from cell wall pectin Vegetable products.

The laminarin is extracted from kelp (a mixture of brown, red or green algae left by the withdrawal of the tides). Sucrose (one of the permitted basic substances) is considered an elicitor with an insecticidal effect via the stimulation of natural plant defense mechanisms. As such, it can be used on apple and corn.

The elicitors can be produced by synthesis and induce a defense reaction of the plant. Fyfofend FYTOSAVE® is a compound based on chitosan and pectin (COS-OGA). Syngenta BION 50 WG® contains acibenzolar-S-methyl, a compound that has fungicidal properties and, as an analogue of salicylic acid, initiates the defense of plant cells.

2.4.4. Natural herbicides or 'bioherbicides'

It is much more interesting to manage spontaneous flora by cultural practices or the management of wild and public spaces than to seek to eliminate them. However, the search for alternative solutions for weed control has gone beyond the scope of experimentation. Various techniques have proven their effectiveness: use of heat (foam and hot water, thermal burners, solar heat and even microwaves), plastic mulch, geotextiles, electric weeding, brushing...

However, there is still a road ahead to popularize these techniques and find the most effective strategies for their implementation. In order to intervene punctually and in addition to a rational management of weeds, the possibility of using bio-control products remains an issue for research. **Two pathways are possible**: biological control or formulation of natural herbicides (bioherbicides).

'**Biological' weeding**, which is the biological control technique in which the effect of pests or weed diseases is activated, is particularly difficult to implement. No conclusive results have been obtained so far by exploring this path. If the use of certain animals (sheep, chickens) for the weeding of orchards or parks remains an appreciated alternative solution, its implementation, often complicated (when it comes to managing animals in a public space) limits the interest.

'Bioherbicides' are now defined as 'products of natural origin with weed control'. These products represented less than 10% of the biopesticides put on the market, mainly in Ukraine, Canada and the United States, but the approval of certain natural substances that are effective will certainly change the situation in the coming years. Because of their large-scale use, we will focus on **two categories of bio-control products that can be used for weed control**: micro-organism products and natural substances.

❑ Micro-organisms-based bioherbicides

Already in the 1980s, the first micro-organism-based bioherbicides were born, but they have never penetrated the market. Bioherbicides of this type attempt to cause damage to weeds by infecting and invading the tissues of these plants until necrosis by releasing active enzymes (pectinases, cellulases, lignases) or toxins that interfere with the metabolism of the plants.

These commercial products (many of which have disappeared for lack of success!) contain, for example:

- plant pathogens (*Colletotrichum gleosporioides*), Phoma (Phoma®), *Chondrostereum purpureum*, *Phytophthora palmivora* (Devine®), *Puccinia* (Woad Warrior®), *Sclerotinia minor* (Sarritor®), *Alternaria*...);
- strains of certain pathogenic bacteria such as *Xanthomonas campestris*: Camperico®).

❑ Bioherbicides from natural substances

Various natural substances have shown an herbicidal effect. Some come from the fermentation of certain microorganisms. This is the case of vinegar (acetic acid, a base substance), derived from yeasts, contained in the product NATUREN FERTILIGENE®. The effectiveness of the vinegar is reduced because it acts only by burning the leaves without destroying the roots. The annual plants are killed, but the perennials, on the other hand, grow back two to three weeks later. It takes about six passes a year to get a good result. The cost may therefore discourage users of this product.

Another more promising example is thaxtomine A, a phytotoxin produced by Streptomyces acidiscabies, a bacterium responsible for common scab of potato. Thaxtomine is a natural and biodegradable herbicide, unfortunately still too expensive to produce to be fully exploited. However, in Canada, a technical grade active ingredient (MBI-005 TGAI) and an end-use product (MBI-005 EP®), the active ingredient of which is a mixture of Streptomyces acidiscabies strain RL-110T (killed and non-viable) And thaxtomin A have been authorized and registered for the control of dandelion in turfgrass (Kentucky bluegrass and fescue).

Other natural substances are extracted from plants. This is the case of pelargonic acid (also called nonanoic acid) a non-selective contact bioherbicide whose efficacy reaches 85 to 90% of the reference product (glyphosate). It is at the same time weed-killer, desiccant and defanant. Originally derived from odorous pelargonium, it is now extracted in large quantities from rapeseed oil and even from sunflower. In Belgium, pelargonic acid is found in several commercial preparations available to individuals associated with glyphosate (e.g. ROUNDUP FAST® or ROUNDUP SPRAY®). Paradoxically, it is therefore products of Monsanto that contain pelargonic acid! In France, Syngenta markets KATOUN®, Jade BELOUKHA® and Clairland or Compo HERBISTOP®. All these products have obtained sales authorizations in Europe (on vines and for the de-potting of the potato).

Also available is the Neudorff FR weed killer, FINALSAN ULTIMA JARDIN® based on pelargonic acid and maleic hydrazide (very low dosage). In order to act to the roots, two applications of this substance at one week intervals are generally necessary to overcome most perennials, including thistle or bindweed. Maleic hydrazide (used in agriculture as a growth regulator, especially as a germination inhibitor for potatoes), which is not a natural substance, is not considered to be toxic to humans, Environment, unlike glyphosate.

2.4.5. Conclusion on biopesticides

The development and use of bio-control agents and products is in full swing as these ‘alternative’ products meet an increasing demand for solutions that better respect the health of users and the environment. The variety of these new products and their modes of production is impressive, and one can only rejoice. Since they originate from the natural environment and their activity is explained by natural mechanisms, their effect is potentially less on man or on flora and fauna.

Nevertheless, like any organism or substance that is deliberately introduced into the environment and indirectly into the food chain, it is necessary to evaluate its risks using tried and tested methodologies, regardless of the price to be paid. Indeed, the registration process is an economic obstacle, forcing many laboratories to transfer the exploitation of their patents to large agrochemical companies, the latter being the only ones with the capacity to finance the studies required for the evaluation files.

Only active substances and plant protection products which have been evaluated by EFSA and the Member States are entitled to claim an acceptable risk under normal conditions of use. Any other substance, even a natural substance, which has not been the subject of such an examination must, therefore, be treated with caution and suspicion.

Let us add that, for pesticides or biopesticides, the risk assessment has the same limitations, due to the test protocols and the uncertainties associated with the methods and limitations of the models used. Total risk control is an illusion. In the case of some bio-control products, the risk assessor will be even more cautious, as it is often difficult to transfer the evaluation methods used for chemicals to micro-organisms. How, for example, can one validly assess the impact of a microorganism used as a bio-control agent on the microflora of the soil from which it has been isolated? It has to be recognized that it is more complicated and requires an entirely different approach than that used for chemicals.

2.5. Alternative control methods to chemical products

2.4.1. Flooding

Flooding can be used to control certain crop enemies. Many pests and diseases cannot survive in flooded soil. In fact, the number of disease pathogens in the soil is reduced after the flooding period. Furthermore, flooding may kill lepidopteran pupae and the nymphs of other insects.

A typical example is the small beet armyworm (*Spodoptera exigua*), the pupae of which are found in the soil. Another important example concerns root knot nematodes (*Meloidogyne* sp.). In flooded soil, nematode populations decrease to a very low level if the flooded period is sufficiently long. A period of at least one month is recommended.

The farmer can often submerge his fields in the floodable shallow areas or in soils bordering rivers where horticultural crops are cultivated. If tomatoes are grown on a previously submerged plot, few problems will arise with the Meloidogyne (root knot) nematodes.

2.4.5. The use of trap crops

Trap crops are plants that attract certain pests (like cyst nematodes) but which prevent the pests from completing their life cycle. The root exudates of some plants (used as « green fertilisers ») cause cyst nematodes (*Globodera* and *Heterodera* genera) containing eggs to hatch. The larvae will infest the radicle system of these plants – they are either unable to survive and end up dying, or the producer digs them up or destroys (with a total herbicide and/or by burying) the crop at a sufficiently early stage. The number of nematodes in the soil will decrease thanks to the hatching of some of the cysts (between 30 and 70% of cysts present in the soil) and the absence of proliferation. This technique is recommended in cases of **heavy** soil **infestations**.

Trap crops of Angola pea, sunflower, maize or crotalair may, for instance, be distributed around **tomato** plants to keep the cotton boll worm (*Helicoverpa armigera*) at bay. It should be noted that some plants such as *Tagetes* are nematode antagonists.

2.4.6. Agro textiles

'Agro textiles' (woven, non-woven or knitted) are intended to form a physical barrier preventing insects from eating, stinging or sucking plants in order to prevent direct or indirect damage (viral transmission, soiling with excrement, etc.). The choice of the mesh size will depend on the insect to be controlled.

Meshes of the order of 300 µm and 500 µm are required for thrips and aphids, respectively. The tightness of the mechanical protection must be as perfect as possible and the plants must not touch the screens. Disappointing results are obtained with insects where the pupae (e.g. carrot or cabbage flies) or larvae (e.g. cotton boll worm) remain in the plot soil.

They are often used to **protect nurseries** against aphids, white flies, virus carriers, thrips or flea beetles.

These 'screens' intended to provide physical protection should have a minimal effect on rising temperatures, irrigation and ventilation. However, given the climatic changes triggered by agro textiles, which hamper air exchanges and reduce light, their use is often restricted to warm regions.

2.4.7. Soil solarization

This solar disinfecting method is carried out by covering the soil with a plastic cover. The need for watering to bring the soil moisture to the field capacity has been widely demonstrated. Light intensity must be able to generate a rapid rise in temperature within 3 days of applying the plastic cover, and warrants the use of a suitable, UV-resistant plastic film.

The interest of solarisation has mainly been for the control of pathogenic soil fungi, weeds and nematodes and less for other pests.

Small plots undergoing solarisation

Solarisation appears to have a greater effect on the relative balance between the various organisms present in the soil, especially antagonists/pathogens, than by a mode of action comparable to chemical treatments which create a ‘biological vacuum’. In a certain number of cases it can help to implant antagonists in the environment.

2.4.8. Steam sterilization of soils

The injection of water vapour (steam) after soil preparation raises the temperature of the soil to a level that proves fatal for numerous target organisms (diseases, pests and weed seeds). Steam will, therefore, disinfect the soils, protect crops chiefly against soil fungi and destroy weed seeds. The extent of the disinfecting procedure is proportional to the thickness of the treated soil and, therefore, to treatment time. Treatment costs remain high, but the method does not trigger any residue problem.

Equipment for vapour treatment (vapor ‘cloches’).

A temperature of 75 °C is considered necessary to destroy the seeds of weeds and the principal fungi. Steam can be applied to the soil either with plastic covers or using ‘cloches’, which are metallic plates fitted with steam injectors. The metallic cloches are left in place for 5 to 10 minutes in order to reach a temperature of 80 to 90 °C at a depth of 8 to 10 cm, which is broadly sufficient to ensure effective weeding, but which may be inadequate for the control of soil fungi (recontamination at deeper layers).

Side effects have been reported with this type of disinfecting procedure: rise in pH and salinity. An increase in ammonium (NH_4^+) and nitrate (NO_3^-) and even nitrogen dioxide (NO_2) has been observed on decomposition of the organic matter. These factors must be taken into account for fertilisation purposes. Furthermore, excess levels of soluble manganese may be present when disinfecting at depth.

2.4.9. Hand picking

Hand picking is a control method that is sometimes recommended for destroying large, clearly visible insects. This method is especially **suitable for small plots**, e.g. in the small-scale production of market garden plants. This method is used regularly in China.

Typical insects that be collected by hand include the major Coleoptera, which are clearly visible because of their size and colour, caterpillars, large bugs and grasshoppers. ***Spodoptera littoralis*** (cotton leaf worms) are easy to destroy after hatching because they remain grouped together on the leaves on which they emerged. Leaves on which their eggs have been laid can be removed.

2.4.10. Scaring and deterring pests

The positioning on the plots of scarecrows, covers or shiny plastic strips between the plants keeps seed-eating birds at bay. These items move or make a noise in the wind, which frightens the birds. Smoke is also used but it can contain substances obtained by combustion, which are toxic and can contaminate the products (e.g. benzopyrenes).

2.4.11. Burning for weed control

Burning kills weeds by thermal shock triggered by a wave of heat (usually a naked flame, but sometimes very hot water): the affected areas are destroyed following degradation of the waxy cuticle and the coagulation of proteins due to thermal shock. Only aerial parts are affected. Burning destroys 80 to 90 % of annual weeds (especially dicotyledons) when applied just after emergence. However, late treatment to annual weeds or application to hardy strains has a substantially less marked effect.

Example of thermal weeding (Photo B. Schiffers)

Appendices: Definitions and various preparations

A.1. Useful definitions

Rational management/control – *guided management:* initial IPM phase involving progressive chemical control thanks to the application of economic tolerance thresholds and the rational use of specific products or products with a slight multipurpose mode of action (IOBC/SROP, 1973).

Integrated pest management (IPM) – *integrated control* or *integrated pest control:* a system for managing pest populations, which, in the relevant environmental context and dynamics of the populations of pest species, utilizes all of the appropriate techniques as consistently as possible in order to keep pest populations below significant economic injury levels. In a restricted sense of the term, it applies to the management of a single species of pest in given crops or in particular areas. In the broader sense of the term, it applies to the harmonious management of all populations of pest organisms in their agricultural or forest environment. It does not involve the imposition of two control techniques (such as chemical control and biological control) but the integration of all the management techniques adapted in line with the natural regulating and limiting environmental factors (FAO, 1967).

Integrated protection – *integrated plant protection, integrated pest management (IPM), integrated crop protection:* a system for controlling harmful organisms that uses a series of methods that satisfy economic, ecological and toxicological requirements but give priority to the intentional implementation of natural limiting factors in accordance with tolerance thresholds (IOBC/SROP, 1973).

Integrated agricultural production – *integrated agricultural production:* a production system that implements a series of cultivation techniques that satisfy ecological, economic and toxicological requirements with a view to obtaining an optimal harvest in qualitative terms (IOBC/SROP, 1980).

Integrated production (integrated farming) – *integrated production (integrated farming):* an agricultural system for producing foodstuffs and other high-quality products that uses resources and mechanisms of natural regulation to replace harmful effects on the environment and to ensure long-term agricultural viability (IOBC/SROP, 1993).

Competition – this refers to a situation in which a resource is not available in sufficient quantities to meet the needs of two individuals of the same species (intraspecific competition) or the needs of two populations of different species (interspecific competition). The phenomenon of competition triggered between species exploiting the same type of resource in a stable environment, leads to the elimination of one or other of the said species over a more or less short-term period (principle of mutual exclusion or even competitive exclusion). It can develop following the intentional introduction of a natural enemy.

Predation – is defined as the capture of prey by carnivorous animals; unlike competition, this phenomenon does not lead to the elimination of prey populations with a balance being struck depending on the aptitude of the predator to capture its prey and, inversely, depending on the ability of the prey to escape capture. Nevertheless, the level of predation can reach very high levels when the prey cannot flee from the predator: this applies to numerous insects such as aphids, which off-set this handicap with a very high biotic potential. Predators are often seen to congregate in plots where the prey is in greater abundance.

Parasitism – parasitism is characterized by the association between two species, one of which, known as the host, harbors the second, which exists at trophic levels at the host's expense. This relationship is generally strict with a parasite being infested in one, or even several specific host species, whereas predation, described above, is a broader and often less specific relationship. Parasite growth cycles can be extremely complex with some parasites having to pass from two or even three hosts in succession. Moreover, a free phase may succeed a parasitic phase within the same cycle. The uncertainties of such a growth cycle are generally off-set by a strong reproduction potential or even an aptitude for asexual reproduction. Recent usage has given rise to the term **parasitoid** when the host does not survive the parasitic action.

Resistance – can be defined as the ability of one variety to produce a more abundant, high-quality harvest than ordinary varieties with the same pest density. Resistance to a disease or pest can be total or partial.

Tolerance – refers to the ability of a variety to develop and reproduce despite the existence of a pest population identical to that damaging a susceptible variety. The use of resistant and tolerant varieties also strengthens the survival rate of the species used. Therefore, this method is naturally part of the integrated pest control framework.

A.2. Preparations containing Baculovirus

Initially harvest approximately 20 infected cabbage looper caterpillars (*Trichoplusia ni*) and crush them thoroughly with a drop of water. The homogenate thus obtained is transferred using a clean cloth. Finally, the homogenate is diluted until a sufficient volume of spray to treat approximately half a hectare is obtained. After 3 to 4 days, the caterpillars become sick and die. This preparation must be applied as soon as possible, when the caterpillars are still young, in order to prevent them from causing serious damage. Good results have been obtained with the cabbage looper caterpillars and the cotton bollworm (*Helicoverpa armigera*).

Another method for spreading the viral disease to caterpillars is to use a dormant form, which is highly resistant to environmental factors. This can be obtained by fermenting the homogenate of infected caterpillars outlined above. This homogenate is diluted with water in a pot. The mixture is left to ferment for a few days at ambient temperature in the uncovered pot. The dormant forms of the virus produce a whitish sediment. The water above the sediment can be discarded. Dormant forms can be kept for up to two weeks in a freezer.

A.3. Preparations containing Neem

Summary of the process for using neem:

- Collect the neem fruits or seeds under the trees.
- Leave them to dry in the shade for a few days.
- Carefully grind the seeds to obtain a fine powder.


Collect and grind the neem seeds (Pictures S. Dihoue)

- Mix the powder with water in a container, and leave to macerate for 12 hours.
- Filter.
- Add a small piece of soap (e.g. so-called “Marseille” soap).
- Splash or spray onto the plants.


Preparation of the neem extracts (Photos S. Dihoue)

- The active product is mainly found in the kernel. For this reason, twice the quantity of powder obtained from whole, dried fruit is required compared to that obtained from seeds alone.

Preparation of 10 liters of neem extracts:

- Small boxes of tomato concentrate can be used to measure the powder. One box filled to the top contains approximately 50 grams of powder.

- If powder obtained from seeds is used, 10 full boxes are needed for 10 liters of water. In the case of powder obtained from whole fruit, 20 full boxes of powder are required per 10 liters of water.
- The powder is wrapped in a fine cloth, which is then placed in a fine cloth bag.
- This is immersed in a bucket containing 10 liters of water and left to macerate overnight (approximately 12 hours). The cloth and its contents are wrung out from time to time.
- The following day, approximately 1 spoonful of grated soap is dissolved in a small quantity of water. The solution thus obtained is then mixed with 10 liters of neem decoction.

Application:

Approximately 500 liters of spray (mixture of neem and water) are applied per hectare using a backpack sprayer. If no sprayer is available, the product can be applied using a watering can or a supple, wooden broom, which is immersed in the bucket. The application is directed to visible insects and to those areas of the plant to be protected. In the case of aphids and other sucking insects, the lower surface of the leaves should also be treated.

A mixture of neem powder and wood (or bran) shavings can be directly applied to the ears of the plant in the case of maize and sorghum. The mixture comprises 50% neem powder and 50% sawdust. Approximately 0.5 gram of neem powder is applied per ear, i.e. 1 gram of mixture per plant (a pinch). Application begins around 10 days post-emergence and is repeated every 7 to 10 days (preventive method). The rain will wash the product to the bottom of the ear where the pests are located. Sometimes there is no need to treat all of the plants in the field. Application can be limited to areas where plants present spotted stalk borer damage (curative method).

A.4. Soap-based preparations

The spraying of a soapy solution is a straightforward method for controlling aphids and thrips. 30 grams of soap (e.g. so-called “Marseille” soap) or 30 ml of liquid soap are mixed in 5 liters of water. The solution should ideally be tested on a few control plants in order to ensure that it does not damage the plants. The plants are inspected after 2 days to check that this solution has not burned the leaves.

A.5. Tobacco-based preparations

Tobacco contains nicotine, which is a highly toxic, organic poison. Its leaves and stems are used to prepare sprays that can be applied to the plants to control the number of insects (aphids, caterpillars, flea beetles, thrips, leaf miners) and mites.

Preparation of a tobacco-based insecticidal spray:

- **Method 1:**
  Crush or grind 1 kg of tobacco stems and leaves, and mix the homogenate thus obtained with 15 liters of water and a small quantity of soap. Leave the mixture to stand for 1 day, then filter carefully in order to remove any plant particles. Treat with

the solution thus obtained using a sprayer fitted with a nozzle to ensure very fine sprays.

