TRAINING

MANUAL

FOUNDATION OF CROP PROTECTION

COLEACP

- AGRICULTURAL PRODUCTION AND PROCESSING -
FOUNDATION OF CROP PROTECTION

Chapter 1

Extent of crop enemies and need to protect them

1.1. Extent of crop enemies and need to protect them

As a result of the combined action of diseases, attacks from pests and competition from weeds, it is estimated that almost **50% of world agricultural production** is lost before or after harvest. Estimated losses, per region and per crop, published in 1965 by H.H. CRAMER were reviewed in 1990 by E.C. OERKE *et al* for the 8 largest crops (cotton, soya, rice, maize, potato, coffee, wheat and barley).

They reveal the **substantial difference** that exists between the 'production potential' of the varieties used and the 'outputs actually recorded', attributing it mainly to the damage caused to crops by pests, even in regions where the most up-to-date agronomic techniques are used.

Thus, OERKE estimates that the drop in production is comparable from one region to another when modern production techniques are used, but without any protection strategy. With cotton, for example, output may drop to 15.9% of potential production, compared with 60% currently achieved using various methods of protection.

Relative extent of losses

- ■ Without protection
- ■ Avoided losses
- ■ Production

Origin of losses

- ■ Weeds ■ Pests
- ■ Diseases

Development of world demography
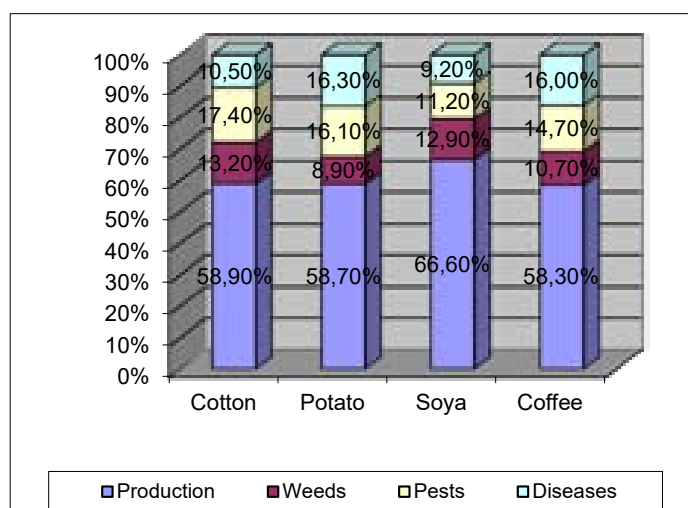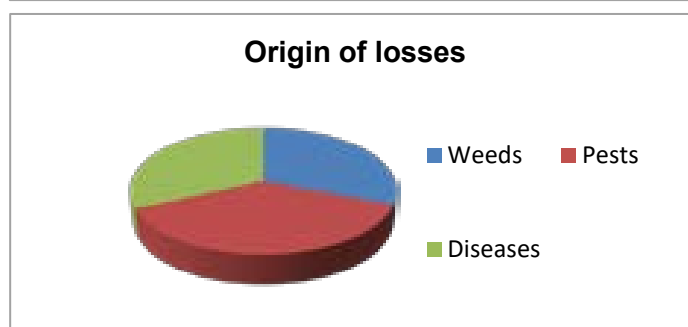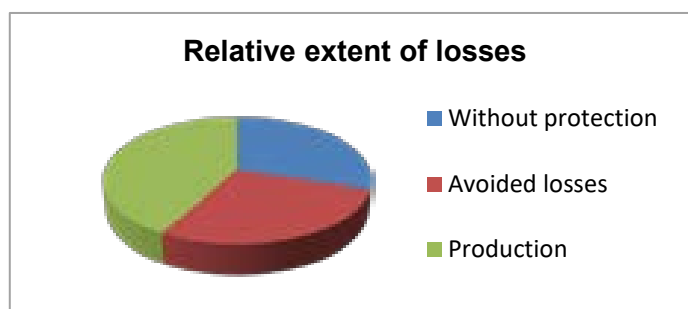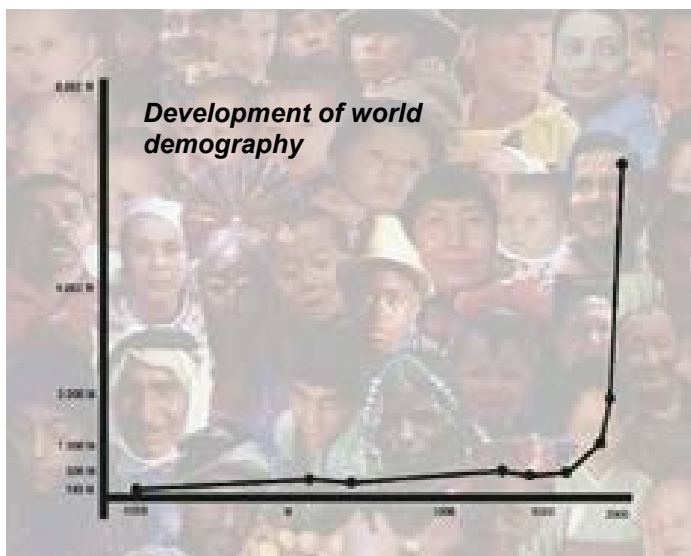
The explosion of demographic growth over the last few decades, will continue until at least 2100, with the world population rising from over 6 billion to approximately 11.5 billion human beings at the end of the 21st century. What is more, the average increase in the standard of living in some regions where economic growth is strong and rapid also leads to an increase in the world's food needs.