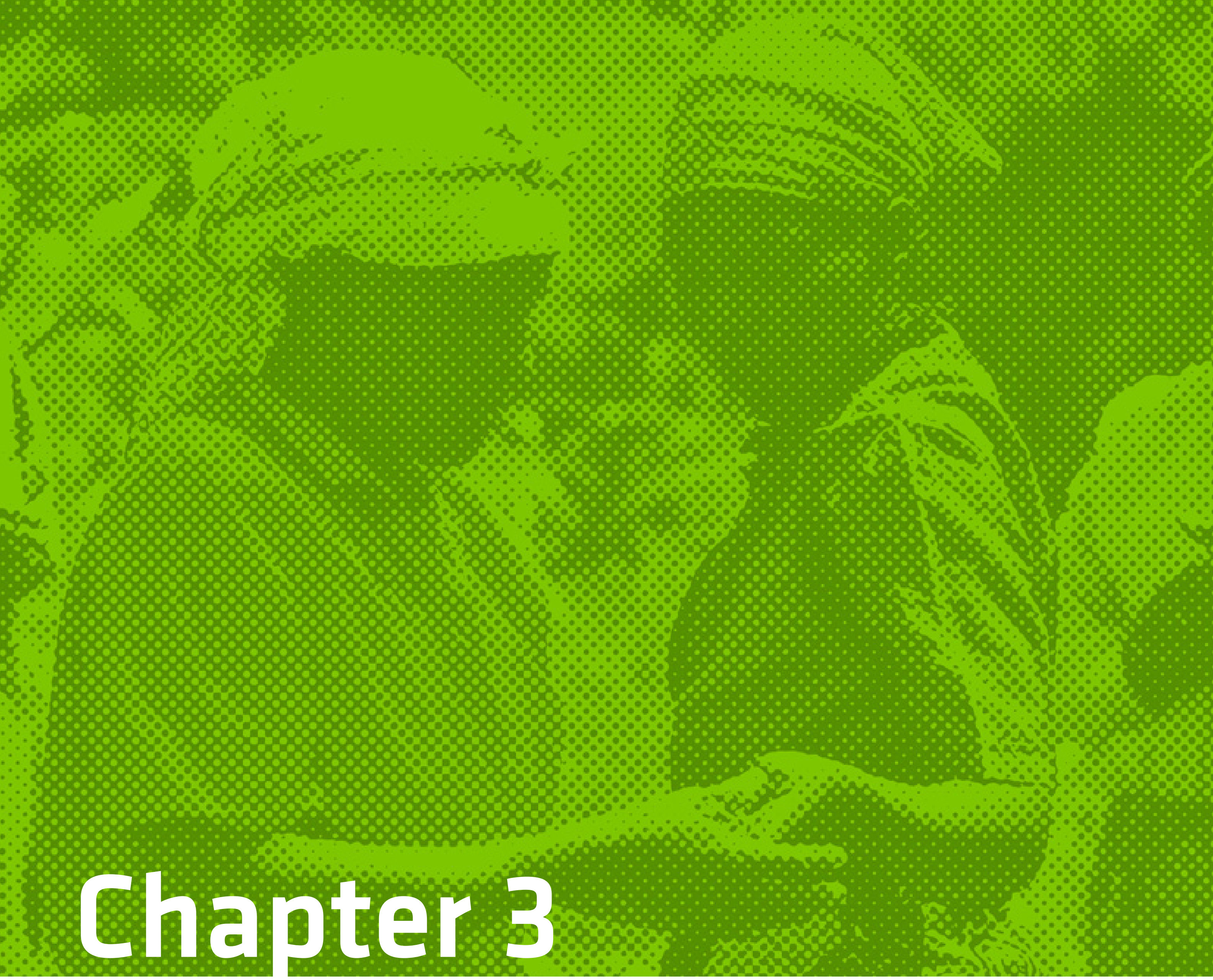
➢ **Method 2:**
Mix 250 grams of tobacco (e.g. taken from a collection of cigarette butts) with 4 liters of water. Add 30 grams of soap (e.g. so-called ‘Marseille’ soap).

Gently boil the mixture for 30 minutes and then filter carefully. Add 16 liters of clean water to the filtrate and treat with the solution thus obtained using a sprayer fitted with a nozzle to ensure very fine sprays.

A.6. Implementation of a germination summary test

The implementation of a germination test prior to sowing is an effective method for ensuring the ability of seeds to produce robust plants. Carry out this summary germination test. It is recommended in particular for vegetable, cereal and pulse seeds:

- collect 100 seeds from a batch intended for plantation;
- place the seeds on a damp cloth or absorbent paper in a glass jar or another clean container;
- keep the cloth or absorbent paper slightly damp;
- examine the seeds every day for one week to check for germination and the emergence of roots and shoots. Count the number of seeds that have germinated out of the 100 initial seeds and remove them from the jar. The number of germinated seeds will indicate the proportion of healthy seeds in the original batch;
- if not enough seeds (e.g. 90%) have germinated, dispose of the batch or increase sowing density.



Chapter 3

Developing an integrated pest management strategy

3.1. What is meant by a crop protection 'strategy'?

It is possible to talk about a 'strategy' when **a set of coordinated methods and actions** are intentionally implemented **with the aim of achieving a specific goal**. A strategy involves consistent preventive measures and actions implemented at all stages of cultivation (before, during and after harvesting), based on a sequential approach (e.g.: before and during sowing, during the growing phase, during flowering, fruiting, harvesting and post-harvest), to achieve one or more **objectives**.

Therefore, it is crucial for the producer to **clarify his objectives** before considering developing a strategy for protecting his crops. However, as we know there are often **numerous and occasionally contradictory objectives** in this field.

These may include:

- maximizing yield (most often 'optimizing' yield);
- controlling production costs;
- preserving the commercial quality of products;
- complying with standards governing residues;
- reducing environmental impacts (soil, water, air, biodiversity, biomass);
- preventing the destruction of pollinators and auxiliary insects;
- preventing the emergence of resistance in bioaggressors;
- complying with regulations (in particular authorized products and 'Good Plant Protection Practice') as well as clients' specifications (e.g.: GLOBALG.A.P., Tesco NC, Perfect Charter, Terra Nostra…;
- etc.

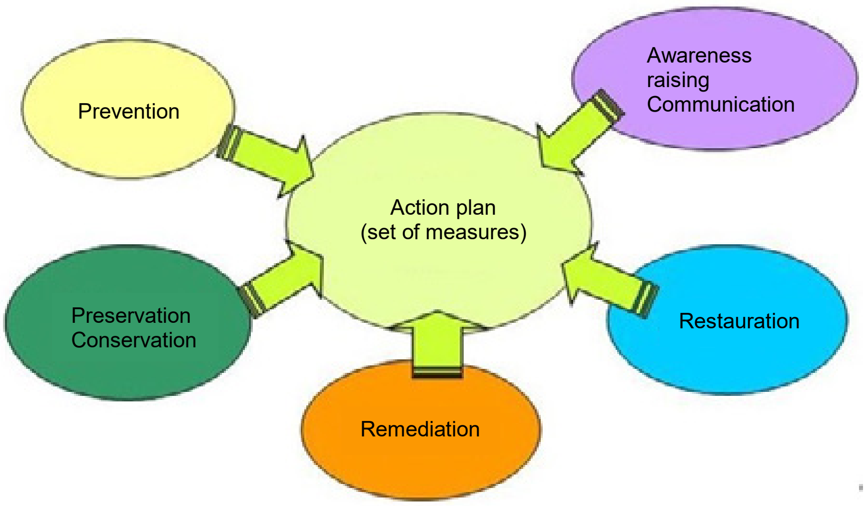
On an operational level, a strategy will translate into a '**technical protection itinerary**' (also known as an '**IPM itinerary**': IPM meaning 'Integrated Pest Management'), which can be regarded as an '**action plan**'. All good strategies will also include '**alternative action plans**', in other words options for control that can be used in the case of unforeseeable events, which significantly change the situation (e.g.: unforeseeable extreme weather events, abnormal invasion by a harmful organism, a circumvention of varietal resistance by a bioaggressor, etc.). However, 'integrated protection' cannot simply be reduced to a technical itinerary. A system needs to be devised by adopting **a long term vision**.

Therefore, under pressure from weeds and bioaggressors of all kinds, developing an '**integrated pest management strategy**' means **examining all prevention or control methods** that will maximize the chances of achieving the desired objectives (e.g.: protecting a harvest by reducing the risks affecting the quality and safety of food). The action plan originates from **complex strategic thinking**, as it needs to differentiate between the desire to achieve the intended objectives and the constraints faced by the producer (e.g.: the economic situation, environmental characteristics, the farmer's expertise, the availability of resistant varieties or the desired plant protection products, etc.). Each producer must find their own best combinations of pest management practices and/or methods to develop an action plan that is **relevant to their operation**: protecting their assets, successively working on weaknesses to manage the impacts of each choice, removing traditional plants and learning to tend to a crop **by first and foremost thinking of the agroecosystem as a whole**.

The 'action plan' will specifically include:

- environmentally friendly agronomic practices;
- preventive measures (e.g.: prophylaxis, certified seeds or seedlings, tolerant or resistant varieties);
- preservation actions (e.g.: preserving soil fertility) and conservation actions (e.g.: establishing hedges that provide a habitat for auxiliary insects or birds);
- awareness-raising measures (training, communication with small producers);
- restoration measures (e.g.: improving the level of organic matter and soil biomass);
- remedial actions (e.g.: releasing auxiliary insects, creating insect hotels, augmentoriums and insectariums, intercropping, etc.).

This amounts to adopting the principles of agroecology as part of integrated pest management: not acting *against* nature ('fighting enemies'), but working *with* nature ("reactivating ecological processes for your own benefit and taking advantage of ecosystem services to protect your crops").



Nevertheless, good strategic thinking must include **available resources** when analyzing the problem and formulating the action plan, as benefiting from certain resources or not, or benefiting from sufficient resources, may have a significant impact on the definition of objectives, on the one hand, and on the actual ability to devise a coherent action plan, on the other.

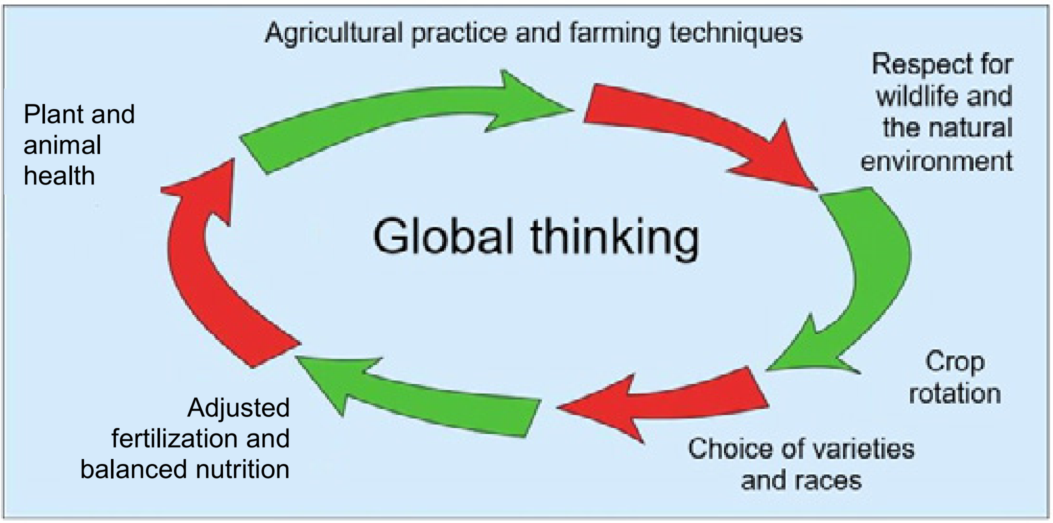
Therefore, a 'good' strategy must not ignore the question of resources *per se*as this may actually result in anticipated objectives being abandoned as 'unrealistic' or at least in them being reformulated. For Robert Kaplan, the fact that 90% of strategic initiatives fail to meet their objectives is not due to a lack of clear formulation, but because of general implementation difficulties caused by an overestimation of the producer's and/or the company's capabilities. The resources allocated may be human, (bio) technological, industrial, commercial or financial. However, financial resources have their own specific characteristic in that they enable other resources to be acquired. As a result, it is obvious that a company's financing and debt servicing capacity enables it to have greater flexibility when developing its strategy. Meaningful reflection on resources also enables **those that exist locally, and which are often underestimated, to be used** (e.g.: extracts of local plants with insecticidal properties or traditional knowledge and practices) and provides an understanding of how to take advantage of them, specifically in order to minimize production costs and save resources.

Analyzing the company's position (accountability, perception and awareness of risks, etc.) cannot simply be limited to the purely economic aspects of the strategy, but must also **incorporate health issues** as well as **environmental and social aspects** into a global **sustainable development** type vision. The 'action plan's' actions and operations require not only an allocation of resources, but also **a long term commitment on the part of the company**, in particular if capacity building is necessary (e.g.: training for managers, middle managers and workers or small producers that supply the company). This long term vision is vital for influencing behavior and fundamentally changing practices.

The strategic approach can be briefly defined as 'the ways and means' of determining the least worst way ahead, in the medium or long term, by taking account of the external environment (risks and opportunities) and the capabilities and opportunities available internally. A good strategy is permanently profitable and rewarding, which guarantees its durability.

3.2. The four key aspects to consider in all strategies

'**Global thinking**' must form the basis for ensuring the **good health of crops** (and also of animals), as shown in the following diagram: good agricultural practice (the backbone of everything), respect for auxiliary fauna and biological balances within the environment, suitable crop rotation that enables pressure from bioaggressors to be limited, the choice of hardy and resistant varieties, balanced fertilization that does not weaken the plant.



When considering developing an integrated pest management strategy, there are **four key aspects** that need to be examined:

- **the bioaggressor** (the enemies of crops, which cause damage deemed economically unacceptable for the producer: fungi, bacteria, viruses, insects, mites, nematodes, rival weeds or parasites etc.);
- **the crop** (the species grown, from which good a quality and quantity of production is expected);
- **environmental conditions** (the physical condition of the environment, climate, biodiversity etc.);
- **agricultural practice** (the cultivation method adopted and the operations carried out).

Each is an individual aspect and **no one is more important than the others**.

Nevertheless, it must be acknowledged that, in the majority of cases, in terms of controlling bioaggressors, most attention is paid to studying the bioaggressor, its biological cycle and its effects on crops, and **too little to the other factors.** This attitude is usually the result of decades of systematic and intensive use of pesticides (fungicides, insecticides and herbicides) which, because they are easy to use (by simply following the instructions on the label) and are effective (albeit temporarily or partially because of resistance to these products, which emerges sooner or later), have released researchers and farmers from the need to reflect on the overall environment in which they are used. As soon as their effectiveness diminishes or when the active substances are withdrawn from the market, researchers and farmers are consequently caught off guard when it comes to understanding how to analyze the plant health problem and to develop a different strategy for containing the damage.

Therefore, for each of these four key aspects, there is a need, on the one hand, to pay attention to their own specific characteristics, and particularly to those that have a decisive effect as part of crop protection, but, on the other hand, **to interactions between all these key aspects**.

3.2.1. Regarding the bioaggressor

In order to develop an integrated pest management strategy, a number of the bioaggressor's characteristics must be known, including:

- its nature (accurate identification, possibly as far as the pathotype, strain or subspecies);
- its biological cycle (with or without asexual and sexual stages, single or multi-cycle);
- the length of its cycle, depending on climatic conditions and/or available resources;
- its forms (e.g.: a perfect or imperfect fungus, heterotrophic or autotrophic, larval or adult stage for insects, juvenile or mature stage for nematodes etc.);
- its or their infective/harmful stages;
- the consequences of its infestations in relation to its host's stage;
- its main hosts (and possible alternative hosts);
- its susceptibility or, on the other hand, its resistance to plant protection products;
- its ability to circumvent the resistance of varieties;
- etc.

As we can see, all this information often lies more within the domain of a specialist in entomology, nematology or phytopathology than a small producer, as an in-depth knowledge of basic biological characteristics is required. Hence the importance of producing 'IPM itineraries', which could be put into laymen's terms and recommended to producers.

It is often believed that bioaggressors are external factors introduced into agricultural production. However, in the majority of cases, they occur naturally in the agroecosystem. Bioaggressors and their accompanying species – predators, parasites, pollinators, rivals and decomposers – all form part of the agricultural biodiversity associated with crops and perform a whole range of ecosystem functions Outbreaks or infestations of bioaggressors usually occur when the natural processes that regulate them are disrupted. Pesticides eliminate pests, but also their natural enemies, which can result in an outbreak of infestations causing damage to crops that is greater than prior to chemical treatment (the 'boomerang' effect).

Two examples illustrate this:

➢ Significant infestation by **leaf miners** (*Liriomyza* sp.) frequently results from the elimination of their natural enemies caused by the excessive use of insecticides, which no longer have any effect on the leaf miner larvae that shelter in the leaves. As a result, once free of their natural enemies, leaf miner populations explode. Thus, it is frequently necessary to make use of specific insecticides that reach the larvae in the leaves to combat this pest.

- **Spider mites** (mites) are often poorly controlled by insecticides that also have acaricide properties (dimethoate for example) and, what's more, these products are generally harmful to auxiliary insects. By using this kind of product indiscriminately, the effect is frequently the opposite of that desired and, free of their natural enemies, populations of spider mites explode. It is preferable to use specific acaricides, which have little or no impact on auxiliary insects, to control spider mites.

Serious spider mite infestation affecting a tomato plant (photo G. Delhove)

A certain balance, which is often hard to achieve, must be maintained between bioaggressors and their natural enemies. In effect, it is important to remember that complete eradication of a bioaggressor on a plot will reduce the available resources for maintaining its natural enemies, which are a fundamental part of the system's resilience. Consequently, the objective is to "manage the control of insect pests to the point where natural predation operates in a balanced way and crop losses caused by pests are kept to an acceptable level" (FAO).

3.2.2. Regarding the crop grown

Logically, this aspect is better understood by the producer, who frequently has long experience of his crops.

The main characteristics to consider are:

- the type of crop (*i.e.* the species grown, as well as whether it is an annual or perennial crop);

- the variety (with its requirements and susceptibility);
- the growing cycle (as well as the length of the cycle);
- the sensitive cultivation stages;
- the plant's ability to recover in the event of infestation.

As regards **variety**, in the case of tomatoes, for example, there are numerous variations in the plant's growth and earliness, as well as the shape and color of the fruit. The main groups include early and late varieties, ribbed or smooth fruit, round or elongated fruit, and even varieties for industrial food processing or the fresh produce market. The first major difference is the type of growth (indeterminate or determinate). Another significant difference is the level of **resistance or tolerance** to diseases and insects.

Here are some of the key aspects to consider.

1. **Indeterminate and determinate varieties:** the growth of indeterminate varieties continues after each new truss. In the case of determinate varieties, there are only one or two leaves between the inflorescences and the stem ends with a terminal inflorescence. Varieties with compact growth, in particular determinate type varieties, will be more prone to diseases that need high atmospheric humidity to develop (leaf bacterioses, mildew etc.), as the plant will be poorly ventilated.

Tomato plant with determinate growth (photo G. Delhove)

2. **Varietal resistance:** there are disease and pest resistant genes. Local varieties may already have these resistance characteristics. It must be possible to identify and opt for these varieties in cultivation areas where these diseases are present. Imported varieties with a familiar resistance are not necessarily able to express this resistance in local conditions. These kinds of resistance need to be checked in advance. There are numerous resistances to diseases and insects, depending not only on the particular species of pest but also on the race of pathogen. Prior knowledge of the type of pest present is essential to avoid unnecessary investment in more expensive seeds for resistant varieties. In effect, resistance can be expressed in a specific environment and be limited or entirely lacking in other surroundings. Consequently, it

is essential to check whether the disease resistance of the proposed variety has been monitored in the local environment. Resistances are indicated using a code, which relates to the disease and also, sometimes, to the race of the phytopathogen. This code appears on the labels of seed packets alongside the name of the variety. A number of resistances can be incorporated into the same variety.

Resistance to diseases

3. ***Varietal tolerance:*** does not prevent the disease from occurring, or at least certain symptoms, but does not compromise the profitability of the crop. It may have a value that is as beneficial as complete resistance, as it will not specifically favor the selection of strains of a pathogen that are able to overcome this tolerance. In practice, a balance is established between the plant and its parasite. As for resistance, a high soil temperature can disrupt (void) the plant's tolerance.

Certain bioaggressors may be present in a given crop **at all stages of the crop's growth** while others only occur at one or more stages of cultivation. However, their presence in the plant does not necessarily mean a loss of yield or a poorer quality harvest. A given bioaggressor will cause more or less significant losses **depending on the cultivation stage at which it occurs**. For example, leaf miner flies occurring during the harvesting period for tomatoes will have virtually no impact on the harvest, as it takes time for a significant population that could affect photosynthesis to develop. By contrast, if this pest occurs at an early cultivation stage, the impact on the growth of plants can very quickly become significant if the level of infestation increases substantially.

3.2.3. Regarding environmental conditions

A number of aspects relating to the surroundings, *i.e.* the environment in the broadest sense, significantly affect the relationships between crops and bioaggressor including, primarily, climatic parameters (including, possibly, the micro-climate created around a crop because of its behavior or the fact that it is under shelter) such as temperature, relative humidity, sunlight, photoperiod, difference between daytime and night time temperatures, etc.