However, there are only two ways of increasing production: **increasing the cultivated surface area, on the one hand**, and **improving productivity per hectare on the other hand**.

Depending on the type of economy in which they operate, and the economic context in which they live, farmers – whose aim is to secure a decent and increasing income for themselves (which is not necessarily the result of maximum productivity per hectare) – exploit one or other of these factors if they can. So, as long as land that is easy to cultivate is available, it may be more advantageous for them to increase the ground they cultivate than to make use of more inputs (fertilizer and pesticides).

Nevertheless, in practically every region of the world, **farmers are now faced first of all with a limitation of arable land available, and secondly with a drop in soil fertility (deterioration of soil, erosion)**.

This means that the only option they have in the medium and long term is **to increase productivity per hectare** and to **reduce post-harvesting losses**.

In developing countries, food-producing resources, and cereal crops in particular, will have to increase by around 70% by 2020, if the estimated 6.5 billion inhabitants are to be assured dietary security.

Almost all this increased food supply will have to come from countries that are themselves under development. To meet this forecast increase, it will be necessary to see a sustainable increase in the outputs of the main crops of cereals and leguminous plants, and a reduction in farming losses caused by pests and diseases.

Since the possibilities of expanding irrigation and areas suitable for arable farming are limited, **future strategies** ought to be based on **increasing the productivity of the ground and the water resources available**. Undoubtedly, there is no more extensive wastage of these resources than investing time, money and labor in food production only to see these crops swept aside, completely or partially, by infestations with pests, diseases and weeds (see table). Depending on the level of the losses and costs concerned, improving plant health control seems to be an important strategic means of increasing the food resources in existence in developing countries.

Plant nutrition		**Plant protection**
Increases production	Improves quality	Guarantees production

*Often underexploited, **fertiliser** can deliver immediate production gains as long as varieties selected for their high potential are used.*

***Plant protection** makes use of cultural, genetic, mechanical, biological and chemical methods, used in strategies which are both preventive and curative. The response of crops to the protection techniques is not always as easy to describe as numerous environmental and climatic factors interact.*

Actual production and estimated losses of eight harvests from 1988 to 1990, per parasite and per region (in US $ billion)

Region	Actual production	CAUSES OF LOSSES			
		Pathogens	**Insects**	**Weeds**	**Total**
Africa	13.3	4.1	4.4	4.3	12.8
North America	50.5	7.1	7.5	8.4	22.9
Latin America	30.7	7.1	7.6	7.0	21.7
Asia	162.9	43.8	57.6	43.8	145.2
Europe	42.6	5.8	6.1	4.9	16.8
Former Soviet Union	31.9	8.2	7.0	6.7	22.1
Oceania	3.3	0.8	0.6	0.5	1.9

Source: E. Oerke et al., Crop production and crop protection: Estimated losses in major food and cash crops*, Amsterdam, Elsevier, 1995.*

However, the **incomplete information about the actual losses caused by parasites** and the actual and potential gains of plant health control constitute a great hindrance to formulating a strategy intended to improve plant health control. If all the losses caused by parasites rise to 50%, as indicated by certain researchers, States and organizations such as the World Bank and the CGIAR (*Consultative Group on International Agricultural Research)* must undoubtedly devote more resources to reducing these losses.

Recourse to the inputs available (fertilizers and pesticides) may considerably increase production, and consequently reduce the need to cultivate 'marginal' land, protecting the most fragile ground from deforestation, erosion and rapid degradation.

However, when output makes progress thanks to input, selection of variety, irrigation and improvement of crop protocols, the crops also become **more attractive** for the pests and often **more sensitive** to disease or to competition from weeds.

In order to safeguard the production potential, this leads to the **need to use effective methods of monitoring and protecting the crops**.

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1.2. General information about pests, diseases and weeds

A cultivated field or plot constitutes an artificial environment where natural biodiversity has largely disappeared. By concentrating the cultivated species, the farmer encourages populations of pests and epidemics responsible for reducing the output per hectare of the crop. The damage caused to agricultural production and stored foodstuffs by pests, diseases and weeds often represents **over a third of the harvest**.

The agents responsible for these significant losses are mainly **plant-eating insects,** which are easily the most harmful: **nematodes, fungi, viruses and bacteria, not forgetting weeds.** Strategies for protecting crops and methods of controlling these pests are then needed in order to maintain a high level of production.

Pests of the main crops world-wide
(Source: Bayer CropSciences, List of pests, 2001)

Cotton	whitefly, bugs, leaf hoppers (especially dangerous because they are vectors of viral disease), *heteroptera*, *helicoverpa* caterpillars
Maize	wireworm, fruit fly, bug (as vector of viral disease)
Cereals	bugs (especially dangerous because they are vectors of viral disease)
Leguminous crops	bugs, whitefly, leaf hoppers, thrips, caterpillars attacking the leaf and the fruit, leaf miners
Ornamental plants	bugs, whitefly
Rice	leaf hoppers, web moth (*Sparganothis pilleriana***)** of rice, aquatic weevil, leaf roller
Stone fruits	bugs, mealy bugs, leaf miners, codling moths, winter moths
Citrus fruits	mealy bugs, bugs, leaf miners, white fly, jumping plant lice
Potato	bugs (especially dangerous as vector of viral diseases), leaf hoppers, Colorado potato beetle
Rape	blossom beetles, stem flea beetles, weevils
Banana plant	Nematodes

Fungal disease affecting the main crops in the world
(Source: Bayer CropSciences, List of pests, 2001)

Cereals	powdery mildew, rust fungus, *rhynchosporiosis*, septorioses (*septoria*), and brown spot disease, rot and smut
Rice	pyriculariosis (*pyricularia*), *rhizoctoniae* and other diseases of the leaf
Leguminous crops	infected seeds, rust fungus, rotting of fruits and leaves, grey mould, powdery mildew and mildew, diseases of the foliage and the fruits (e.g.: *alternariosis*, *cercosporiosis* etc.)
Potato	mildew, *rhizoctonia*, silver scurf
Vine	powdery mildew and mildew, grey mould
Pome fruits	scab, mildew, *monilia*
Stone fruits	*monilia*
Mango	*cercosporiosis*
Peanuts	*rhizoctonia*, *sclerotiniosis*, *cercosporiosis*, rust
Banana plant	*cercosporiosis* (Sigatoka disease affecting the leaf system of the banana plant)
Rape	*sclerotiniosis*, phoma lingam
Coffee plant	coffee rust

However, a rational and effective fight against crops, pests and diseases **involves minimum knowledge of their lifestyle, their biology and their principal characteristics** in order to be able to identify them both with certainty and as quickly as possible on the basis of the symptoms observed, for an effective and profitable response.

1.3. Crop infestation, damage in production and at post-harvesting stage

Threats to crop production can arise at an **early stage**, from sowing onwards. **Seeds** that are healthy, high quality and disinfected (not affected by viruses, free from all types of bacteriosis and not colonized by the larvae of insect pests) must be used and **seedbeds** must be maintained under good, healthy conditions, free from nematodes, viruses, insects carrying disease etc.

Inadequate growing practices (choice of plot and type of soil, inadequate rotation, destruction of beneficial insects, poor weeding and elimination of debris from crops after harvesting, contaminated ploughing tools, harsh pruning etc.) may also be responsible for massive infestation.

> **Frequent phytosanitary inspections of plots** and orchards, the use of traps, regular soil analyses, clearing weeds from seedlings, observing diseased plants are all necessary in order to detect the start of attacks, to monitor them and if necessary halt their development.