For example, growing tomatoes sheltered from the rain enables the occurrence of diseases such as mildew, bacteriosis and blight to be restricted, but the lack of water on the leaves encourages the growth of powdery mildew as well as the spread of certain biting/sucking insects, such as aphids or white fly, which are no longer disturbed by the rain. Pests such as spider mites and *Aculops lycopersici* (tomato russet mite) flourish in hot and dry weather. By contrast, a mite such as *Polyphagotarsonemus latus* (broad mite) prefers (moderately) warm, wet and overcast conditions.

A locally constructed shelter for growing vegetables (Photo G. Delhove)

Tomato leaf mould (photo G. Delhove)

Tomato leaf blight (photo G. Delhove)

Mildew on a tomato leaf (Photo G. Delhove)

The prevailing wind speed and direction, the wealth of biodiversity in the surrounding area, the soil etc. are also parameters that must be included when analyzing interactions.

The **environment also needs to support the maintenance of populations of control species**, which will survive in 'refuge zones' for auxiliary insects in the absence of a crop. The establishment of hedges, flower strips, windbreaks, untreated zones, etc. is designed to encourage an ecological balance by prioritizing small and medium sized plots and refuge zones. Farmers have a direct interest in becoming better acquainted with the functioning and dynamics of ecosystems, as well as the role of harmful organisms, as an integral part of agricultural biodiversity.

A henna hedge in Burkina Faso (Photo G. Delhove)

Examples include:

- the establishment of a strip of sorghum to encourage auxiliary insects to combat okra pests in Martinique and, specifically, aphids (biological control by conservation);
- vegetation cover in mango orchards in La Réunion (a habitat for generalist predators);
- the introduction of individual dill and coriander seedlings on farms (a habitat for parasitic micro-wasps, hoverflies, lacewings and ladybirds);

Coriander seedlings (Photo G. Delhove)

- the establishment of tropical milkweed beds (*Asclepia curassavica*) (a habitat for milkweed aphids *Aphis nerii*, which provide prey for ladybirds, hoverflies and parasitic wasps),
- the establishment of marigold and tagetes (*Tagetes* spp.) beds or individual seedlings (a habitat for predatory *Orius* bugs),
- the establishment of plants such as gliricidia (*Gliricidia sepium*), pigeon pea (*Cajanus cajan*), basil (*Ocimum basilicum*), sunflower (*Helianthus annuus*), crotalairia (*Crotalaria* sp.), etc. for their contributions of secondary prey, pollen and nectar, etc.

The **soil is the environment surrounding the roots** of plants and, ideally, it needs to have a good structure, porosity and depth, as well as the ability to retain water and must contain nutrients that can absorbed by plants. Plants will grow less well and will be less robust if all these characteristics are not good. At ground level, **it is important to ensure a high biodiversity of organisms** that could provide a greater variety of ecosystem services with different functions: breaking down organic matter, recycling nutrients (mineralization), stabilizing the soil structure, contributing to the formation of organic matter, regulating water, controlling diseases, pests and weeds, etc.

3.2.4. Regarding agricultural practice

Agricultural practice either encourages or discourages the growth of weeds as well as the development of bioaggressors and primarily, of course, plant protection practices and the inputs used (fertilizers and pesticides). Excess nitrogen tends to make the crop more prone to certain diseases, but many other practices employed by the producer make the crop susceptible. These include, for example: a lack of crop rotation or rotations that are too short, or even an inappropriate choice of precedent crop, till or no-till farming, the destruction of residue from the precedent crop, use of the “stale seed bed” technique to germinate the seeds of weeds brought to the surface, or pruning and leaf-stripping operations that reduce ambient humidity, etc.

Certain **agricultural practices must be considered as a whole**, as they apply to all crops and enable a great many bioaggressors to be prevented.

- ***Avoiding excess moisture:*** heavy and poorly structured soil causes excess moisture, which leads to root asphyxia, the development of diseases and a reduction in the resistance of plants. By contrast, it reduces the development of nematodes by making it difficult for them to move.

- ***Removing infested seedlings without waiting for growth to be complete:*** plants infested by certain bioaggressors must be removed at a very early stage (as soon as symptoms are observed) otherwise the bioaggressor will spread very rapidly through the crop, towards neighboring fields, or contaminate the plot’s soil. The uprooted plants must be destroyed (burned, buried outside the plot or properly composted). For other enemies, seedlings will only be uprooted if they are heavily infested. At this point, the plant will no longer be very productive anyway and will represent a source of infestation for the rest of the field or neighboring fields. In certain cases, instead of removing the entire plant, it is possible to simply remove and destroy certain parts such as infested fruit (fruit infested with fruit flies, for example).

- ***Practicing crop rotation:*** for example, for tomatoes, avoiding precedent crops from the Solanaceae family (egg plants, peppers, potatoes, etc.) or ones that could harbor common enemies (beans, carrots, cucurbits, etc.). Crops such as onions, garlic, cabbages and cereals are good precedent crops for tomatoes.

- ***Avoiding growing sensitive plants nearby:*** these may have pests that can travel to the species you wish to grow. This must be taken into account when choosing the species to be grown or, if possible, they should be uprooted. For example, you should avoid growing a species that is susceptible to red spider mite alongside a crop that already has a large population of this pest.

- ***Avoiding the excessive use of windbreaks:*** if a windbreak’s permeability is below 50%, this creates a favorable microclimate for numerous enemies and, above all, fungal diseases (more persistent moisture on the plants).

The **irrigation method is also important**. For example, for tomatoes, not wetting the leaves (by using surface or drip irrigation) reduces the risk of developing diseases that need water on the leaves to flourish (*Xanthomonas*, *Alternaria etc.*). By contrast, this provides the ideal conditions for other enemies to develop (*Leveillula taurica* or other powdery mildews, *Tetranychus*, *Bemisia* etc.). Surface irrigation also has the drawback of transmitting enemies such as *Fusarium* and *Meloidogyne* via the irrigation channels.

Carrot seedling infested with powdery mildew with drip irrigation (Photo G. Delhove)

A number of agricultural practices enable soil protection to be aided by limiting the negative impact of human intervention that damages the natural structure of soils and that of rain, sun and wind:

- limiting or ceasing ploughing operations in order not to disrupt soil life;
- maintaining permanent vegetation cover;
- producing and returning a high level of biomass to the soil using a combination and/or succession of multifunctional plants;
- using mechanical or vegetation-based erosion control measures;
- etc.

So, all in all, the **production method** significantly influences the environment's biodiversity and, as a result, the overall resilience of the cropping system. There is a strong link between "soil – agricultural practices – biodiversity – the crop's susceptibility to infestations". Moreover, **prevention**, which figures prominently in integrated pest management strategies, includes not only prophylaxis, but **must also be considered in a much broader sense**: with cropping systems that are intrinsically less vulnerable to bioaggressors and less favorable to their proliferation (e.g.: practicing agroecology), limited use of chemical control is more reasonably foreseeable, as the conditions that are suitable for alternative solutions to be effective have been met (in biointensive organic agriculture it will even be possible to completely forgo chemical products for crop protection,[1] without too much trouble). Consequently, prevention will be based on a set of basic rules:

- using certified seeds (sorted and disinfected),
- choosing disease resistant or tolerant varieties,

[1] Certain chemical products are still authorised for organic farming, under very strict conditions, even though the general rule is not to use any of them. A list of authorised substances and their uses is available, depending on locally applicable regulations and, possibly, specifications to be complied with. Producers should refer to it.

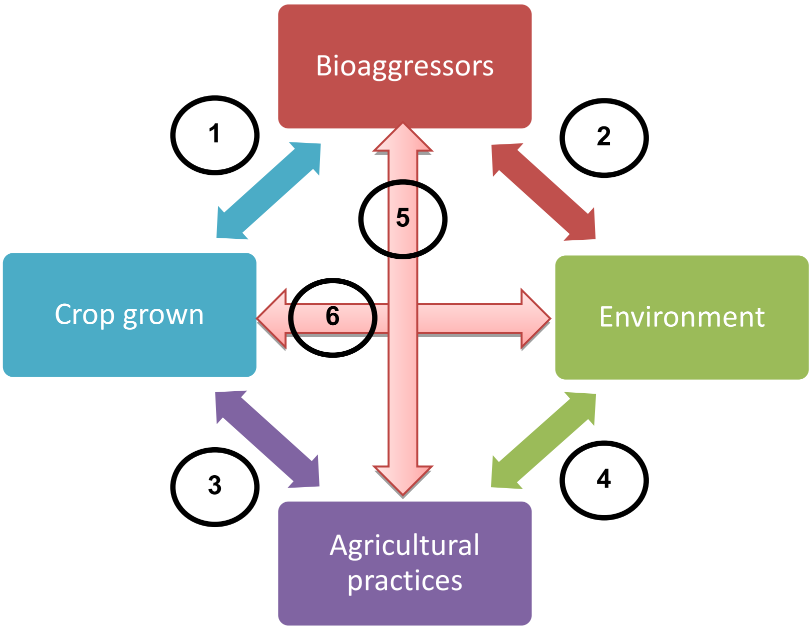
- managing your plot in such a way as to reduce bioaggressors infestations (avoiding high risk precedent crops, sowing too late, less densely, not using too much fertilizer, removing crop residues, etc.),
- diversifying and rotating the species and varieties grown (e.g.: by intercropping) to limit weeds and prevent the emergence of resistant bioaggressors.

As highlighted by the FAO, "**the first line of defense is a healthy agroecosystem"**.

3.3. Interactions to be considered

The interactions between these 4 aspects are complex. To illustrate the potential link between these aspects, think of a spider's web: by pulling one thread, you could unbalance or displace the entire web.

As shown in the following diagram, **we can identify six possible interactions,** which will be analyzed below.



3.3.1. Interactions between the bioaggressors and the crop grown

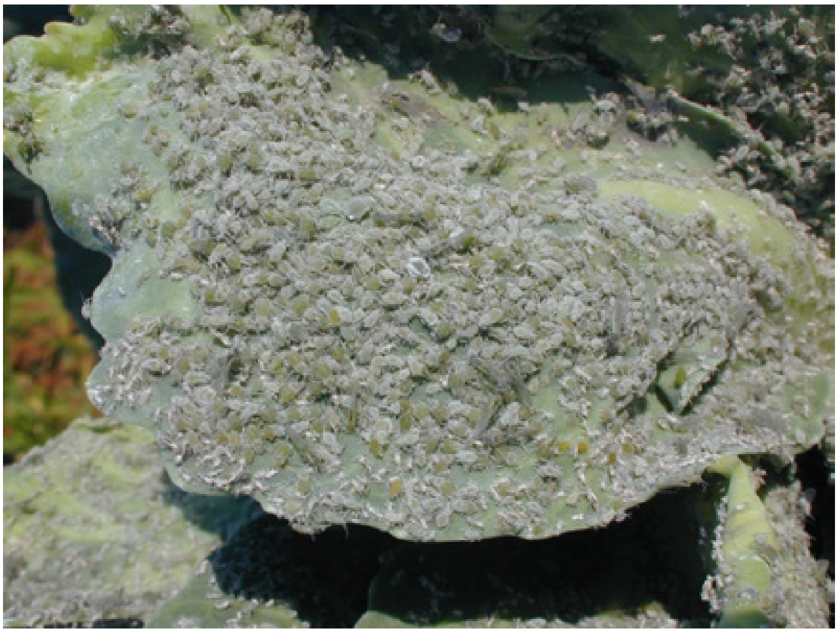
The crop grown may be a more or less 'effective' host for the bioaggressor. The latter is attracted to the host crop by chemical messages (volatile organic compounds or VOCs). VOC emissions vary in terms of composition and intensity depending on the crop's growth stage.

For example, studies have been conducted on the link between the broad bean weevil (*Bruchus rufimanus*, a beetle) and field beans (a plant from the *Fabaceae* family on which this beetle is specifically dependent): broad bean weevils appear far more attracted to field bean plants when they are flowering, a time that coincides with the period of sexual maturity for female broad bean weevils. These female weevils are irresistibly drawn to the plants in order to lay their eggs on them. Researchers have been able to identify the volatile compounds emitted by the plants and, subsequently, to synthesize them for use in traps (adhesive strips with a scent diffuser). Hundreds of female weevils become stuck to the trap strips, which considerably reduces egg laying on the crop.

Where a crop's chemical substances **attract auxiliary entomophagous** organisms, the release of these substances is deemed to form part of the plant's defense system against phytophage organisms. For example, cassava plants infested by the mealybug *Phenacoccus manihoti* are the main source of volatile compounds that are attractive to the endoparasitic wasp *Apoanagyrus lopezi*.

To reduce the food for phytophage insects, the plant does not necessarily need to produce a substance that is highly toxic to the insect. In effect, **repellent substances** are generally detected by phytophage pests before they begin to feed. One of the most widely studied cases is that of Brassicaceae isothiocyanates. The repellent nature of Allyl isothiocyanate for generalist butterflies and moths and for non-Brassicaceae-dependent insects has been demonstrated. However, the presence of repellent secondary molecules does not necessarily mean that these pests are completely prevented from feeding.

Plants also secrete **feeding stimulants**. For example, cabbage aphids (*Brevicoryne brassicae*) feed on host plants containing glucosinolates that induce them to feed. It should be noted that the plant's young organs, the most active locations for synthesizing secondary substances, are the favored targets for infestation by this specialist phytophage species.



*Cabbage aphids (*Brevicoryne brassicae*) on a cabbage leaf (Photo G. Delhove)*

Host plants can be located by bioaggressors in different ways. For example, winged aphids avoid certain plants when they arrive in a habitat. These behavioral responses are governed by olfactory stimuli, although certain visual cues are also involved. For green peach aphids (*Myzus persicae)*, green and yellow colors have been correlated with the location of a suitable host plant.

Methyl eugenol is a substance that is found in plants. More than 450 plants belonging to 80 families contain varying levels of methyl eugenol, but it is spice plants (for example, clove and basil: *Ocinum basilicum* and *Ocinimum sanctum*) and medicinal plants, which generally contain the most; however, for the same species, the concentrations vary depending on the variety. Methyl eugenol in plants may have different functions, including a repellent and/or antifeedant effect for insect pests, as well as providing a defense against fungal, bacterial and viral diseases. However, methyl eugenol has turned out to be a powerful attractant for the adult males of certain fruit flies *(Tephritidae)*; therefore, it is used both for monitoring populations and for pest control, by placing it in traps or other devices. Methyl eugenol is thought to be a precursor to the sex pheromone in the fruit fly *Bactrocera dorsalis*.

The pest management strategy known as 'push-pull' attempts to take advantage of certain plant/pest interactions. It consists of making the crop repellent to pests (push) while also attracting them (pull) to areas where they can be managed (physical or chemical destruction), trapped or simply diverted from the crop at its sensitive stage. This combination generally appears more effective than using the two aspects separately. The repellent properties may originate from the appearance of the crop (color, size, shape), the presence of repellent companion plants or spraying with repellents (synthetic repellents, volatile compounds originating from non-host plants for the pest, pheromones etc.). The attractant area may comprise visual traps or attractant plants, possibly treated with pheromones or other natural or synthetic substances. It should be noted that, in the case of known applications of this technique, certain repellent plants have an attractant effect for auxiliary organisms, the activity of which is encouraged in plots and/or on trap crops, around the perimeter.

To control cabbage moth, it is possible to combine round cabbage with plants that have a trap effect (Chinese mustard, pak choi etc.) and others with a repellent effect (onion, garlic, basil etc.), which may disrupt female *P. xylostella* looking for egg laying sites and, thereby, reduce infestation.

Melon fly (*Bactrocera cucurbitae)* is a significant economic pest on the island of La Réunion and represents the main issue for cucurbit crops. Although chemical pest control generally enables the damage caused by this fly to be minimized, it has the drawback of being expensive and not very selective in terms of insect life. Trap crops have been identified and these are two wild cucurbits, bitter melon (*Momordica charantia*) and ivy gourd (*Coccinia grandis*). Existing correlations between the development of *B. cucurbitae* and these plants have been identified, but also the response of mature females in relation to these. Ripe ivy gourd (*Coccinia)* fruit is equally as attractive as zucchinis and has the advantage of being unfavorable to the development of *B. cucurbitae* prepupae in comparison to bitter melon, which spreads rapidly. On the other hand, bitter melon leaves and stems are extremely attractive to females. These initial results provide information regarding the possible use of wild cucurbits as a trap crop for zucchini plots.

It is worth remembering that the extracts or essential oils of plants can be used to control bioaggressors. One of the best known plants is neem, which contains azadirachtin and other substances. Others, which are renowned for their repellent properties, include lemon grass (*Cymbopogon citratus*), citronella (*C. winternarius*), cinnamon (*Cinnamomum zeylanicum*), cumin (*Cuminum cyminum*) and thyme (*Thymus vulgaris*). Studies have confirmed the repellent properties of extracts of some of these plants on silverleaf whitefly (*Bemisia tabaci)*, a major tomato pest and carrier of viral infections. Once identified and characterized, these substances could, in time, enlarge the range of weapons for agro-ecological crop protection and thereby help to put an end to the use of chemical pesticides. For example, a product containing thyme oil and tagetes oil has been authorized by the Sahelian Pesticide Committee for the control of whitefly on tomatoes.

Other plants, with repellent or insecticidal properties, are also frequently used to create extracts for spraying on crops: these may be cultivated plants, for example, onion bulbs, garlic cloves, peppers, papaya leaves, or wild plants, for example: *Bidens pilosa*, *Cassia alata*, *Annona reticulata*, *Lantana camara*, *Mellitia versicolor*, *Morinda morindoides*, *Tagetes sp.*, *Tithonia rotundifolia*. When creating farm hedges or planting in areas that cannot be used for crops, it is worth thinking about planting this kind of plant as a source for making extracts for spraying and/or for producing biomass that can be used, specifically, for composting or for the RCW technique (Ramial chipped wood), a kind of *mulch* made from woody species, which enables soil fertility to be improved; on the other hand, some of these plants (for example, *Lantana camara and Tithonia*) can be useful when they flower to help maintain certain auxiliary organisms, such as hoverflies that attack aphids.

Lantana camara *seedling (Photo G. Delhove)*

Tithonia *flower visited by a hoverfly (Photo G. Delhove)*

Hoverfly larvae eating aphids (Photo G. Delhove)

Plants are constantly faced with a vast range of pathogens (fungus, bacteria and viruses) and feeding organisms including insects, and yet, in the majority of cases, they grow without any problems. In effect, plants have an innate immune system based on the detection of pathogens and on defense responses, just like animals. When a pathogen comes into contact with a plant, a race begins between the invader and the plant, which needs to defend itself as quickly as possible. The result of this 'molecular warfare' determines whether the pathogen is able to spread and infect the entire plant or if the infection is halted.

It is possible to trigger early defense responses in a plant using substances that are known as elicitors. Elicitors are recognized by the plant's receptors and trigger a cascade of defense reactions. Consequently, plants treated preventively with an elicitor mobilize their means of defense in advance, which provides a more effective and rapid response when the pathogen appears. A Belgian company has developed a complex of natural oligosaccharides (COS-OGA). When sprayed on a plant, it is detected by the latter and interpreted as a distress signal caused by an imminent threat foreshadowing a fatal outcome. The plant responds to this immediately by mobilizing its own defenses. Therefore, correct use of this elicitor, in terms of concentration, formulation and application sequence, induces a state of immunity (premunition), which helps the plant react effectively to an attack by a pathogen and, specifically, fungi. This complex has been developed into a commercial product, which has already been authorized in several countries for vegetable crops grown under glass, to control powdery mildew, and for vines, to control mildew and powdery mildew. The use of this type of product should enable the use of chemical fungicides to be reduced by 30 to 50%.

3.3.2. Interactions between the bioaggressor and the environment

Environmental conditions that will **influence the development of bioaggressor** are mainly those relating to climate, the year's weather conditions and the resources available to the latter, within the crop and nearby (on alternative hosts). Biodiversity and the balance between bioaggressors and its parasites or predators are factors that influence control of its population. Therefore, producers can choose, for example, to delay or bring forward sowing (technique of staggered growing), or alter the micro-climate (by pruning in an orchard, reducing the planting density or combining crops). By using untreated refuge zones, grass strips, planting hedges and creating flower strips, which will provide pollen, they can encourage an explosion in the populations of species that control pests. Producers can remove host plants that provide a staging post for diseases.

Producers will need to adapt their practices to suit climatic conditions during the crop cycle. For example, when growing tomatoes in the rainy season, it is essential to avoid high-density planting, which may encourage the development of *Xanthomonas*, *Alternaria*, *Cladosporium* and *Phytophthora infestans,* which spread through contact between the plants themselves and result from sustained high humidity caused by a lack of ventilation. Likewise, it is vital to prevent part of the crop being in the shade of windbreaks or trees, to allow the leaves to dry out more quickly after rain. In addition, **pruning and leaf stripping enable the incidence of certain tomato leaf diseases to be reduced**. The aim of these operations is to remove both old leaves at the base of seedlings plants and (hungry) secondary offshoots, which are undesirable for staked crops. The aim is to have a crop that is not bushy, well ventilated and where all the leaves and fruit benefit from sunlight, in order to restrict the development of certain fungal diseases (leaf blight, leaf mould) or bacterial diseases. By contrast, this technique should be avoided if it is not possible to disinfect pruning tools (e.g. using bleach).

By installing windbreaks, producers alter the climate on the plot and may reduce the crop's susceptibility to infection by a fungus or bacteria, for example. It is understandable that, on large plots used for monoculture, the options for altering the environment are reduced to a bare minimum: In this case, **a radical change in the way of managing** crops is essential.

The importance of maintaining hedges (Photo B. Schiffers)

The **existing conditions at ground level** will also more specifically influence telluric bioaggressors. For example, infestations by *Meloidogyne* nematodes are less significant in heavy soils or soils with high levels of organic matter than in sandy soils, as pests move more easily in the latter kind of soil and encounter less antagonists. Should it not be possible to improve the soil over the entire area under cultivation, one option is to provide organic matter locally, as close as possible to the root systems of seedlings, for example. It has been demonstrated in Senegal that growing tomato seedlings on a mound enables nematode infestations to be considerably reduced and yields to be significantly increased. An **improved structure and greater biodiversity of fauna and flora on a ground level generally results in better natural control** of bioaggressors. Poor soil structure reduces the ability of runoff water to infiltrate the soil profile and, hence, encourages the establishment of a humid microclimate in the soil. In this respect, several studies have demonstrated that compaction caused by working the soil has significantly exacerbated the damage caused by fungal diseases, including, for example, *rhizoctone solani*. Producers can improve/maintain a soil's good characteristics with suitable practices (see point 3.2.4).

3.3.3. Interactions between the crop grown and agricultural practices

Agricultural practices influence the growth of plants. Where established agricultural practices are suitable and properly implemented, they are not only beneficial for the environment but also guarantee profitability and productivity.

First of all, it is important to optimize the **management of inputs**, in terms of both fertilizers and pesticides, in order to avoid excessive use and to reduce the negative impacts. Fertilization can have a negative effect on natural enemies. Improving practices will enable erosion and the need for fertilizers and pesticides for lants to be reduced.

Beds created in the right direction in relation to the slope to prevent erosion (Photo G. Delhove)

Agricultural practices in seedbeds significantly influence the growth of **seedlings subsequently transplanted** to fields. In effect, it is extremely important to take strong seedlings that are free from all bioaggressors out of seedbeds. This makes it easier for seedlings to recover after transplanting and prevents bioaggressors being transferred to fields with the seedlings being transplanted. For example, it is crucial to choose a soil that is free from bioaggressors, as well as a healthy environment (with no weeds or neighboring old crops), along with soil conditions that are favorable for seed germination and the growth of young seedlings (no heavy or flood-prone soil), as the location for establishing a seedbed. It is also essential to avoid locations with too much shade, which will make the seedlings become “leggy” and fragile. **Agricultural practices that compact soil** create difficult growing conditions for plants, as the root systems struggle to develop; the plants will be stunted and lack the strength to fend off bioaggressors.

Space reserved for a seedbed (Photo G. Delhove)

Raised seedbed to avoid flooding (Photo G. Delhove)

Improvers (liming, organic matter, trace elements, liquid humic and fulvic acids, etc.) enable the soil pH, fertility, texture, structure and composition to be altered and can also encourage or discourage certain bioaggressors with a beneficial effect on the plant’s growth or a direct effect on the bioaggressor. For example:

- in soils that are too acidic, liming allows damage caused to okra and tomato crops by *Fusarium* to be limited (by raising the pH to 6.5-7.5),
- plentiful organic matter will encourage *Sclerotium rolfsii* but will be useful in controlling the *Meloidogyne nematode*, pink root disease in onions, and also make it easier to remove weeds (*Cyperus*, *Imperata*) by loosening the soil,
- compost containing 4 % (by weight) of dried shellfish shells (chitin) added during production has a nematicidal effect.

The **type of crop grown** also influences the kind of agricultural practices that can be employed. For example, crops that cannot cope with any excess moisture in the soil need to be grown on ridges or in raised beds in areas of land that are prone to flooding.

Kale grown on ridges to avoid excess water (Photo G. Delhove)

Preparation of raised beds to avoid excess water (Photo G. Delhove)

Training seedlings, including plants with indeterminate growth (tomatoes) or climbing plants (passion fruit), will require supports during growth.

3.3.4. Interactions between the environment and agricultural practices

Agricultural practices employed on farms must be chosen to **reduce the negative impact on the environment to a minimum**. A number of agricultural approaches (organic farming, conservation agriculture – CA – and sustainable agriculture) have this aim.

Agricultural practices can have a detrimental, neutral or favorable effect on the quality of the environment on the farm itself, as well as on the environment outside the farm (air, water, fauna, flora etc.). Chemical pesticides are often considered harmful to the environment, but other practices, such as a lack of anti-erosion systems, can also be detrimental.

The kind of existing natural environment (air or land) will influence the choice of agricultural practices to be employed for plants to cope best with the existing conditions or to alter, as far as possible, the characteristics of the existing environment (e.g. creation of a micro-climate by using physical protection, improving soil characteristics by adding improvers etc.).

For example, in very hot and dry weather conditions, farmers will seek to **mitigate the stress suffered by plants by establishing systems** that enable a micro-climate to be created around them: windbreaks, protective screens, shades, agroforestry for shade and to cut out drying winds, mulching, localized irrigation in basins, etc. In climates that are too wet, farmers seek to use agricultural practices (pruning, low-density planting etc.) to alter/mitigate environmental conditions by ventilating crops and, above all, by preventing excess water in the soil (drainage, ridges etc.).

As part of the **concept of ecological intensification**, the type of production advocated endeavors **to be in harmony and symbiosis with the environment**, by using natural resources without harming them and by making use of ecosystem services. For example, in terms of managing bioaggressors, the use of cultivated or wild plants, encouraging the spread of auxiliary organisms, allows certain pests to be ‘naturally’ controlled and enables the use of pesticides that are harmful to the environment to be reduced.

The intensification of natural processes by sowing directly under plant cover enables the chemical, physical and biological fertility of the soil to be restored, as well as providing the best expression of the genetic potential that defines the levels of resistance to bioaggressors and levels of productivity. However, ecological intensification assumes that research is providing relevant solutions to two major challenges, which are, the need to produce more when agricultural space is shrinking and to produce better in order to protect the environment.

3.3.5. Interactions between the bioaggressor and agricultural practices

Agricultural practices include mixed cropping, strip cropping, intercropping, ground cover and agroforestry. It is now widely recognized that the development of more sustainable agricultural production systems depends on reducing the use of pesticides and, as a result, the establishment of cropping systems encouraging biodiversity and based on the use of services provided naturally by agro-ecosystems. More than just a move towards new farming techniques, agro-ecology also takes its inspiration from traditional agricultural practices or those employed in developing countries, which are based on enhancing biodiversity and establishing methods modelled on natural ecological processes. Of the various services provided by ecosystems, natural control of pests is seen as one of the most important.[2]

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[2] See E. Étile, “Pratiques agricoles favorisant la répression des ravageurs des cultures par leurs prédateurs naturels” (Agricultural practices encouraging the control of crop pests by their natural

Diversity in agro-ecosystems can encourage the activity of natural enemies and thereby reduce pressure from pests and related costs. However, it has been demonstrated that simply increasing diversity can potentially exacerbate certain plant health problems. Consequently, it is important to think carefully about the underlying ecological mechanisms before considering agricultural practices that enable a crop's allies to make an optimum contribution.

The majority of factors limiting the effectiveness of natural enemies within agricultural systems (e.g. pesticides, a lack of food or the absence of alternative hosts) are the **consequence of disturbance regimes imposed on these systems**. Efforts to preserve natural enemies should focus not only on these limiting factors, but also the disruptions that cause them.

Weeding can play an unexpected role. Let's look at the example of moths and butterflies that are maize pests. The larval stage of the fall armyworm (*Spodoptera frugiperda)* can cause major damage to maize crops in the eastern Canadian provinces. It has been demonstrated that these larvae consistently appear more often in maize fields with no weeds than in fields where complex populations of natural or selected weeds are growing.[3]

A corn borer and its parasitoid

Other authors report that the parasitic wasp *Eriborus terebrans* has a greater tendency to parasitize the European corn borer *Ostrinia nubilalis* in fields with weeds than in weeded fields.[4]

In Senegal, four species of hymenoptera have been identified as parasitoids of *P. xylostella*. These are *Oomyzus sokolowskii*, *Apanteles litae*, *Cotesia vestalis* and *Brachymeria citrae*. *Apanteles litae* has turned out to be the most abundant species during the dry season, but O*. sokolowskii* is encountered more regularly. The overall rate of parasitism is of the order of 10%, which is relatively low compared to higher rates of

predators), *Revue de littérature présentée à Agriculture and Agroalimentaire Canada, 6th August 2012*, Montreal, 2013.

3 M.A. Altieri and C.I. Nicholls, *Biodiversity and pest management in agro-ecosystems*, 2nd ed., New York, Food Products Press, 2004.

4 D.M. Pavuk and B.R. Stinner, "Influence of Weeds in Corn Plantings on Population Densities of and Damage by Second Generation *Ostrinia nubilalis* (Hubner) (Lepidoptera: Pyralidae) Larvae", *Environmental Entomology*, No. 20, 1991, pp. 276-281.

parasitism in other countries, such as South Africa. In order to increase the rate of parasitism, the solution would be to replace applications of synthetic insecticides with formulations made from natural products (neem oil or extracts) or biological products (*B. thuringiensis*) to encourage biological control by conservation, while improving the environment around cultivated plots (see 3.3.6).

Adult Cotesia *sp. hymenoptera (Photo G. Delhove)*

Aphids mummified by parasitoid

In general, a reduction in the intensity of labor enables a more stable environment to be created, which encourages the development of more diverse species in the soil and increases the presence of pest predators or antagonists. The greater the reduction in the intensity of labor, the more the abundance and diversity of fauna increases. However, the effects vary from one species to another, depending on their specific ecological characteristics. For example, species whose larval or pupal stages occur in the ground are particularly susceptible to soil working.

3.3.6. Interactions between the environment and the crop grown

The development of agricultural environments with the aim of encouraging the control functions of natural enemies defines the practice of '**conservation biological control**'. It is now widely accepted that conservation biological control should form the basis of all programmes for managing the enemies of crops, whether these are biological or integrated.

The 'simplification' of the agricultural environment and the weakening of the natural defenses of agricultural ecosystems have resulted in the intensive use of chemical inputs to quickly stem invasions of pests, weeds or diseases that have become more common. Monocultures are environments in which it is hard to establish effective biological control, because the resources they offer are not sufficient to ensure that populations of natural enemies perform optimally. Semi-natural habitats, such as forests and woods, hedges, field edges, fallow land and meadows contain numerous beneficial species of arthropods. This stability is created by the fact that these habitats are more complex and offer greater biodiversity than annual monocultures, which have been weakened by several centuries of simplification and regular disruption. The conservation or creation of these habitats is key to the development of sustainable agriculture. In order to focus conservation efforts, it is important to precisely understand how these habitats offer suitable resources for maintaining populations of natural enemies and optimizing their control function, it is essential to aim for '**good diversity**' and to examine the resources that auxiliary organisms need. Semi-natural habitats provide insects - both predators and parasitoids - with alternative prey and hosts to the target pests, as well as plant nutrients.

Small growers in a diversified environment in the Democratic Republic of Congo (Photo G. Delhove)

The dynamics of pest populations depend in numerous parameters, including agricultural practices on the plot (e.g. phytosanitary treatments) and biological control (by means of natural enemies), as well as the landscape (composition and arrangement of the space). Consequently, as regards the cabbage moth (*Plutella xylostella)* in the Niayes region of Senegal, a number of studies have highlighted the influence of the type of vegetation close to cabbage production plots. Uncultivated areas could create refuges for auxiliary organisms that may control the cabbage moth. It has been noted that, the more complex the landscape and the greater the number of insecticidal treatments the higher the infestation rate, while the greater the presence of host plants and orchards in the landscape the higher the level of biological control by parasitoids.

Round cabbage crop in the Niayes region of Senegal (Photo G. Delhove)

3.4. The integrated pest management tool kit

Alternative and complementary methods to chemical pest control (e.g. flooding, solarization, geotextiles, thermal weeding, the use of biocontrol agents and application of the principles of biological control, etc.), measures for the management of diseases and pests, as well as the '**16 basic principles**' of integrated pest management have been presented in detail.[5] We will provide a brief reminder of these 16 key principles (to understand their wording, we recommend that you carefully reread the expected results and related risks):

Principle 1:	Obtain good quality seeds or planting material (cuttings, seedlings)
Principle 2:	Choose fertile soils and suitable locations for planting
Principle 3:	Adopt good practices in seedbeds and maintain good hygiene
Principle 4:	Adopt suitable spacing and planting arrangements
Principle 5:	Plant crops to ensure that their growth period coincides with a low incidence of pests and diseases
Principle 6:	Practice crop rotation
Principle 7:	Adopt good soil conservation practices
Principle 8:	Adopt appropriate water management practices
Principle 9:	Weed regularly (limit competition depending on the growth stage)
Principle 10:	Regularly inspect fields (monitor crops)
Principle 11:	Keep fields perfectly clean (remove crop residues)
Principle 12:	Effectively control bioaggressors
Principle 13:	Encourage the growth of populations of natural enemies (auxiliary organisms)
Principle 14:	Reduce the use of chemical pesticides to a minimum
Principle 15:	Adopt good harvesting practices
Principle 16:	Use clean and good quality storage facilities

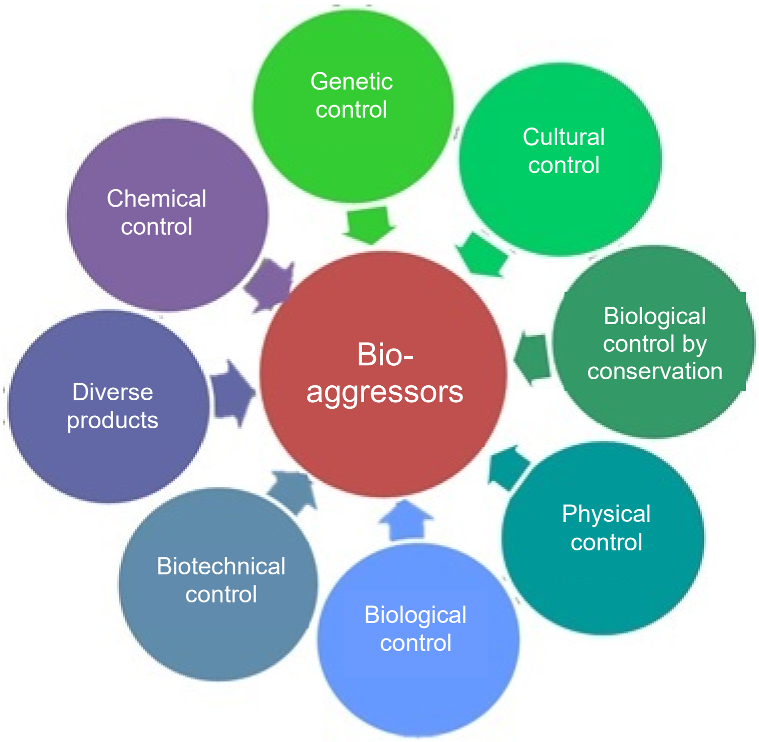
However, articulating all these principles and all these methods **does not in itself constitute a strategy**: it is still necessary to know what resources you have at your

[5] Chapter 2: Principles of biological control and integrated pest management Appendix 1 to Chapter 2 also contains a definition of the main concepts associated with integrated pest management.

disposal and how you can best combine them to most effectively achieve the stated aims (i.e. optimum protection at the lowest 'cost').

All the methods and preventive measures for pest management and control – which have previously been presented – constitute the '**tool kit**', which producers can use when developing their integrated pest management strategy. Therefore, it is vital to inform producers of the existence of these methods, their effectiveness and their limits.

It is equally as important to make use of producer's traditional remedies, based on their experience, where they prove to offer an appropriate solution. In effect, they are generally more affordable than other methods. As a result, these lists of principles and methods are not necessarily exhaustive. Any other suggestions, which aim to reduce the pressure from bioaggressors and the use of chemical products, are also useful and worth assessing before being incorporated into an IPM strategy.



Each of the 'tools' should be assessed in advance by producers, by analyzing their benefits and drawbacks, as they are all interesting (the first being the ability to alternate between different methods), but it is possible to encounter either negative impacts or constraints for each of them (economic, technical, environmental etc.), which limit their use. Ideally, when choosing a method, **producers should analyze it** by assessing the '**sustainability**' of their choice. To do this, they must consider the method in light of three key aspects ("**Profit – People – Planet**"):

Let's look at a few examples of the methods available to producers:

Proposed method	Profit	People	Planet
Synthetic chemical pesticides	Interesting (generally low cost compared to the potential gain)	In most cases, bad or very bad (impact on the farmer's health, residues in the food harvested)	Bad to very bad (persistence, lack of selectivity, loss of biodiversity). It is often the case that less than one percent of the pesticides applied actually reach the target harmful organisms, with the remainder contaminate the air, soil and water.
Resistant varieties	Very interesting (except for GMOs or very expensive patented varieties)	Very good (reduction in treatments)	Very good (with no impact, except for GMO seeds)
Biological control	Higher cost (multiplication, repeated releases, etc.)	Good, but requires specific expertise (mandatory training)	Very good (except if invasive external organisms are introduced)

Reducing sowing or planting density	Not really interesting (loss of yield/ha in the case of a population that is too small)	Interesting (reduction in treatments) Very few negative impacts (but some work, such as pruning, is arduous)	Interesting (avoids treatments by improving the micro-climate, enables other ground cover plants to grow, which improves the plot's biodiversity)

Integrated pest management strategies allay concerns relating to the risks posed to human health and the environment by pesticides. They need to form an integral part of the sustainable intensification of crops. Therefore, it is necessary to apply this kind of systemic approach to resolving all bioaggressor issues.

3.5. The strategic approach

3.5.1. Developing an 'IPM strategy'

Over the course of the past 50 years, integrated pest management has established itself as the world's **leading holistic plant protection strategy**. Since its emergence in the 1960s, integrated pest management has been based on ecology, the concept of ecosystems and the goal of sustaining ecosystem functions (FAO, 1966[6]).

The development of a strategy always begins (**stage 1**) with conducting **a detailed analysis** of the plant health problem, the context (crop management method, agricultural practices) and environmental conditions (analysis of 4 components). This analysis should help determine:

- ***The nature of causes*** for pest epidemics and infestations. Plant health problems may be caused by a combination of factors. Where the problems results from intensification methods (for example, inappropriate density of seedlings or labor that disperses the seeds of weeds, or water stress, which can increase the susceptibility of crops to diseases), it is necessary to alter these methods and adapt agricultural practices. In the case of invasions of pests – locusts for example – it may be useful to apply the biological control or eradication methods used in the place of origin.

- ***The proportion of production that is threatened***, in order to choose an appropriate level of pest control methods. In effect, the risks of damage caused by pests are often overestimated, as crops can compensate in physiological terms for the damage caused by pests, to a certain extent. In other words, the response must not be disproportionate. Integrated pest management combines control, monitoring and prevention. Monitoring enables interventions to be tailored to the actual risks… and, subsequently, for the impact of actions taken to be assessed.

- ***What could make the cropping system less vulnerable*** to infestation by bioaggressors. Integrated pest management is based on the notion that the primary and principal line of defense against bioaggressors in agriculture is a healthy agro-ecosystem, within which the biological processes that underpin production are protected, encouraged and enhanced. Soil management methods employing **an ecosystem approach** – mulching, for example – can create refuges for the natural enemies of pests. Enriching the soil with organic matter provides other sources of food for non-specialist natural enemies and the antagonists of plant diseases and, at the beginning of the period, increases populations that will limit pests. Improving biological processes can increase yields and sustainability, while also reducing the cost of inputs. Integrated pest management, as an **ecosystem-based strategy**, has been a huge success worldwide.