- **Gnawing insects** devour the different parts of the plants (caterpillars of the Lepidoptera family, larvae and adult Coleoptera, grasshoppers and crickets of the Orthoptera family). **Biting-sucking insects** suck up the sap from plants and weaken them. They are also vectors of viruses (whitefly, mealy bugs, zigzag leaf hoppers, greenfly, bugs, thrips).
  Certain insects cause damage to plants because they lay eggs. The development of the larva in the plant tissues is accompanied by consumption of these tissues (fruit flies, leaf-miners that dig tunnels in the leaves). As for underground insects, they attack the roots and tubercles (mole crickets, grey worms). Insects may also be responsible for considerable damage to stored foodstuffs (grains, flour, meat etc.). Some insects, which are recognized as "quarantine organisms" must be detected in harvested products (ideally prior to their dispatch).

- **Fungi and bacteria** penetrate through the roots, stalks, leaves and fruits through cuts and natural openings, or directly through intact surfaces, resulting in the appearance of marks of different colors or rotting. This damage makes fruit and vegetables unsuitable for consumption and may occur both when they are growing and after harvest.
  Numerous fungi and bacteria are responsible for post-harvesting damage and most viruses infect fruit and vegetables during the growing period and develop during storage, especially under favorable storage temperature conditions. Excluding the direct damage they cause to plants and fruit and vegetables, fungi may also contaminate foodstuffs with the toxins ('mycotoxins') they release or by

inducing in plants products of natural defense ('phytoalexins'). Some of these compounds are particularly dangerous to consumer health even at low concentrations (regulations on acceptable concentrations have, been fixed by the European Commission). The invasion of stored products by fungi, thanks to favorable conditions (temperature and/or humidity too high) is generally the cause for contamination by mycotoxins such as aflatoxins or ochratoxins.

- **Nematodes** invade the roots which swell (galls) and the root system becomes nodular; secondary roots develop and the supply of water and nutritional elements no longer takes place: the plant becomes stunted, yellows and withers. In fact, water absorption is very often "impaired". Assimilation of potassium is reduced, as well as that of sodium, at times. Often a higher concentration of the other mineral elements can be observed in the aerial organs. In the potato, *Ditylenchus destructor* causes a reversal of the relative levels of sucrose and starch.

- As for **weeds**, these may be directly harmful to the crop as they may compete for nutritional elements and water, from the moment the cultivated plant begins to develop. Consequently, this affects the assimilation of chlorophyll in the cultivated plant and therefore its growth. In addition, some weeds grow faster than the crop that has been planted and may therefore be responsible for stifling the developing plant. Finally, weeds may house various parasites (viruses, bacteria, fungi and insect pests) and may therefore be a source of infestation.

Hence the damage caused by the various plant pests and parasites, both when growing and during post-harvest storage, are numerous and vary in importance depending on the state of infestation, the robustness of the plant and the early nature of the intervention which must remain effective and compliant with quality and environmental regulations.

The type of treatment (plant health control) must be appropriate, and must take into consideration the following:
- the organisms to be controlled (efficacy);
- the sensitivity of the crops (selectivity);
- the aim pursued (to limit development, prevent an infestation, eradicate a pest or a disease, etc.);
- regulatory requirements (plant control regulations) and those of specifications (quality standards);
- the skill of the operators;
- safe use and means of protection of personnel;
- targets of competitiveness (profitability of control);
- impact on the environment (durability, protection of bees, etc.).

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1.4. The challenges facing crop protection

1.4.1. The limitations of the current production model

Although the task of agriculture – producing more at the right price – has benefited society as a whole, there are effects which are damaging to the environment. After a long struggle, everybody nowadays recognizes the **polluting nature of intensive agriculture** as practiced in numerous areas of the world. Faced with the environmental and socio-economic damage caused by agricultural practices that were considered until only recently as cutting-edge, fears and concerns of public opinion are spreading in Europe and elsewhere. Preservation of the environment by the grower is now explicitly perceived as a mark of respect for the consumer, at least as much as the guarantee of the food safety of the product.

Generally speaking, **the chemical protection of crops**, even if usually effective, **does not give full satisfaction**, not just in relation to the sustainability of agro-ecosystems (loss of biological diversity, deterioration of the physical-chemical quality of the environment), but also because its efficacy is increasingly being limited by the appearance of pest resistance, modifications to the parasite spectra and by the appearance of serious imbalances in the environment (water pollution, contamination of the soil and the air).