The **next stage** (**stage 2**) will consist of **identifying different methods** for preventing and managing bioaggressors, *i.e.* those that facilitate **the control of bioaggressors** (the IPM tool kit). Chemical eradication, as practiced in conventional chemical pest control, is

[6] FAO, "Proceedings of the FAO world symposium on integrated pest control, Rome, 1965", Rome, FAO, 1966.

replaced by biological control of weeds, diseases and pests by combining various approaches (preventive, curative, protective). The stated aim of integrated pest management is to reduce populations of bioaggressors below the **economic injury level** and not to achieve 100% effectiveness. At the same time, careful observation of spontaneous biological controls in and around the crop should drive producers to preserve and maintain functional biodiversity. This is how adherence to the principle of integrated pest management defined by the FAO is ensured: "a pest management system that, taking account of the specific environment and the population dynamics of the species in question, uses all the appropriate techniques and methods, in as compatible a way as possible, with the aim of maintaining populations of harmful organisms at levels where they do not cause economic damage" (Milaire, 1995).

As for **the choice of methods** (**stage 3**), which will be incorporated into the integrated pest management strategy, these will be assessed from **a long-term perspective** (e.g. of the entire rotation, *i.e*. by measuring the effects over a number of years and even over a number of crops), with **an ecosystem approach** and **on the basis of their sustainability** (analysis of the 3 key aspects). The timetable and spatial configuration **of both crops and treatments** have an effect on the dynamics of weeds, diseases, pests and their natural enemies. It is necessary to combine an ecosystem approach with the use of modelling ("alerts") to **anticipate the problems** that can be caused by bioaggressors. For example, it is essential to use resistant varieties, ensure crop rotation, practice intercropping, choose the optimum period for sowing and only **treating to a limit**. To reduce losses, pest management strategies should take advantage of species that are beneficial to the predators, parasites and competitors of pests, as well as biopesticides and certain low-risk synthetic pesticides. It is also vital to **invest in upgrading the knowledge and expertise of** farmers.

Consequently, a strategy is defined (**stage 4**) with possible alternative options in the event that a particular method should fail: it is vital, at all costs, to avoid intervening in a catastrophe with an emergency chemical treatment that could seriously disrupt the ecosystem, which involves **careful and regular monitoring of crops**. The consequences of the inappropriate and undesirable application of pesticides could affect not only the crop itself but also subsequent crops (remember that, in organic farming, in the event of an enforced chemical intervention, a period of "regeneration" lasting several months will be imposed on the producer). **Agro-climatic models**, decision-support tools and plant health bulletins, where these exist, enable phytosanitary treatments to be properly positioned. Nevertheless, it is essential to remember that the strategy defined in a provisional manner **will require fine tuning** in line with the year's parasite situation and weather. For example, repeated rainfall encourages the leaching of phytosanitary product deposits and contamination by certain diseases (e.g. mildew). Likewise, persistently wet weather during flowering increases the risk of other fruit diseases occurring.

The strategy must remain a 'framework' for action and not a 'recipe' that the producer needs to apply without due consideration. Therefore, guides and other integrated pest management itineraries are tools for reflection, training and decision-support, but they must never replace the producer's own reasoning.

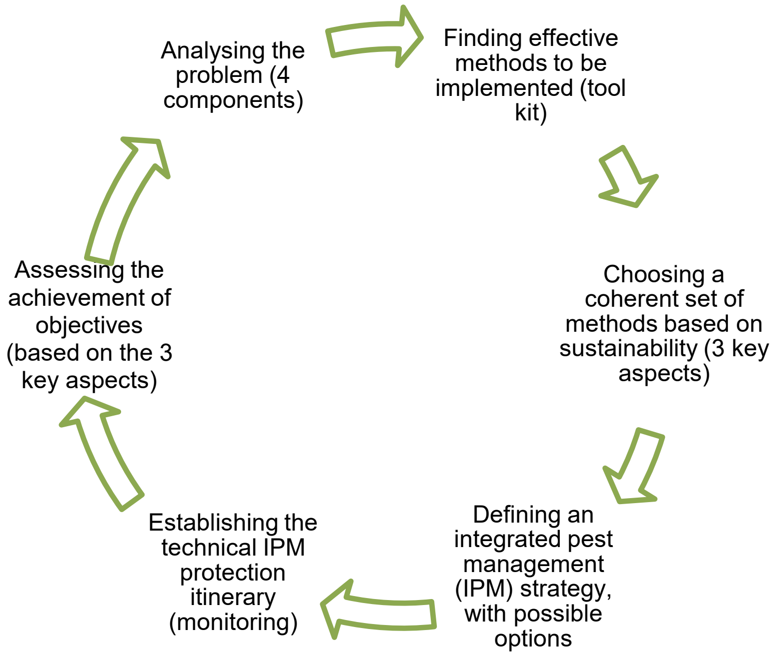
To find out whether the choice of an IPM strategy is acceptable and profitable, there are techniques and tools, the implementation of which cannot be improvised, including the well-known SWOT matrix, which is used by plant protection experts. **SWOT** (Strengths – Weaknesses – Opportunities – Threats), is an extremely practical tool during the strategic diagnosis phase. This tool has the advantage of summarizing the strengths and weaknesses of a strategy as regards the opportunities and threats generated by its 'environment' (we are talking about market requirements in general, such as regulations, specifications, sales price pressure etc.).

Strengths	Resources and/or expertise available (these are an advantage). For example: availability of resistant varieties, availability of selective pesticides, presence of skilled personnel who are able to accurately identify various diseases, a knowledge of economic waste limits, properly developed plots with hedges, etc.
Weaknesses	Lack of one or more key success factors (implementation problems). For example: a lack of skilled personnel making the monitoring of bioaggressors impossible, lack of a clearly defined waste limit, request from a client for a precise variety, which is not resistant, the practice of monoculture, etc.
Opportunities	The environment may offer certain potential opportunities, which need to be identified in order to be developed for one's own benefit. For example: wooded areas for agroforestry, soils that are rich in organic matter, people who are skilled in phytopathology or a nearby plant clinic, a new variety demanded by consumers that is disease-resistant, demand for organic crops, increased sales prices, etc.
Threats	Certain ongoing or future changes may have a negative impact on the result of an IPM strategy. For example: invasive harmful organisms, circumvention of a variety's resistance, falling market prices, departure of a qualified employee, inability to obtain biocontrol agents because of border closures, etc.

Though effective, SWOT analysis requires a minimum amount of training.

The final stage (**stage 5**) is assessing the achievement of objectives, thanks to the strategy implemented and measuring its sustainability. This involves engaging in objective analysis, with the difficulty often being questioning one's own options… and thereby recognizing one's lack of expertise or limits. Nevertheless, a great many external causes can also explain why objectives are not, or only partially, achieved.

The **development cycle for an integrated pest management strategy** can be presented as follows:



3.5.2. Assessing your strategy

All integrated pest management strategies should be based on the principle of continuous improvement. This means that assessment and periodic revision of the strategy are essential. In fact, producers themselves work in an intuitive way. They use a 'trial and error' type approach to build up their knowledge and define their strategies for managing weeds, diseases and pests.

The strategy developed and implemented must be assessed on the basis of the **4 following criteria, at least**:

1. **Effectiveness** (in the prevention and control of bioaggressors).
2. **Efficiency** (relationship between the cost of measures adopted and performance in terms of achieving objectives).
3. **Sustainability** (overall balance between the key aspects – Profit/People/Planet –
4. **Compliance** (compliance with standards, specifications and market requirements).

Principle 8 of Directive 2009/128/EC[7] states that "Based on the records on the use of pesticides and on the monitoring of harmful organisms the professional user should check the success of the applied plant protection measures". Therefore, farmers must check the success of their entire crop protection strategy and carry out an assessment at the end of the season, which takes account (in accordance with ECOPHYTO, France) of:

[7] Directive 2009/128/EC of the European Parliament and the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides.

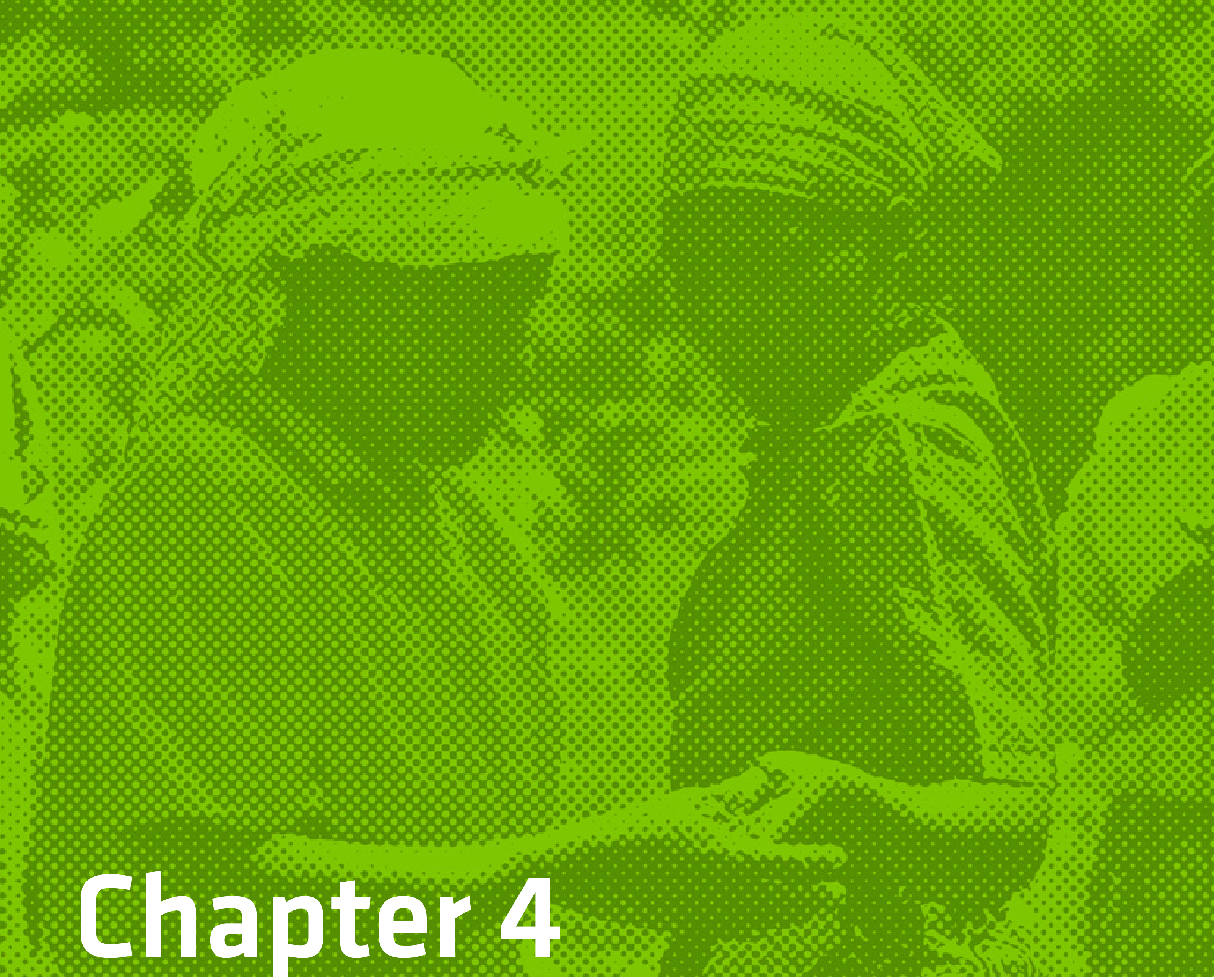
1. **parasite pressure for the year**, which is known thanks to the monitoring of bioaggressors;
2. preventive management methods implemented;
3. curative management methods adopted;
4. possible incidents or unforeseen events occurring during the period.

Example of a retrospective assessment (adapted from the FAO):

Problem observed	• Loss of the agro-ecosystem’s functions resulting in serious pest infestations
Indicators	• Change in the age structure of pest populations • Emergence of resistance to pesticides and abnormal outbreaks of secondary pests • Ever more intensive use of pesticides • Loss of yield and a reduction in farmers revenues
Causes	• Excessive use of pesticides • Poor crop management • Weather conditions • Emergence of new pests
Response	• Analysis of the causes of pest infestations, development of a strategy for re-establishing the agro-ecosystem's functions and restoration of the institutional capacities needed to guide this re-establishment • Avoid solutions that perpetuate this problem • Reinforce integrated pest management capacities by investing in human capital

Assessing the strategy enables **the effectiveness of the combination of proposed methods**, as well as the **salvage** solutions implemented **during the course of the season**, **to be evaluated**. The final assessment must enable avenues for reflection for future years to be highlighted while also taking care **not to systematize protective schemes**, which would not be as effective with different climatic and parasite conditions.

The assessment may take the form of a report or crop monitoring tables. All of these documents should provide a checklist for the technical itineraries developed and their effectiveness. For farmers, the assessment may take the form of a plant protection register. For consultants/advisers, the annual assessment provides a general summary of the advisory services provided during the course of the year and the principal crops covered by recommendations.



Chapter 4

Case studies

4.1. Integrated control of the whiteflies

4.1.1. Identification of the problem

The three main types of whitefly pests are: ***Trialeurodes vaporariorium***, (glasshouse whitefly), ***Aleurodes brassica***, (cabbage whitefly) and ***Bemisia tabaci***, (sweet potato or tobacco whitefly). This last whitefly is a quarantine pest in the EU which means that if it is if found on produce entering into the EU, the produce they are found on can be impounded and destroyed. The reason is that *Bemisia* is a very effective transmitter of viruses, particularly the **devastating leaf curling virus**.

Whitefly adults (leaf) with larva

Virus symptoms (mosaic virus on tomato)

(Photos H. Wainwright)

Whiteflies are common pests of a **wide range of plants** and cause extensive damage by sucking sap from plants; they reproduce very fast under favorable conditions. Uncontrolled, whitefly stunt the growth, reduce yields and can kill a plant by direct feeding, loss of leaf quality and water loss. Larval instars of whitefly produce vast quantities of honeydew during feeding which spreads on lower leaf surfaces. Honeydew is a liquid rich in sugars. Up to 2,000 nymphs may be found on a single bean leaf, each capable of producing 20 drops of honeydew in an hour.

Sooty moulds grow on this sugary solution. Although honeydew helps parasites locate the whitefly, excessive amounts make it difficult for tiny parasitic wasps, such as *Encarsia*, to walk on these surfaces. The sooty mould that grows on the leaf and fruit surface can significantly affect the appearance and marketability of the crop.

Whitefly larvae have developed a feature called a lingula, which they use to flick away annoying levels of honeydew! *Bemisia* is responsible for silver leaf in marrow and leafy crops such as herbs and lettuce. Entire crops can be destroyed by silver leaf.

It is important to distinguish between the three whitefly species above because *Bemisia* is a more efficient transmitter of virus diseases, including the devastating tomato leaf curl virus. *Bemisia* also has a very wide host range. Biotype B of the whitefly, *Bemisia tabaci* (also known as **poinsettia strain**), has a phytotoxic saliva, causing silvering in squashes.

Often viruses are associated with specific crops because the vector has specific feeding habits. However, *Bemisia tabaci* (Biotype B) is able to adapt to almost any plant species which means that a virus normally associated with a specific plant could appear in other crops. Females are better vectors than males.

Most *Bemisia tabaci* (Biotype B) have increased fertility and a strong tendency to develop resistance to pyrethroids, organophosphates and carbamates. *Bemisia* is known to respond to excessive pesticide programmes by laying more eggs and producing more female offspring.

Chemical control of whitefly fails eventually because of over reliance on pesticides. Worse still, is that resistance is thought to be ‘stable’, in other words, a chemical does not recover its effectiveness after a period of non-use.

4.1.2. Biological cycle of the parasite

The adult glasshouse whitefly is a small, uniformly white ‘moth-like’ insect about 1 mm long. It holds its wings flat against its body whereas *Bemisia* holds its wings like a tent over the body. This exposes the yellow color of *Bemisia*’s body, which distinguishes it from *Trialeurodes*. *Bemisia* also frequently sit in pairs on the leaf.

The glasshouse whitefly lays between 50 to 300 eggs, depending on the host. These are often laid in semi-circles on the underside of **young leaves** with smooth surfaces; on hairy leaves they are less regularly positioned. Eggs are white when laid, turning black after a couple of days. *Bemisia* lays its eggs individually, rather than on groups like *Trialeurodes*. Eggs are attached to the leaf surface by a basal pedicel and protected by wax secreted by the adult. The waxy layer makes eggs difficult to control with pesticides. Unfertilized eggs develop into males and fertilized eggs into females.

Eggs hatch into the mobile, ‘**crawler**’ stage, which seeks out a suitable position for feeding. They then ‘**plug**’ themselves into the leaf and enter their sedentary, feeding phase (scales). The scale can probe through droplets of poison on the leaf surface, to feed from the phloem – rendering this type of pesticide less effective. Hence the importance of systemic pesticides.

Scales develop through several instars before pupating on the leaf. The pupae and eggs are non-feeding stages both covered in a waxy layer – making them almost impossible to kill with pesticides. If the whitefly problem is noticed too late, there may be too many insecticide ‘resistant stages’ (egg and pupae) present to achieve adequate control with pesticides alone. This makes a continuous spray programme inevitable.

The pupae of *Trialeurodes* are creamy white with straight sides and a flat top. The sides have a corrugated surface and the top of the ‘lid’ often has a fringe of waxy strands. *Bemisia* pupae are a rusty yellow, flat, without the raised sides and have no fringe on the ‘lid’. By wrapping the leaf around a pencil, the side view of the pupae is more easily

inspected. The parasitized pupae of *Trialeurodes* turn black whereas those of *Bemisia* turn brown.
Adults emerge from the pupae by bursting their way out of the pupal case. An obvious split can be observed in the case; whereas, if a parasite such as *Encarsia* has emerged from the case a perfectly round hole is eaten through the casing to permit the adult wasp to emerge.

Adults mate within 10 – 20 hours of hatching and live between two and three weeks. Nine to 15 generations of *Bemisia* may occur every year. The complete development of a generation requires an accumulation of 269.5 degree days.

4.1.3. Factors affecting the occurrence

Whiteflies are found on a wide range of plants both weeds and crops. They are particularly common on Cucurbitaceae (cucumbers, squashes and zucchinis), Euphorbiaceae (cassava and poinsettia), Malvaceae (cotton and okra) and Solanaceae (peppers, tobacco, tomatoes and eggplant).

The whitefly flourishes in dry weather and can spread rapidly on the wind moving from one crop to another down wind. Whitefly adults do not tend to move when cold (below 15 °C) and do not like rain.

4.1.4. IPM approach

Whiteflies are difficult to control by conventional pesticide programmes, because:

- the adults are very mobile and are difficult to contact using a pesticide when temperatures are warm;
- the egg and the pupae are very well protected against pesticides as they are covered by waxy layers and do not feed;
- in any crop all stages of the life cycle are present, therefore targeting the adults or the scales does not reduce the impact of the populations as much as is required;
- the life cycle is relatively short and reproduction rates are fast.

Therefore to control or at least reduce the impact of whitefly, an integrated approach must be used that combines many techniques, to reduce the pest populations and resulting crop damage.

All aspects of the life cycle and behavior of this pest should be taken into account when developing an IPM strategy. By reducing the number of whitefly moving from one life-stage to the next, the overall peak in each generation will be reduced. This will make it more feasible for biological controls to be used, since vast numbers of parasites will be required if there are huge peaks in populations of the whitefly. Migration of naturally occurring parasites is likely to be too slow to control large peaks in pest populations – in this case, innundative releases of equally high numbers of mass-produced parasites will be required.

Monitoring whitefly is important part of IPM. Adult whiteflies are attracted to yellow sticky traps. Traps (100 – 300 cm 2) spaced at 1 per 6 m2 will assist in control of up to 50-60 percent of the pests. Traps are usually hung near the top of the plant, but whiteflies are poor fliers and the best catches are on traps at 30 cm from the ground.

❑ **Physical controls**

Importing whitefly eggs or scales on rooted cuttings is an important source of infestation. Screening planting material for infestations is difficult and time consuming but should be considered.

❑ **Petroleum oils, soaps and starch**

Oils and starch when sprayed onto the scales of whitefly can act as suffocants. Various products are marketed around the world that are based on these ingredients. Soaps work by partially removing the waxy layer from the scales and causing them to desiccate and die.

❑ **Cultural controls**

Whiteflies respond to high levels of nitrogen in the sap by laying more eggs. Adjustments to the fertilizer programme may reduce population growth rates and make biological control more feasible.

Whiteflies overwinter or bridge between crops on live plant foliage. Weeds not only provide a host for whitefly but also are a host for serious virus diseases.

❑ **Reduce infestations from old crops**

Old crops with high levels of whitefly and little parasitization represent a threat to newly planted crops as the irrigation is switched off and plant quality declines. Crop residues should be destroyed immediately after harvest.

❑ **Trap plants**

Certain plants, such as tobacco, brinjal and okra are particularly attractive to whitefly. These could be used as ‘trap plants’ in organic situations, to be destroyed before pupation occurs, or used as ‘banker plants’ for the breeding of parasitic wasps.

❑ **Wind breaks**

Adult whiteflies are known to be poor fliers. Row orientation may affect the pattern of infestation in an outdoor crop. If it is possible to manipulate this pattern, it may also be possible to ‘spot treat’ with chemicals to allow beneficials to establish in pesticide free zones, where pest levels are lower.

4.1.5. Biological control for whiteflies

❑ **The parasitic wasp *Encarsia formosa***

The parasitic wasp, ***Encarsia formosa***, is used routinely in European glasshouses to control whitefly. It is effective and inexpensive in the EU. It also occurs naturally elsewhere, notably in Kenya. *Encarsia* is a very effective means of controlling whitefly and can either be introduced right at the beginning of the crop before whitefly is seen or when it first appears.

Encarsia needs a constant 17°C for the adult wasps to fly in search of prey. Problems establishing *Encarsia* on certain plants are likely to be due to the plant having very hairy leaves, which makes it difficult for the small wasp to walk on the surface, or there being too much honeydew on the leaf.

Encarsia is also **very sensitive to pesticides** and **careful attention** should be paid to the spray programme for both insecticides and fungicides.

The adult wasp is about 0.6mm long with a black head and yellow abdomen. Eggs are laid in the 3rd and 4th larval stage of the whitefly – for this reason routine applications are required to parasitize younger scales as they mature.

An adult Encarsia Formosa *(Photo H. Wainwright)*

Development occurs inside the host and, after 2-3 weeks, pupae of the glasshouse whitefly (*Trialeurodes*) turn black, and tobacco whitefly (*Bemisia*) turn brown.

The adult *Encarsia* emerges from the pupae by eating a small exit hole.

Whitefly scales, with about 50% parasitized with Encarsia Formosa (the black scales) (Photo H. Wainwright)

Encarsia should be introduced routinely on a preventative basis. The minimum application rate is 0.5/m2/week. Introductions should start just after planting.

- **Entomopathogenic (insect killing) fungus *Beauveria bassiana***

Beauveria is another commercially available insect disease (fungus) with a broad range of targets including whitefly, thrips, aphids and mealybugs. There are for instance two commercial products available in Kenya. It can be tank mixed with adjuvants, insecticidal soaps or oils. No residual harmful effect has been observed on beneficial insects. Do not use with fungicides! However under dry conditions fungi have limited activity, as they prefer humid conditions to infect the target insects.

4.1.6. Pesticides and resistance management

The use of pesticides that are used against whitefly in an IPM strategy include the insect growth regulators teflubenzuron and buprofezin, and the other pesticides including pymetrozine, imidacloprid, thiacloprid and acetamiprid, however the last three are all neonicotioids and, if overused, can lead to pesticide resistance. In designing an IPM spray programme the grower should not overuse pesticides with the same mode of action (and thus belonging to the same resistance group, e.g. neonicotioids), and should consider the appropriate time in the life cycle for application (e.g. adults and/or larvae).

4.1.7. Conclusions

Whitefly is a major pest of **many crops in the tropics**. They stunt growth and reduce yield, the honeydew disfigures the crop and they transmit diseases which present a major constraint to production. Whiteflies are a very successful pest as they multiply rapidly, develop pesticide resistance quickly and have many hosts. To enable them to be controlled, an integrated approach is required that utilizes many approaches contributing to sustainable management of the crops.

4.2. Integrated control of leaf miners

4.2.1. Identification of the problem

Leaf miners are a major pest of a range of crops and weeds in many African countries. The leaf miner is recognized by the characteristic mines in the leaf and the feeding marks on leaves and pods. The damage is caused by the loss of leaf, hence reduced photosynthetic area and reduced growth and the visual appearance of feeding marks that cause the product to be rejected. Secondary effects where feeding occurs, appear when there is a risk of pathogens entering the wound. However leaf miners are not thought to be vectors of any plant viruses.

There is more than one species of leaf miner, however they are difficult to identify as separate species in the field. The most important leaf miners from a horticultural point of view are the three species in the genus *Liriomyza* which are of a particular problem, the tomato leaf miner *L.bryoniae*, the American Serpentine leaf miner *L.trifolii*, and the pea leaf miner *L.huidobrensis*. These leaf miners are polyphagous, that is that they have a wide host range so affect many crops and weeds. However there are over 2,000 species of leaf miner in the world.

The leaf miner is an example of the introduction of an alien pest in Kenya. In the 1970s Kenya developed a chrysanthemum cuttings industry, with stock material brought in from Florida, USA. However with it came the alien American Serpentine leaf miner, *Liriomyza trifolii*. Subsequent exports to places like the UK were found to be contaminated and in 1979 the UK temporarily withdrew the license permitting imports of chrysanthemum cuttings from Kenya. The cuttings industry went into decline and Kenya's reputation as a source of high quality planting material also suffered. As a consequence KEPHIS (Kenya Plant Health Inspection Service) now has the mandate to control all imports and exports of live organisms, whether on imported plant material or exported fresh produce.

The leaf miners *Liriomyza bryoniae* and *Liriomyza huidobrensis* are both **quarantine pests in the EU**. That is if found on produce entering into the EU this produce can be impounded and destroyed.

4.2.2. Life cycle of the pest or disease

❑ **The pest**

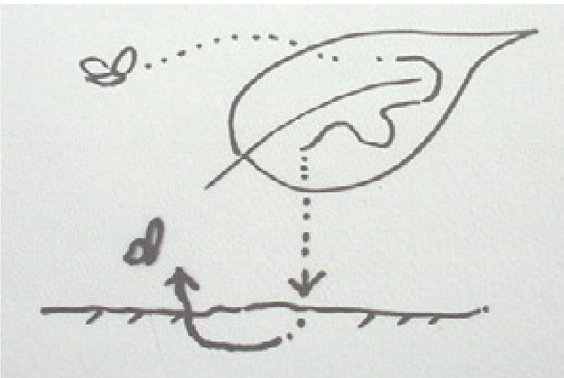
Leaf miner adults are like small flies, being members of the order Diptera (the true flies). The adults are small, yellow and black and one or two millimeters in length. The life cycle of the leaf miner consists of an egg, three larval stages (instars), a pupa and then the adult fly. The female uses her ovipositor to make a hole in the upper side of the leaf. This is where she lays her egg, and is sometimes referred as an egg spot and is oval in shape. Leaf miners also feed from holes in the upper side of the leaf and these are round in shape and larger. Males have no ovipositor and are dependent on the female to make the feeding holes.

Leaf miner feeding marks on a spinach leaf that makes it unmarketable (Photo H. Wainwright)

When the eggs hatch the larvae immediately begin to eat into the leaf mesophyll, but leave the outer leaf and stalk intact. The larvae do not come into contact with the outside of the leaf. As the larvae mine, they pass through the larval stages, though these are difficult to identify from the outside of the leaf.

In *Liriomyza* species, the third instar cuts a hole in the low side of the leaf and falls to the ground. They will crawl into the ground and pupate. A small percentage of larvae remain attached to the underside of the leaf where they will pupate. Not all species of leaf miner will pupate in the ground, as some pupate in the leaf mine (e.g. Chrysanthemum leaf miner).

The adult emerges from the pupa and the cycle continues. The length of the life cycles is temperature and species dependent, but typical egg to adult is 2-3 weeks at 25 °C, and the number of eggs a female lays varies between 50-150 per female.



Drawing by H. Wainwright)

The life cycle of the leaf miner: the adult fly lays its egg in the leaf, the egg hatches into a larva and this creates a leaf mine. The final larval stage falls to the ground to pupate; an adult subsequently emerges from the soil (

❑ **Factors affecting the occurrence**

Leaf miners are a major horticultural pest in leaf vegetables, and pea and bean crops. They are more prevalent in hot dry weather. They are found at all altitudes in countries like Kenya, but they cause the greatest damage in temperate environments at high altitude (2,000 meters at the equator).

4.2.3. IPM approach

Leaf miners are **difficult to control by conventional pesticide programmes**, because:

- the adults are very mobile and are difficult to contact using a pesticide;
- the larvae inside the leaf are protected by the leaf mesophyll, therefore any pesticide must be translaminar or systemic to gain any control;
- in any crop all stages of the life cycle are present, therefore targeting the adults or the larvae does not reduce the impact of the populations as much as is required;
- the life cycle is relatively short and reproduction rates are fast.

Therefore to control or at least reduce the impact of leaf miners, an integrated approach must be used that combines many techniques, to reduce the pest populations and resulting crop damage.

All aspects of the life cycle and behavior of this pest should be taken into account when developing an IPM strategy. By reducing the number of leaf miners moving from one life-stage to the next, the overall peak in each generation will be reduced. This will make it more feasible for biological controls to be used, since vast numbers of parasites will be required if there are huge peaks in populations of the leaf miner. Migration of naturally occurring parasites is likely to be too slow to control large peaks in pest populations – in this case, innundative releases of equally high numbers of mass-produced parasites will be required.

4.2.4. Physical controls for leaf miner

The ability to **reduce the number of eggs laid in the leaf** without effecting yield plays a **significant role** in the control of leaf miner.

❑ **Leaf coatings**

Leaf coatings such as anti-transpirants could be examined as barriers for leaf miner egg laying as well as providing a barrier to sap sucking pests such as whitefly, aphids and spider mite. Leaf coatings may also provide some protection from penetration by the germinating spores of diseases, which enter the plant through the leaf.

❑ **Sticky traps**

Leaf miner adults are attracted to yellow sticky traps.

These are used not only for monitoring but also for mass trapping (photo).

However the disadvantage of sticky traps is that they are non-specific and will trap beneficial insects (e.g. *Diglyphus*) as well.

Mass trapping on the side of a field (Photo H. Wainwright)

4.2.5. Cultural controls

- **Regulate nitrogen use**

There is very strong evidence that excessive nitrogen applications exacerbate leaf miner problems as well as building up populations of other sap-sucking pests (whitefly and aphids in particular).

It is logical to consider a compromise - reduce nitrogen applications (and accept some yield reduction) to gain the advantage of fewer pesticide applications (with the possibility of improved profitability): the application of fewer pesticides could compensate for loss of yield.

- **Reduce reinfestation**

An important source of infestation is the flies that hatch from pupae, which have remained in the soil between crops. Under natural conditions, most of the pupae are within the top 5 cm of the soil surface. Inverting the soil, so that this layer is deeply incorporated, could make it physically too difficult for adult flies to emerge and re-infect newly planted crops.

- **Trap plants**

Certain plants and varieties provide attractive egg laying sites for leaf miner e.g. broad bean (*Vicia fabae*). If such plants are used as ‘trap plants’ to concentrate the attention of leaf miners, it may be possible to dilute the field population by attracting leaf miner away from the newly planted crop.

Trap plants could also be managed as ‘field insectaries’ for parasitic wasps such as *Diglyphus*. The trap plants will not have pesticides applied and natural migration of *Diglyphus* is more likely than in the crop. This assumption is supported by observations of high levels of *Diglyphus* when older crops are no longer sprayed (post-harvest). There will be more pests in the trap crop than the crop and also no pesticide residues to repel the parasite.

4.2.6. Biological controls

Commercially raised parasitic wasps are used routinely in Northern European glasshouses for the control of leaf miner.

Before considering biological controls the possible pest and disease profile of the crop needs to be considered as a whole. The fungicides and insecticides used for other pests could be harmful to the parasitic wasps. Therefore the user should consult **the database of pesticide specificity**.[1]

Pyrethroids, such as lambda-cyhalothrin (Karate) and deltamethrin (Decis), are, however, very toxic to beneficial organisms and persistent and should not be used.

❑ **The parasite *Diglyphus isaea***

Diglyphus isaea is a wasp that parasitizes the leaf miner. *Diglyphus* is an ectoparasite which means it never enters inside any of the life cycle stages of the leaf miner. The female wasp paralyzes the larva and then lays a single egg inside the leaf mine by the side of the paralyzed leaf miner larva. When the egg hatches, it begins to feed on the leaf miner adult and eventually kills it.

The *Diglyphus* wasp has three larval instars before pupating and then hatching into an adult. All stages of development occur in the leaf mine and the adult *Diglyphus* emerges by making a hole in the upper side of the leaf to begin the cycle again. The length of life cycle is again temperature dependent but is similar to the leaf miner. The main reason *Diglyphus* is such a good biological control agent is that it lays many eggs (up to 250 per female).

The presence of *Diglyphus* can be demonstrated by seeing the adults. These are small wasps, with short jointed antennae. In the leaf their eggs and larvae can be seen, mainly by stripping away the leaf laminar to expose the inside of the mine. In addition the mines tend to be shorter and an adult exit hole of the *Diglyphus* can be seen on the top side of the leaf.

❑ **Harvesting *Diglyphus* from crop waste**

The use of *Diglyphus isaea* is not economic if the grower of crops like peas and beans has to purchase the wasp from commercial suppliers. *Diglyphus* is one of the more expensive biological control agents. In addition this wasp is not readily available commercially in countries like Kenya. However *Diglyphus* isaea does occur naturally in Kenya and can invade crops like peas that are infected with leaf miner and where the spray programme is moderated and persistent broad spectrum pesticides are avoided.

[1] www.koppert.com.

Pea crop waste being used as an 'on-farm' source of Diglyphus isaea *(Photo H. Wainwright)*

Following harvest, instead of destroying the crop, the waste is collected and placed in boxes. In the sides of the boxes, clear plastic jam jars are placed and the emerging *Diglyphus* are attracted to the light. These jars are removed and emptied up to twice a day to 'harvest' the *Diglyphus* which are then re-released into the pea crops. *Diglyphus* should be released into a young crop to gain maximum benefit as release into old crops will give little time for the *Diglyphus* to have much impact on the leaf miner population.

Harvesting jars being inspected in the side of a box covering crop waste (Photo H. Wainwright)

4.2.7. Pesticides and resistance management

Pesticides that are used against leaf miner in an IPM strategy include abamectin, cyromazine and thiocyclam hydrogen oxalte. In designing an IPM spray programme the grower should not overuse pesticides in the same resistance group, and should consider the appropriate time in the life cycle for pesticide application (e.g. adults and/or larvae).

4.2.8. Conclusions

The leaf miner is a major pest of exported crops and this is not tolerated by importing authorities. The characteristics of the leaf miner make it difficult to control by pesticide alone. Therefore by integrating a series of control measures, including cultural, physical, biological and chemical, the pest can be controlled in a safe and effective method.

4.3. Integrated control of *Phytophthora* in pineapples

4.3.1. Identification of the problem

Pineapples worldwide commonly suffer from heart and root rot caused by *Phytophthora* fungi (***Phytophthora cinnamomi*** and ***P. parasitica***). The presence of this disease first becomes obvious when a plant begins to wilt and leaves turn yellow. Dried foliage tends not to fall off and roots become dark in color. *Phytophthora* can kill pineapples and will spread quickly in waterlogged soils.

It has a latent stage, so may be present in planting material, undetected. It should be considered as an important disease and under the control of plant health authorities, particularly in propagation farms. Without regulation it can jeopardize livelihoods and contaminate soils.

Phytophthora is more prevalent in regions where average annual rainfall is greater than 500 mm (20 inches) and soils:

- are acid to neutral with low amounts of nutrients and organic matter;
- have few micro-organisms;
- are poorly drained.

Burning off crop debris post-harvest may destroy *Phytophthora* to a depth of 15 cm below the soil surface. However, any relief is temporary, as the fire also lowers surface soil organic matter and microbial populations, making it more favorable for its growth.

4.3.2. How are pineapples infected?

Phytophthora is a **soil borne disease** which can also infect the roots of a wide range of plants other than pineapples. The infection agent is a 'zoospore' which is a motile spore with a tail that helps to propel the spore through the soil-water film in search of plant roots. The zoospore enters the root, just behind the root tip, where there is soft tissue. Once inside the root, the zoospore germinates and produces fast growing mycelia, or 'fungus roots', which grow inside the pineapple root, releasing enzymes which dissolve the pineapple root tissue, allowing the *Phytophthora* to absorb the nutrients released by decaying pineapple cells.

The mycelium strands can also be found in the soil, having grown out of decaying plant tissue. Spore sacs, called sporangia are produced on the mycelium in moist and aerobic conditions and at temperatures of 22-28 ºC. In each sporangium 30-40 zoospores are formed and released. Zoospores can survive up to four days without finding a root tip to invade. Occasionally, *Phytophthora* may also invade pineapples through the leaf axils, where water accumulates and rain-splash could deliver *Phytophthora*-infected soil particles. If the soil dries out, conditions become less favorable for growth and the mycelium may form another type of spore, the chlamydospore. This resting spore has a thick cell wall and is able to survive in the soil or host tissue for many years, waiting for growth conditions to become suitable again. The mycelium can also survive on plant debris on or in the soil.

4.3.3. Infection of planting material

Pineapple is propagated by crowns, slips and suckers. Infection can occur soon after adventitious roots emerge from the crown. If this happens, there is very little root regeneration after infection, as feeder roots are not replaced – and newly planted crown can die.

The new pineapple variety MD2 is very prone to *Phytophthora*. Keen to move in to MD2 as quickly as possible, many growers are undertaking on-farm propagation to build up stocks as quickly as possible, since the writing seems to be on the door for the older varieties, if MD2 is available.

Infected crowns rotted off with Phytophthora (Photo H. Wainwright)

However, on-farm propagation runs its own risks of production of poor quality plants infected with pests and diseases.

This is the dilemma, especially for small scale farmers, desperate to cling to their opportunity to make a living from pineapples. They may produce their own plant material to safeguard their future, but they cannot produce clean plants free of *Phytophthora* and mealy bugs and they then infect their future crops for years to come.

Purchase of cultivated plants, of known origin and with clean tissue, which are then planted into virgin or sterilized soil, without *Phytophthora,* is vitally important for the success of this variety. Since *Phytophthora* can be a silent, latent disease, if extreme caution is not taken from the outset, an unwitting propagator can spread the diseases to many hectares of good pineapple land, where it will remain for many years.

Poor hygiene in on-farm propagation units (Photo H. Wainwright)

It is critically important to improve plant propagation practices to prevent further spread of *Phytophthora* which has caused serious losses in some areas. *Phytophthora* will spread fast, especially during the rainy season, unless action is taken immediately. *Phytophthora* will stay in the soil for more than 10 years and there are no registered organic controls. Implementation of field and nursery hygiene is seriously important for immediate action to ensure the future profitability of the farm.

4.3.4. Cleaning up propagation

If the propagation unit is contaminated, move it to a clean site as the ground will also be highly contaminated. Begin by preparing a level surface without dips, to prevent water from accumulating. There should be a slight slope so that water can drain away. Have deep drains around the edge of the propagation house to take heavy rain water away from the unit. (*Phytophthora* has a motile zoospore which spreads the disease by swimming in water). Make sure the roof plastic is intact so that rain splash on the pots is prevented. Pots should have holes in the base and should be raised off the floor so that they are free draining. The pots must not be touching so that the diseases cannot move easily from plant to plant.

Irrigation should either be by drip (spaghetti type) irrigation or by hose with a fitting on the end which allows water to be switched off between pots. There should be no water splash in the propagation house during watering.

The plant slips should not be taken from fields where *Phytophthora* is present. Very healthy mother plants should be clearly identified in the field and slips only taken from these plants. The ideal situation is that slips are not taken from commercial fields after fruiting but that a special mother plant area is set aside on virgin land specifically for plant production.

If bioassays prove positive – the biological control agent for *Phytophthora*, a beneficial fungus called Trichoderma, is likely to be of benefit at all stages of propagation as a preventative treatment. Soils and leaf axils should also be treated with Trichoderma.

4.3.5. Reduce the risk of disease in the field

It should be assumed that all plant material has *Phytophthora*, since it has a Latent Phase of infection when the disease cannot be seen. Mark out *Phytophthora* hotspots in fields and rogue plants at the first signs of infection, before the mass releases of zoospores which will spread by rain splash and irrigation water.

Phytophthora hotspot (Photo H. Wainwright)

Do not pile slips in heaps exposed to rain as zoospores from one infected plant will quickly spread to other plants in the heap. Do not dump rouged (removed) plants at the edge of the field. A sledge made of heavy duty plastic, sufficiently wide so that two people could drag it between rows with edges which will flap over the top of the plants, will minimize contamination of the field when removing plants. Rouged plants are a serious threat to future production and should be burned as quickly as possible. Alternatively they could be buried in a deep pit well away from the production site, from where water, carrying infectious zoospores, will not drain towards a production field.

4.3.6. Fungicide treatments

Mark with a post the spots where plants are removed. Fungicide treatments should be made to all areas where plants have been removed as well as the ten plants on either side of the affected area, which are very likely to already be infected. Products like propamocarb hydrochloride, fosetyl aluminum, metalaxyl and etridiazole (protectant) may be tried. However the elimination of *Phytophthora* is virtually impossible with fungicides alone.