It therefore means that growers have to look for other solutions and turn their sights towards production models that are more compatible with sustainable development. "Crop protection is therefore at a crossroads" (Deguine, CIRAD [*Centre de coopération internationale en recherche agronomique pour le développement* – Agricultural Research for Development].

Nowadays, faced with the growing European demands in terms of **food safety** and faced with the increasingly stringent commercial requirements of **major retailers**, it is essential for growers to **revise their practices**, not just in order to supply products which comply with regulations (e.g.: compliance with the MRL (maximum residue levels) and other regulations) and to safeguard their market shares, but also to **produce in an 'ethical' way** by respecting the environment.

In fact, it is no longer sufficient for growers to take into consideration the efficacy and profitability of treatments, or even solely the 'food safety' aspects of their methods of plant protection, as little by little the market has imposed criteria on them which touch on respect for the environment, the protection of biodiversity and the ethics of the methods used. Moreover, in an increasingly competitive international market, the intensive farming systems which require a lot of input risk leading to economic risks. The development needed must involve a significant reduction in quantities of input in order to reduce the cost price and the indirect costs (e.g. purification of contaminated water).

Through lack of evaluation and objective scientific information about the impact of the methods of control on the environment and on the possibility of significantly improving the

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current plant health practices, **the place reserved for chemical control in the crop
protocols will be clearly called into question**.

For that matter, the agri-food industry and the major retailers have taken to including in
their specifications an increasing number of 'environmental requirements' (e.g.:
GlobalG.A.P., Charte PERFECT, Terra Nostra, Hypermarket C1000, Ethical trading
initiative/ETI, Well thought-out Agriculture, and so on), the ISO 14001 certification or PPP
certification (*Production Plus Propre* – Cleaner Production) adopted in Tunisia, based on
integral prevention of pollution) and eco-labels such as the EU 'Ecological label'
(23 groups of different products, and over 250 certificates already granted to hundreds of
products in Europe).

The '**environmental challenge**' was also evident in **the reinforced requirements and
the ever-more stringent restrictions** concerning the marketing authorizations of active
substances, mirroring the recent development of the revision of European Directive
91/414/EC[1] that questions the economic profitability of developing new families of active
substances. This European Directive 91/414/EC was replaced both by **a new regulation**[2]
(encompassing the marketing authorizations – MA – for plant protection products – PPP)
and a **new Directive**[3] relating to the sustainable use of pesticides and the reduction of
the risks and negative impacts of PPP, especially through the development and
simplification of Good Practices.

Authorisation for active substances	Marketing Authorisations (MA)	Sustainable use of pesticides + Reduction of risks and impacts on health & environment	A scientific evaluation of the environmental risks and management measures proposed is therefore an ethical and regulatory necessity.

Scope of Directive 91/414/EEC   *Amended by Regulation (EC) 1107/2009 &
Directive 2009/128/EC*

At European level, the sustainable use of pesticides is one of the seven thematic
strategies of the sixth community programme of action for the environment (2002-2012).
Its aim is *"a significant overall reduction in risks and of the use of pesticides consistent
with the necessary crop protection"*.

Thus, within the European regulations for protecting water (e.g. Directive on nitrates,
Framework Directive on water), "Codes of Good Practice" are indicated for the use of

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[1] Council Directive of 15 July 1991, concerning the placing of plant protection products on the
    market, *OJEC*, L 230 of 19 August 1991.

[2] 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, *OJEU*, L309 of 24 November 2009.

[3] Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009
    establishing a framework for Community action to achieve the sustainable use of pesticides,
    OJEU, L309 of 24 November 2009.

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inputs (fertilizer and pesticides). As another example of this idea, we can also mention the "River Contracts" (management of catchment areas), the "Quality Charters", etc.

These different 'Good Practices' will only be really effective on the development of agricultural practices **if their efficacy can be demonstrated, measured** and if they are **accepted by the growers** via consultation, agreement and voluntary compliance, prompted by their awareness of the need to change their practices to preserve their means of production. Nevertheless, the impact of new techniques for protecting the quality of the products, the environment and the health of the operator still needs to be evaluated.