Successful treatments include phosphonic acid and its buffered salt potassium phosphonate. Researchers have shown that a single pre-harvest (pre-plant) spray of potassium phosphonate, at all rates tested (2.5, 5.0, 10.0 and 15.0 kg/ha), protected pineapple roots from damage by *Phytophthora* when assessed at the first fruit harvest 2 years after planting. This single pre-plant application was as effective as either the four post-planting foliar sprays of potassium phosphonate or soil drenches with metalaxyl over the same period.

4.3.7. Detection and monitoring

The problem is serious enough to require a *Phytophthora* supervisor on the farm to make sure all these prevention actions are taken in a timely manner.

After fruit harvest the young slips are exposed to pesticides (Photo H. Wainwright)

❑ **The potential for IPM in pineapples**

Pineapples are in the ground for many months and are grown in climates which permit all year round growing conditions. This is a suitable stable environment for a successful IPM programme. The problem which needs to be addressed is the scale of production which can be many thousands of hectares of a single crop, often grown without rotation.

Pests and disease flourish because of the practice of producing plants (slips) from old plantations which have the pest and disease present. MD2 may be the way out of this problem, since it produces very many more slips than the older varieties. At last this may break the cycle since it may now be economically feasible to have specialist, quarantined plant production areas.

If plants were produced away from infested commercial crops, this would form the basis of an IPM programme. The grower would then need to have access to cheap, good quality biological control agents, such as biopesticides and natural enemies. This is only likely to be possible if the pineapple farms form cooperatives and mass rear their own biological control agents. This has been done in other crops and is feasible in pineapples, if the motivation is there to make it work.

❑ **Identification and mapping of *Phytophthora* infestations**

Field symptoms of *Phytophthora* can be **confirmed by soil and plant analysis** but this does not always confirm the presence of the disease, since distribution in the soil is not uniform and detection in plant tissues depends on the stage of development of the disease. A ‘negative’ test result may just mean that the presence of *Phytophthora* is ‘not confirmed’.

Positive tests are most likely from samples collected in the warm months of the year, if the soil is still moist.

❑ Soil sampling method

Ensure that the equipment used to sample the soil is clean and free of *Phytophthora* from another site. Ensure that all tools are free of soil. Disinfect tools with methylated spirit (undiluted) or a solution of household bleach (dilute 1 part in 4 parts water). Rinse with distilled water and wipe the tools dry with clean paper towels.

Only collect soil samples if the soil is still moist:

1. Collect soil and some root material from plants showing early symptoms of disease (e.g. discolored leaves) or newly dead plants near the front of the infestation.
2. Remove litter and surface growth from around the plant.
3. Collect sub samples of soil from all sides of the plant from 5-20 cm below the surface using a spade or trowel
4. Put the sub samples in a clean plastic bag to make one representative sample of approximately 500 grams (i.e. the size of a standard domestic margarine container). Sub samples from several infested plants may be pooled together.
5. Ensure that the sample has been labelled properly with:
   - Contact details (contact person, postal address and phone number)
   - Sample details (map reference location and date)
   - Some background information (including plants infected).
6. Disinfect tools, footwear and hands with methylated spirit or a bleach solution after each sampling occasion.
7. Keep samples between 10-25ºC (not in the fridge).
8. Submit samples for testing as soon as possible

❑ Disinfecting farm machinery

Farm traffic can be a potent method for distributing the disease. Visitors with farm vehicles which have been on another pineapple farm should be prevented from entering fruiting fields.

A **vehicle not cleaned after working** in an infested area could easily spread the disease to another site many kilometers away.

A g**rader** can spread *Phytophthora cinnamomi* over a long distance by moving infested soil.
Infested plant material may even **stick to the wheels of bicycles and footwear**.

Phytophthora is even present in **water draining** from infected land or in irrigation water or **moving groundwater**.

Prevention is easier than cure and **Good Agricultural Practice** is the main method of controlling this disease.

4.4. Integrated pest management of diamondback moth

4.4.1. Identification of the problem

Diamondback moth (DBM - *Plutella xylostella* (L.)) is a common caterpillar pest in *Brassica* crops worldwide and the problem is increasing as DBM has developed resistance to a number of commonly used pyrethroid and organophosphate pesticides. It is a particular problem in countries where all year round growing conditions permit many overlapping generations of diamondback moth to exist at the same time. The relentless build-up of the pest may prompt growers to apply pesticides weekly which can further exaggerate the damage if this also promotes resistance of the pest to pesticides.

Information is available from the Insecticide Resistance Action Committee (IRAC) to identify groups of pesticides with similar modes of action. These should be carefully rotated to minimize the risk of resistance. Unfortunately there are insufficient different types of pesticide available to prevent the build-up of resistance. Cross resistance between pesticides in the same family is now common. This makes it very important to apply the IPM principles described in this programme. IPM, used properly, is an effective resistance management programme.

4.4.2. Identification of the pest and life cycle

The adult diamondback moth is a small moth about 10-12 mm long. Male and female moths can be distinguished easily as the male moth is dark brown and the female is tan-colored. The male has three very distinct white diamond-shaped patterns along its back – hence its name ‘diamondback moth’. The diamond pattern is less distinct on the back of a female moth.


Female diamondback moth

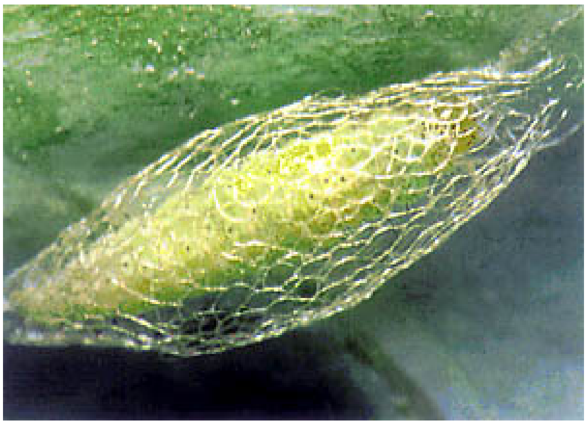

Large caterpillars of diamondback moth

In their life time, female moths will lay more than 150 eggs; they are pale yellow and 0.5 mm long. Eggs are laid in small clusters on stems and both sides of the leaves. Caterpillars are grey-green with a dark head in the first three stages and green with a green-brown head in the last growth stage. Caterpillars grow to approximately 12 mm in length. Like most moths, the adults are nocturnal and are active at dusk and throughout the night. They are really only seen in the day time if they are disturbed from their resting places, under leaves.

Damage to *Brassica* crops is caused by the feeding of young caterpillars which tunnel inside the leaf. Older caterpillars feed on the underside of leaves or tunnel into the plant.


DBM damage makes hole or 'windows' in leaves

Caterpillars which are disturbed from feeding will wriggle backwards rapidly across the leaf surface and may drop to the ground on silken threads. Pupation occurs in an open-mesh cocoon on the leaf surface.


Diamondback moth pupa

The whole life cycle takes from 3 to 8 weeks depending on the temperature. In one year, the moth will complete more than 10 life cycles, given the all year round growing conditions on the Equator. Overlapping generations make it difficult to time the introduction of suitable sprays or biological controls – making it even more important to start any programme as soon as the first moths appear in the crop. If the grower waits for the second generation to occur it may be difficult to keep up with the subsequent generations. Keen scouting is very important.

4.4.3. Integrated Pest Management

Integrated Pest Management for caterpillar pests is the only solution to the caterpillar problem and other pest and disease programmes in today's crop protection scenario. Biological, cultural and physical controls need to be employed to help reduce pest levels and make it less necessary to spray pesticides every week of the season. Broad spectrum prophylactic chemical sprays alone are not a guarantee for caterpillar-free crops. Over-use of pyrethroids or organophosphates will lead to resistance and will definitely reduce the quality and yield of a crop, through their biochemical interference in the growth of plants.

However, pests also reduce yield and quality and effective IPM programmes must replace prophylactic chemical programmes. IPM programmes need to be holistic in design, taking into account all the pest/disease issues, and to integrate the spray and bio-control programmes to address these different problems.

Spray programmes which do not take into account either the presence of natural enemies of crop pests or the weekly changes in total pest populations, could misinterpret risk and justify an additional spray application when:

- the effect of the previous spray has not had time to take effect
- pest populations are actually declining
- the levels of beneficial insects or infection of the pest with natural microbial diseases is high enough to control the pest problem.

IPM programmes are more demanding of management skills. Crop Protection Managers **need to be able to assess risk**, taking many factors into account at the same time, including the knock-on effect of a spray for one disease/pest on the effective bio-control of another disease/pest. The first thing a farm may need to do is to build the capacity of the existing farm manager to undertake this role more effectively – by specialist training from an experienced trainer.

Caterpillars tend to be a seasonal problem – requiring a seasonal plan, which includes preparation for the season, implementation during the season and clean up after the season (to reduce carryover to next season).

4.4.4. Risk management - caterpillar control

Integrated Pest Management uses several related methods and inputs to measure and regulate the build-up of pests and beneficial insects in the crop – in order to prevent damage to the crop. It requires a more detailed understanding of the life cycles of the pests and the factors which effect their distribution in order to make effective use of control methods which when used on their own can be less effective than chemicals. But when a number of control methods are effectively integrated – the resulting control can be as good as or even better than chemical controls.

❑ **Information**

More information is needed to design a farm-specific IPM programme for caterpillars than is normally used to design a chemical programme:

- *Which species of caterpillar are present on the farm as a whole:*
  - where are they generally found?
  - how can their distribution and movement be controlled to prevent migration into the crop?
  - how many moths or caterpillars are there and is the population increasing or decreasing?

- *Which pesticides:*
  - still work effectively on the different caterpillar pests (no resistance)
  - will kill the pest but not their natural enemies and diseases (compatible pesticides)

- *Which natural enemies:*
  - are able to control the caterpillar pests
  - how many are needed to obtain control in relation to the pest levels
  - how can enough natural enemies be 'applied' or 'encouraged to enter' the crop

IPM farm programmes may require local research and development. Inputs will need to be sourced (baculoviruses and *Trichogramma*) and skills developed (quantitative scouting of the whole farm – not just individual crops).

❑ Evaluate and manage risk of resistance to pesticides

Examination of the actual pesticide programmes applied will reveal if:

- there has been excessive use of the same active ingredient (even too many Bt sprays can lead to resistance)
- an over-intensive spray programme, not related to scouting data, has been used
- label rates for active ingredients per hectare have been exceeded.
- applications have not been timed to coincide with susceptible stages (Bt – young caterpillars)

Any of these **failures will increase the risk of resistance** to pesticides developing.

❑ Quantitative scouting

Conventional scouting often provides only limited information, suitable only for a modified preventative programme. Indices for pest incidence can be misinterpreted by scouts. It is not unusual for trained scouts using indices to allow the pest levels linked to these indices to 'drift'.

Once this happens the data becomes meaningless.

- The level of resistance can be measured by regular quantitative scouting before and after sprays.
- Scouting can also indicate if sprays have not been effectively applied (poor cover of the crop) – or not applied to the crop at all (pesticide stolen before application!).
- Quantitative scouting will also provide information on the relative numbers of pests in the crop and determines the introduction rates for natural enemies

- Scouting should take into account relevant life stages (adults, eggs, larvae and pupae).

4.4.5. Physical controls and traps

❑ **Physical controls**

Using overhead irrigation for a few minutes just before dusk has been shown to wash off young larvae which are active at this time as well as disturb the activity of adult moths which are likely to be on the upper surface of leaves at this time.

❑ **Improved use of pheromone traps**

Female moths naturally produce a biological scent (pheromone) which attracts males from kilometers away – to mate. Artificial DBM pheromones attract male moths and are very specific to individual species. Other moths will require a specific pheromone to lure them to one place (for counting or killing). Correct identification of the caterpillars present in the crop will ensure the correct pheromone traps are deployed.

If used correctly, pheromone traps will indicate trends in moth populations and enable crop protection agents to be applied when the most vulnerable pest life stages are present in the largest numbers. For example, parasitic wasps, such as *Trichogramma* can be released when the peak in moth egg laying has occurred and *Bacillus thuringiensis* is applied when young caterpillar larvae are present.

Pheromone trap data should be correlated to physical observations in the crop and crop damage data from pack-house rejects to develop local economic thresholds to trigger pesticide applications.

Pheromone trap counts can be influenced by the:

- position of the trap in relation to the crop and wind direction
- age of the pheromone lure (new lures release larger pheromone peaks)
- contamination of the trap with other scents
- incorrect pheromone used due to misidentification of pest

Scouts must wear gloves to prevent cross contamination of the traps. Think more than twice before putting a pheromone trap **inside** a cropping field – it could **attract** moths into the crop! The grower needs to know when the moths are arriving on the farm – so best to put the traps outside in well thought out strategic positions. Good scouting of crops will confirm if the pest is actually in a particular field and if the numbers have started to rise. Moths come from the prevailing wind side of the farm – so put the traps in between the source and the crops you wish to protect. Perhaps place a barrier (with glue on it) on the leeward side of the trap – to prevent the moths from continuing their flight into the field crop. Common sense – but not many growers do this. Now is the time for common sense.

❑ **Mass trapping of adult moths (away from crops)**

Only mated females lay eggs, therefore a reduction in the number of fecund females should correlate to reduced caterpillar numbers on the crop. Pheromone traps only attract males, but if male moths can be pulled away from the females in commercial fields, there will be fewer mated females in the commercial crops. However, for this to be an effective tool – most of the male moths need to be lured away.

To increase the effectiveness of pheromones as a mass trapping tool – they will need to be combined with lights and trap crops to combine the cues being sent to both female and male moths. The pheromone trap can either have glue inside it, or a water bath (see below). It is best to purchase specifically designed traps for each type of moth lure, if they are available locally and affordable.

Farm made Pheromone trap (NRI/IITA design)

Sometimes pheromones are not available commercially locally. They should be registered as crop protection agents – which may slow down access to this tool in some countries – particularly if mass trapping is the objective (since it may catch non-target species too).

If necessary, it may be possible to devise a method for making farm-produced ‘natural’ pheromone traps with unmated virgin females, collected from caterpillars allowed to pupate and turn into adults in a container. One virgin can attract males from many kilometers away. Up to 50 virgin female moths in a container placed far away from the commercial crops (NOT inside the commercial field in case it attracts adult males into the crop) – may act as a potential mass trapping devise, if combined with sticky boards or water traps, placed near the pheromone trap.

Female moths are smaller in size than the males. Organize a good training course on the farm so that scouts can identify different species of moths and also distinguish between males and females.

Pheromone traps can be purchased from a number of suppliers.[2] The type of trap needed will differ for each caterpillar species and the grower should consult the pheromone supplier for recommendations as to the type of trap required.

Traps should be placed in position a few weeks earlier than the expected seasonal moth appearance – and the counts of adult moths recorded twice a week on a graph, to pinpoint the arrival of the first wave of moths. Remove dead moths from the traps. The rubber pheromone septa will only last about five weeks before the pheromone declines.

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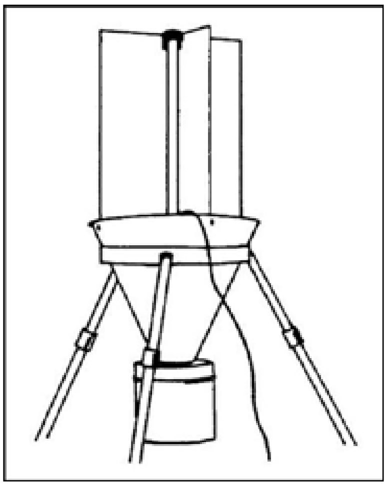
[2] Including Syngenta Bioline (biolineapp.com) operating in the EU and US and South America.

Fresh septa release more pheromone scent and will attract more males than older septa, so ensure that the pheromone septa on the farm are replaced in a rotation – not all at the same time.

Moth flights are usually followed by a peak in an egg laying about one to two weeks later and then a peak in larvae hatch another 1 to 2 weeks later – depending on temperatures. Trap catches may range from zero to 80+ moths per week. Trap catches over 10 per week are likely to result in an egg lay that will require action such as introduction of egg parasitoids, or sprays targeting young caterpillars.

❑ **Light traps**

Light traps at night attract both male and female moths of all species. If combined with sticky traps or water traps they can lure and kill. They need to be tended by night security staff for safety reasons.



Light traps

Light traps may need to be combined with pheromones and trap plants so that moths once attracted, remain in the vicinity of the light and lay eggs there, rather than in crops nearby.

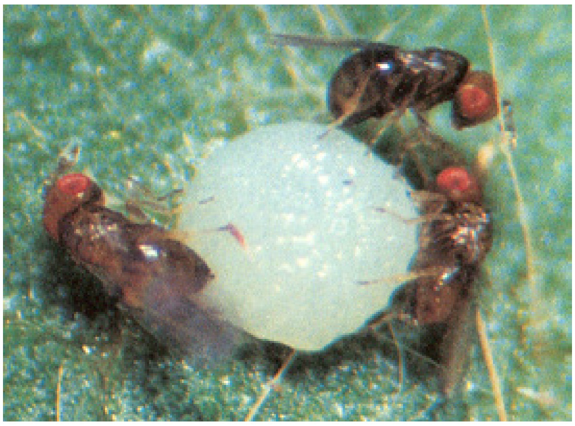
❑ **Trap Crops and Field Insectaries for beneficial insects**

The objective of the trap crop is to encourage DBM moths to land there and begin laying eggs. Good host plants for cabbage caterpillar pests are susceptible cabbage varieties. A fast-growing pakchoi cabbage for example is very useful to attract DBM moths and encourage egg laying in the trap crop rather than the cabbage crop.

If the trap crop is not sprayed with non-compatible pesticides, it will also allow natural enemies such as *Trichogramma*, to build up there, by feeding or parasitizing the various caterpillar life stages from egg through to adult.

The trap crops can be made even more effective if a black light trap is placed within the trap area. Female moths would then lay eggs in the trap crops rather than moving to the the commercial crops. Adult moths like to take nectar and plants which produce a lot of nectar should be provided in the same place (like marigold). A perimeter fence made of netting may assist in preventing the migration of adult moths from this site back to the commercial crops.

The trap crop area would then become an in-field nursery for beneficial insects and even insect diseases. For example, when caterpillar eggs are present, the grower can purchase and apply insects which parasitize caterpillar eggs, such as the parasitic wasp called *Trichogramma*.


Trichogramma wasps laying eggs in Heliothis egg

Additionally, when caterpillars are present, the grower could purchase a baculovirus product and spray it onto caterpillars. The virus is very specific and only kills one type of caterpillar; there are baculovirus products available for diamondback moth.

The trap crops could also be a source of mature caterpillars which could easily be collected and used to make the locally produced pheromone traps described above.

An alternative to spraying the trap plants with pesticides is to actively build up biological control agents. Scouting and management systems should be devised to ensure this does not become a source of infection. If there are too many pests and not enough beneficial insects spray the trap plant area immediately to stop migration from there into the crop.

A single female moth can lay up to 150 eggs, so it is important to take the push pull strategy seriously as this pest has become resistant to pesticides in many areas of the world. It is no longer sensible to dismiss this part of an IPM programme as insignificant or not effective – pesticides are not effective on their own. If a purely pesticide programme is used – resistance will eventually happen – it’s a fact of life which should no longer be ignored.

Don’t plant trap crops and then fail to manage them. They will be a source of pest build-up on the farm. Check them daily and take action daily as required (apply beneficial insects or spray the trap plants or physically kill by hand the eggs and caterpillars on the crop). Based on the fact that on adult female moth lays 150 eggs – one caterpillar destroyed could ‘save’ another 100 or more adult moths or more in the field in the next generation!

Plough in trap crops as soon as the caterpillar season is over otherwise those caterpillar species which pupate in the soil beneath trap plants or on crop debris (older cabbage leaves) could emerge later in the year as another generation of pest moths.

4.4.6. Non-chemical products

- ❑ **Push – pull**

A push-pull strategy will enhance the effect of this approach – by making the crop 'less attractive' – using unpleasant scents. The botanical insecticide made from the neem tree has been used effectively to repel diamondback moth caterpillars in *Brassica* crops and may be useful to repel other caterpillar pests. However, neem on its own will not protect the crop from a massive invasion of moths.

- ❑ **Biological controls for caterpillars**

There are many naturally occurring and common parasitoids and predators of caterpillars, pupae and their eggs. Some of the species that are known to parasitize diamond-back moth larva are of the genera *Diadegma* sp. *Apanteles* sp., *Cotesia* sp. and *Tetrastichus* sp. Providing there are enough of them and they build up in advance of the build-up of DBM in the crop – then they can help prevent economic damage. This is where a Field Insectary becomes useful, as it is a safe haven for DBM and as it is not sprayed, it allows natural enemies to build up.

In addition to predators and parasitoids which are mass produced such as *Trichogramma* and *Orius*, there are a number of microbial insect-specific pathogens which kill caterpillars but do not affect non-target species (baculoviruses and *Bacillus thuringiensis*). Other entomopathogenic fungi such as *Beauveria bassiana* have a wider host range and some strains kill thrips, whitefly and aphids. Entomopathogenic nematodes (nematodes which kill insects) can be effective at killing most caterpillars when sprayed onto caterpillars.

- ❑ ***Bacillus thuringiensis* (Btk and Bta)**

Bt sprays are frequently used in IPM programmes for caterpillar control because they are less harmful to other beneficial insects than most sprays. However, Bta is toxic to aquatic invertebrates, green lacewing and *Metaseiulus occidentalis*. Bt spores do not usually spread to other insects or cause disease outbreaks on their own as occurs with many other insect pathogens.

Bacillus thuringiensis (Bt) is a naturally occurring soil bacterium and one of the most widely mass produced biopesticides, used for more than fifty years for the control of certain caterpillars. There are several types of Bt, two of which (kurstaki and aizawai) are effective specifically against caterpillars (other types control certain beetles and mosquitoes or sciarids). The Bt toxins in the Btk and Bta are different and care should be taken not to over-use either of them, as it is possible to develop resistance to these toxins. In order to manage resistance, the grower should rotate the Btk with the Bta if the pest is susceptible to both types of Bt.

Not all caterpillars are equally susceptible to both Btk and Bta, so the grower needs to identify caterpillars in the crop before spraying an ineffective biopesticide. If the information about susceptibility of different caterpillars to the Bt type, is not available on the Label, or the grower is unsure of the target range of the Bt available – a simple spray

4ztest onto leaves, fed to the caterpillar, will determine susceptibility (caterpillar will turn black and die within 2 days). In general, Bt aizawai products are more effective against small larvae of the leafworm (*Spodoptera litura*) than Bt kurstaki products

Formulations of Bt kurstaki such as Dipel are available for the control of many caterpillar pests including imported cabbageworm, cabbage looper, hornworms, European corn borer, cutworms, some armyworms, diamondback moth, spruce budworm, bagworms, tent caterpillars, gypsy moth caterpillars and other forest caterpillars. Btk is less effective against beet armyworm and diamondback moth has exhibited resistance to the Btk toxins. It is important therefore to use it wisely in an integrated programme with other pesticides and even to rotate Bt kustaki with Bt aizawai (e.g. Xentari) to manage resistance to Bt toxins.

The Bt spray is composed of crystal-shaped proteins and living spores from Bt bacteria. If enough Bt is consumed by the caterpillar, the toxins in the crystal proteins paralyze the caterpillar's mouth and gut. Caterpillars will stop feeding within minutes to one hour after feeding, depending on the dose ingested. The insects' gut wall is broken down within hours by the toxin, allowing Bt spores and the insects' normal gut contents to invade the body cavity. Death occurs with 1 – 2 days and the larvae may become discolored or turn black and shriveled. They may fall, unnoticed by scouts, onto the ground.

Bt will only kill young caterpillars and is not effective on older, larger caterpillars. Therefore close scouting for caterpillar eggs in crops will forewarn the grower when to start spraying Bt for young caterpillars emerging from the first generation of eggs in the crop, after the invasion of adult moths. Consult the label – if a range of application rates is advised, then use the higher rates only if there are larger caterpillars present or the volume of leaves to be covered warrants a high volume spray.

Looper caterpillar (right) infected with Bt – healthy caterpillar (left)

One or two tablespoons of skimmed milk powder can be added to Bt sprays used by organic growers, when caterpillars are not feeding voraciously enough to obtain a lethal dose of Bt (e.g. when the temperatures are low). However, this is not normally done in flower crops. Bt can be tank mixed with many pesticides, as long as the pH remains about 7. It is not advisable to tank mix with alkaline fungicides such as chlorothalonil.

Sunlight will deactivate Bt formulations which are anyway only effective for only one to three days. Since many caterpillars emerge to feed in the night, it is best applied late in the afternoon and not early in the morning – to minimize the exposure to UV light. Rain or overhead irrigation can also reduce effectiveness by washing Bt from crop foliage.

Successful use of Bt depends on correctly identifying the caterpillar as a susceptible species, application to young caterpillars and in the right concentration, at the correct temperature (warm enough for the insects to be actively feeding), and before the caterpillar bores into the flower, where Bt sprays will not penetrate.

❑ Baculoviruses

Caterpillars are killed by very species-specific virus diseases, called baculoviruses. A specific baculovirus exists, and has to be produced, for each different type of caterpillar. There are commercial baculoviruses for DBM available.

Baculoviruses are therefore **very environmentally friendly** as **they do not affect non-target species at all**. It is therefore even more important that the grower properly identifies the caterpillar species present in the crop in order to purchase the correct type of baculovirus. Baculoviruses are not known to replicate in mammals or vertebrates.

Like Bt, the baculoviruses must be ingested by a feeding caterpillar larvae in sufficient quantities to deliver a lethal dose. Unlike Bt – there is no recorded resistance to baculoviruses in target pests. Once inside the host the baculovirus will multiply and kill the host. Application should also be delayed until late afternoon as the product is broken down by UV light. Commercial baculovirus products are produced by several companies.[3]

❑ *Beauveria bassiana*

Several strains of another naturally occurring soil microbe, *Beauveria bassiana*, have been developed as commercial bio-insecticides for a range of pests such as whitefly, aphids, mealybug, thrips and caterpillars. Botanigard and Mycotrol are two well-known commercial products. This bio-insecticide is **broader spectrum than the Bt** and baculoviruses and more care is needed in its integration into an IPM programme relying on other beneficial insects.

Caterpillars on left infected with Beauveria

Beauveria is a white fungus, occurring naturally in the soil, so again it should be applied late afternoon to optimize effect. Spore suspensions are sprayed onto the plant, targeting the bodies of the caterpillars. Spores on the caterpillar's body germinate and penetrate the host body, where its mycelium grows and produces more spores.

It is possible for this entomopathogenic fungus to spread to other pests within the crop, from a sporulating dead body of a caterpillar. Combined applications of *Beauveria* and

3 Including Kenya Biologics www.kenyabiologics.co.ke in Kenya and Andermatt BioControl in Switzerland www.biocontrol.ch.

EPNs (entomopathogenic nematodes) have been shown to be effective means of control for certain other caterpillars.

❑ Entomopathogenic Nematodes (EPNs)

Beneficial nematodes also inhabit the soil – not just the pest nematodes which are so difficult to kill! There are two main genera which are mass produced – *Heterorhabditis* and *Steinernema* spp – of which *Steinernema carpocapsae* is more likely to have an effect on caterpillars than the other species *S. felitae* (normally used for thrips control). The EPN nematodes must be applied to the caterpillar body to have any effect and can be applied through normal spray equipment or through drip irrigation lines (if the soil phase of the caterpillar is the target).

Application rates vary from 1.25 billion per ha to 2.5 billion per ha depending on whether the crop is full-field or if only 50% of the ground is covered by a row crop. Regular applications are needed during the period when caterpillar larvae are present in the canopy or dropping to the soil to pupate (*Spodoptera* and *Heliothis* spp). They will not be an effective treatment on their own and should be integrated with other control methods. The nematodes themselves have a bacterium within their own guts and once inside the host, they regurgitate these bacteria – which kill the host. The EPNs then reproduce within the host, feeding off the decaying body of the host. They are easy to integrate with normal spray programmes as they are tolerant of most fungicides and insecticides – although they should not be applied in a tank mix spray and are obviously susceptible to nematicides applied to the soil.

❑ *Trichogramma* wasp - caterpillar egg parasitoid

In the past, very few growers used *Trichogramma* for caterpillar control due to the broad spectrum sprays being used routinely – however, more growers are beginning to adopt IPM and low pesticide inputs – making it worthwhile reviewing the usefulness of *Trichogramma* as one extra tool in an IPM programme. The tiny parasitoid wasps kill their hosts before their eggs hatch thus preventing crop damage by emerging caterpillars. *Trichogramma* is a minute wasp (shorter than 1 mm) that lays its own egg inside a caterpillar egg, killing the young caterpillar inside the egg. Instead of a caterpillar emerging from the egg, another *Trichogramma* wasp will emerge. Parasitized eggs generally turn brown then black, making them easy to distinguish from un-parasitized eggs. The *Trichogramma* wasp is yellow - brown with red eyes.

Trichogramma *laying eggs in a Heliothis egg.*

Between two to four *Trichogramma* wasps develop within one caterpillar egg, depending on the size of the egg. *Trichogramma* uses its antennae to measure the size of the host egg in order to determine the number of eggs it will lay in it. Other parasitoids species may produce only one offspring per caterpillar egg – hence *Trichogramma* is the commercially most commonly reared parasitoid.

Trichogramma wasps are active in dry periods, particularly sorghum, maize and cotton, which make good 'field insectary' and 'trap crops'. If pesticide sprays are compatible with *Trichogramma*, the population increases from low densities during the rains and become very abundant in the dry season.

However, *Trichogramma* wasps are extremely susceptible to most chemical insecticides and their residues. Pyrethroids for example can leave toxic residues which kill *Trichogramma* for up to 12 weeks after they have been sprayed on the crop – so check the spray history before applying *Trichogramma*. Plan spray programmes 3 months ahead of *Trichogramma* applications to avoid residue problems. *Trichogramma* is distributed commercially as parasitized caterpillar eggs, which are stuck onto cards to be hung in the crop, until the adult wasp emerges. This process takes from seven to ten days, depending on temperature. Female *Trichogramma* wasps then search the crop for new caterpillar eggs to parasitize. Releases should be made at the beginning of the egg laying period and continue as long as pheromone trap catches of adult moths are high and/or fresh eggs are being laid on the crop.

Female *Trichogramma* wasps can parasitize over fifty moth eggs during their lifespan of up to 2 weeks. Adult wasps feed on nectar as well, so it is important to have small flowers (such as alyssum) present in field insectaries near the crop as a nectar food source. Again take care to manage the field insectaries carefully so they don't become a source of pests such as whitefly and caterpillars.

Check with the supplier as to the host range of the *Trichogramma* species available commercially. *Trichogramma brassicae* has been used successfully against DBM (*Plutella*). Once emerged, *Trichogramma* wasps only live about seven days from application date. Since it takes about nine days for any newly parasitized eggs in the crop to develop and the second generation of adults to emerge in the crop – the *Trichogramma* should be applied at least in two applications 5 to 7 days apart – to ensure 'continuous cover' from adult *Trichogramma* wasps. Do not apply *Trichogramma* in extreme heat or during rain in outdoor crops. Optimum release time is in the late afternoon. As long as the *Trichogramma* has been received within 24hrs from the supplier, they can be stored at 8 to 10°C for up to three days, depending on previous storage and how close they are to emergence. Do not allow the temperature to drop below 3 °C. Release rates will range from 25,000 parasitized eggs per hectare for low pest levels to over 200,000 per hectare for high pest levels. The number of developed caterpillars present in a crop as well as actual damage to the crop, is a better indication of the effectiveness of *Trichogramma* rather than percentage egg parasitization – as eggs are generally hard to find.

4.4.7. Pesticides and Resistance Management (IRAC groups)

A well designed spray programme, planned in advance should be implemented. It should take into account the mode of action, the target stage of the pest, the IRAC resistance management group and the effect on non-target beneficial insects which might also be in the crop at the same time. IRAC stands for Insecticide Resistance Action Committee – made up of pesticide manufacturers, such as SYNGENTA, BAYER and BASF, who have jointly developed advice on which pesticides should be used less often than others (those with a higher risk of resistance) and advice on which pesticides should be used instead (rotating pesticides from different groups).[4]

IRAC provides valuable advice to the growers. If there is no resistance management strategy there will be resistance and the pesticide will no longer work. A table of the caterpillar pesticides is provided with details of their IRAC groups and effect on *Trichogramma*, a parasitoid which kill caterpillar eggs and *Orius* a predatory bug which attacks small caterpillars and also eggs.

Common sense needs also to be applied on the choice of pesticide. If the financial risk from crop damage due to caterpillars is too high (e.g. very high invasion of moths and not enough beneficial insects) – then a pesticide should be applied – even if it will kill some beneficial insects.

The following table provides information on the compatibility of commonly used pesticides for the control of caterpillars and their side effect on other beneficial insects.

Table 1:% of the beneficial insect likely to die, if they are present at the time of spraying the pesticide (if they are actually touched by the spray). The actual % death will depend on the effective spray cover of the crop.

		Orius	***NEPs***	***Encarsia***	***Aphidius***	***Ladybirds***
Active ingredient	**IRAC Group**	**% of death (ND : not determined)**				
Chlorpyrifos	1B	>75%	50 - 75%	>75%	>75%	25-50%
Dichlorvos (fogging)	1B	ND	<25%	>75%	>75%	ND
Fiprinol (spraying)	2B	<50-75 %	ND	<50-75 %	>75%	>75%
Fipronil (drip)	2B	<25-50%	ND	<25 %	ND	ND
Deltamethrine	3A	>75%	<25%	>75%	>75%	>75%
Spinosad	5	>75%	ND	>75%	>75%	>75%
Bt aizawai	11	<25%	<25%	<25%	<25%	<25%
Bt kurstaki	11	<25%	<25%	<25%	<25%	<25%
Bt	11	ND	ND	25-50%	ND	ND
Diflubenzuron	15	>75%	<25%	<25%	<25%	ND

[4] http://www.irac-online.org/Resistance/Overview.asp.

teflubenzuron	15	>75%	<25 %	<25 %	<25%	ND
flufenoxuron	15	>75%	ND	<25%	ND	ND
novaluron	15	ND	ND	ND	ND	ND
lufenuron	15	25 –50%	ND	->75%	<25%	ND
methoxyfenozide	18	25-50%	ND	<25%	<25%	<25%
indoxacarb	22A	50-75%	ND	ND	>75%	ND

A similar table can be established for persistence of the active ingredients: the number of weeks after the spray application that the residue **will remain harmful to the beneficials** if they move onto the sprayed leaf after the day of the spray application.

Table 2: Persistence of the a.i. in weeks on plants.

	Orius	***EPNs***	***Encarsia***	***Aphidius***	***Ladybirds***
Active ingredient	**Persistence of the a.i. in weeks on plants**				
Chlorpyrifos	5	2	8-12	12	ND
Dichlorvos (fogging)	ND	0	1	ND	ND
Fiprinol (spraying)	ND	ND	ND	ND	ND
Fipronil (drip)	ND	ND	ND	ND	ND
Deltamethrine	8-12	0	8-12	8-12	8-12
Spinosad	1	ND	2	2	2
Bt aizawai	0	0	ND	ND	ND
Bt kurstaki	0	0	ND	ND	ND
Bt	ND	ND	0	ND	ND
Diflubenzuron	ND	0	ND	ND	ND
Teflubenzuron	4	0	0	0	ND
Flufenoxuron	4	ND	0	ND	ND

Novaluron	ND	ND	ND	ND	ND
Lufenuron	4	ND	0	0	ND
Methoxyfenozide	ND	ND	0	0	0
Indoxacarb	> 2	ND	ND	ND	ND

Caution! The pesticide label should always be read before use on the crop.

Do not apply pesticides not approved for use on the crop and follow instructions for Pre-Harvest Intervals (PHI) to avoid exceeding the Maximum Residue Limit (MRL).

4.4.8 Conclusions: IPM Recommendations

- Produce *Brassica* transplants in seed trays in an insect-proof environment, where DBM moths cannot enter and lay eggs on young plants.
- Learn to identify all life stages of the DBM and its predators and parasitoids.
- Set up a Field insectary well ahead of the planting of the first *Brassica* crops – so that these areas are attractive to the DBM moths before the crop is developed.
- Plan sources of biological control agents – either from neighboring farms with good levels of parasitoids or from a commercial producer of bio-control agents.
- Check plants carefully at least once per week or more often during peak periods and in hot weather – take action as soon as moths appear
- Use *Bacillus thuringiensis* in the early part of the spray programme as this is less harmful to the parasitoids and predators of DBM and may allow them to build up in the crop.
- Do not over-use pesticides, make plans before the crop is planted about which pesticides will be used (check IRAC groups and Pesticide Labels) – save effective but non-compatible sprays with short harvest intervals for emergency use in high pest pressure periods (if there are not enough bio-control agents present).
- Calibrate and maintain spray equipment regularly – poor spraying means more sprays need to be applied than necessary. Dropleg sprayers are better at getting the sprays onto the underside of the leaf.
- As soon as a badly infested crop is no longer needed – plough the crop under the soil **immediately** – to prevent adults from flying to new younger crops.
- Organize the planting programme to ensure young crops are not planted down-wind of old crops – to reduce the migration of DBM from old to new crops.

Most used abbreviations and acronyms

Most used abbreviations and acronyms

ACP	African, Caribbean and Pacific (Group of ACP States that have signed a series of agreements with the EU, called the ‘Cotonou Agreements’)
a.m.	Active matter
a.s.	Active substance
BCA	Biocontrol Agents
Bt	*Bacillus thuringiensis*
CA	Conservation agriculture
DAP	Diammonium phosphate
EFSA	European Food Safety Authority
EPN	Entomopathogenic Nematodes
EU	European Union
FAO	Food and Agriculture Organization: UN organization that addresses food security problems in the world
GAP	Good agricultural practices (set of application conditions that must be defined: dosage, volume, formulation, technique, PHI)
GLP	Good laboratory practices
GMO	Genetically modified organism

IARC	International Agency for Research on Cancer
ICM	Integrated crop management or integrated production
ICO	Independent Certifying Organizations
IOBC	International Organization for Biological and Integrated Control of Noxious Animals and Plants
IPM	Integrated pest management
IRAC	Insecticide Resistance Action Committee
MRL	Maximum residue level
NGO	Non-governmental Organization
NH_4+	Chemical symbol for ammonium
NO_2	Chemical symbol for nitrogen dioxide
NO_3	Chemical symbol for nitric acid
OJEC	*Official Journal of the European Communities*
OJEU	*Official Journal of the European Union*
O.M.	Organic matter
PDS	Plant defense stimulators
pH	Potential of hydrogen

PHI	Pre-harvest interval (number of days to wait before harvesting)
PLRV	Potato Leaf Roll Virus
PPE	Personal protective equipment
PRA	Pest Risk Analysis
RCW	Ramial chipped wood
S.C.	Suspension concentrate
SWOT	Strengths – Weaknesses – Opportunities – Threats
UV	Ultraviolet
VOC	Volatile organic compounds

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Useful Websites

Useful Websites

ABC (Australian Biological Control): www.goodbugs.org.au

ANDERMATT BIOCONTROL: www.andermattbiocontrol.com

COLEACP: coleacp.org/en

CORNELL UNIVERSITY: cals.cornell.edu

CROPLIFE: croplife.org

CSP: www.insah.org

CTA: www.cta.int/en

FAO: http://www.fao.org/home/en, more precisely
www.fao.org/ag/AGP/AGPP/IPM/gipmf/index.htm

GUIDE DE DÉFENSE DES CULTURES AU TCHAD: tchad.ipm-info.org

HORTIVAR PROJECT: www.fao.org/hortivar

ICIPE: www.icipe.org

IFEN: www.statistiques.developpement-durable.gouv.fr

IRAC: www.irac-online.org

KENYA BIOLOGICS: www.kenyabiologics.com

KOPPERT: www.koppert.com

OILB-SROP: www.iobc-wprs.org

PHYTOWEB: fytoweb.be/en

REAL IPM: www.realipm.com

SYNGENTA BIOLINE: biolineapp.com

USDA-APHIS: www.aphis.usda.gov

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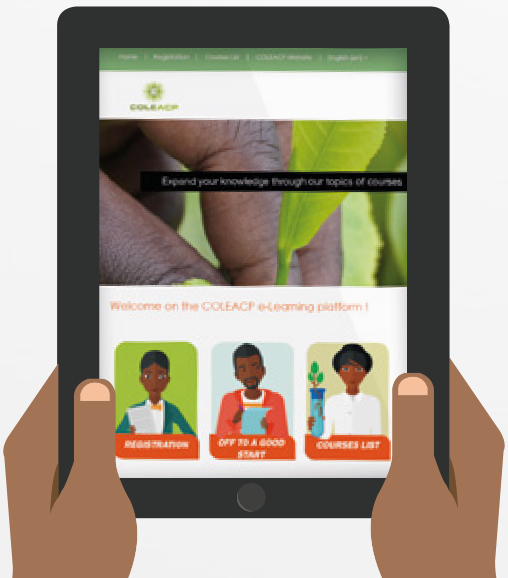

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