The challenges facing growers in the field of crop protection are therefore numerous and the equation is increasingly complex to solve:

- Placing crops in the best possible conditions (especially with regard to their environment and food) to avoid the appearance and development of crop enemies.
- Only intervening when this is justified to safegard the margin of profit and the commercial quality of the products. Avoiding all treatments involving simple 'insurance' and being able to show that each treatment was necessary.
- Identifying the most effective method/s, those best adapted to the level of risk, combining them and minimising the impact on the crop and on the environment. Being capable of showing that the best method of treatment is selected.
- Respecting national and international legislation and the requirements or restrictions of private specifications as part of certifications.
- Keeping a record of all operations carried out to protect the crops and the products harvested. In particular, being able to reconstitute in detail the measurements and dosages carried out.
- Retaining sufficient profit.

On the one hand, the immediate consequence of **retail trade** imposing commercial requirements, impelled more by 'marketing' arguments than by proven technical reasons, and on the other hand, the completion of the process of revising the regulations, **will lead to the reduction of choice for the growers with regard to their control methods,** and even to the rejection of chemical means of protecting their crops.

We are witnessing a globalization of the awareness of the environmental impact of human activities, due to the global nature of a number of environmental questions, such as the greenhouse effect and the resulting threat of global warming, or the preservation of biodiversity, mainly in the hands of the countries of the South, with Northern countries being the main users. In the recent "*Declaration of Libreville*" (2008), 80 health and environmental ministers from 53 African States made a commitment to coordinate their action more successfully in order to reduce the risks to health associated with the environment. They stressed "*the importance of the risks associated with the environment and the emergence of new environmental risks*".

The growers from the countries in the South who export to international markets are faced with the same requirements, on the subject of ethics, as European growers, for example. The management of plant health risks requires new skills to be developed by all those involved in the production chains.

1.4.2. Need for an integral scientific approach to methods of protection and their impact

It is through a **scientific analysis of current practices and the alternatives** proposed that we will be able to show with complete objectivity to the growers the benefit of adapting or changing the methods of protecting their crops, and offering them efficient alternative solutions.

The effect of environmental pollution by inputs, contamination of the air, soil and water, the loss of biodiversity, provide a reminder that the risks caused by the constant interaction between farming activities and the environment are many, differ a great deal, and are sometimes catastrophic in their consequences.[4]

The complexity of these interactions calls for the contribution of research to draw up 'action plans' and the selection of effective and viable measures for managing these risks.[5]

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[4] See INRA-CEMAGREF, ''Les pesticides, agriculture et environnement. Réduire l'utilisation des pesticides et en limiter les impacts environnementaux'', *Collective scientific assessment Inra-Cemagref*, Versailles, Quae, 2005.

[5] See CALVET *et al*., *Les pesticides dans le sol, conséquences agronomiques et environnementales*, Paris, France Agricole, 2005.

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Only an approach such as a **risk analysis**, based on scientifically established foundations, which are systematic and integrated will allow an **objective determination of the impact of the crop protection practices of the growers on the health and safety of products and the environment**.

Although recently used in the field of the environmental impact of certain industrial and agricultural[6] activities, the OECD (Organization for Economic Co-operation and Development) accepts that risk analysis is a tool that allows aims of conservation and food production to be developed. These are less restrictive than the generic aims normally chosen by the decision-makers through a lack of adequate information. Thanks to the application of this method, the risks of environmental impacts associated with protecting crops will be evaluated by a **systematic and scientific approach**, and can thus be classified according to their severity and frequency.

Taking into account the regulatory, technical, economic and social constraints, the results of this analysis first of all allow **more rational management** when having recourse to products for protecting plants, followed by adequate development of alternative methods and lastly **the choice of appropriate measures** for preventing contamination of the environment, *i.e.* that of the operator.

Drawn up after the risk analysis, the "action plan" generally consists of a **coherent body of actions that will all contribute**, directly or indirectly, **to reducing as much as possible the risks** of occasional and widespread pollution, to preserving the quality of the environment (water, soil, air) and to guaranteeing the safety and crop health of the products harvested.

The grower will integrate the body of actions in order to bring his production system into conformity (self-assessment and/or private certifications of the Global-GAP type). This will allow him to **display a 'Quality Policy'** for his company, with precise and consistent aims in relation to his actual capacities (human resources, financial resources and availability of the technology locally). It is therefore essential for associations of growers to be involved in drafting action plans. The project will aim to develop a '**model**' that will allow him to integrate and coordinate the various measures to control the environmental risks.

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6   See EFSA, *Environmental Risk Assessment of Genetically Modified Plants*, EFSA Scientific colloquium summary report, 2007.

Chapter 2

Dynamic epidemiology, and identification of pest populations

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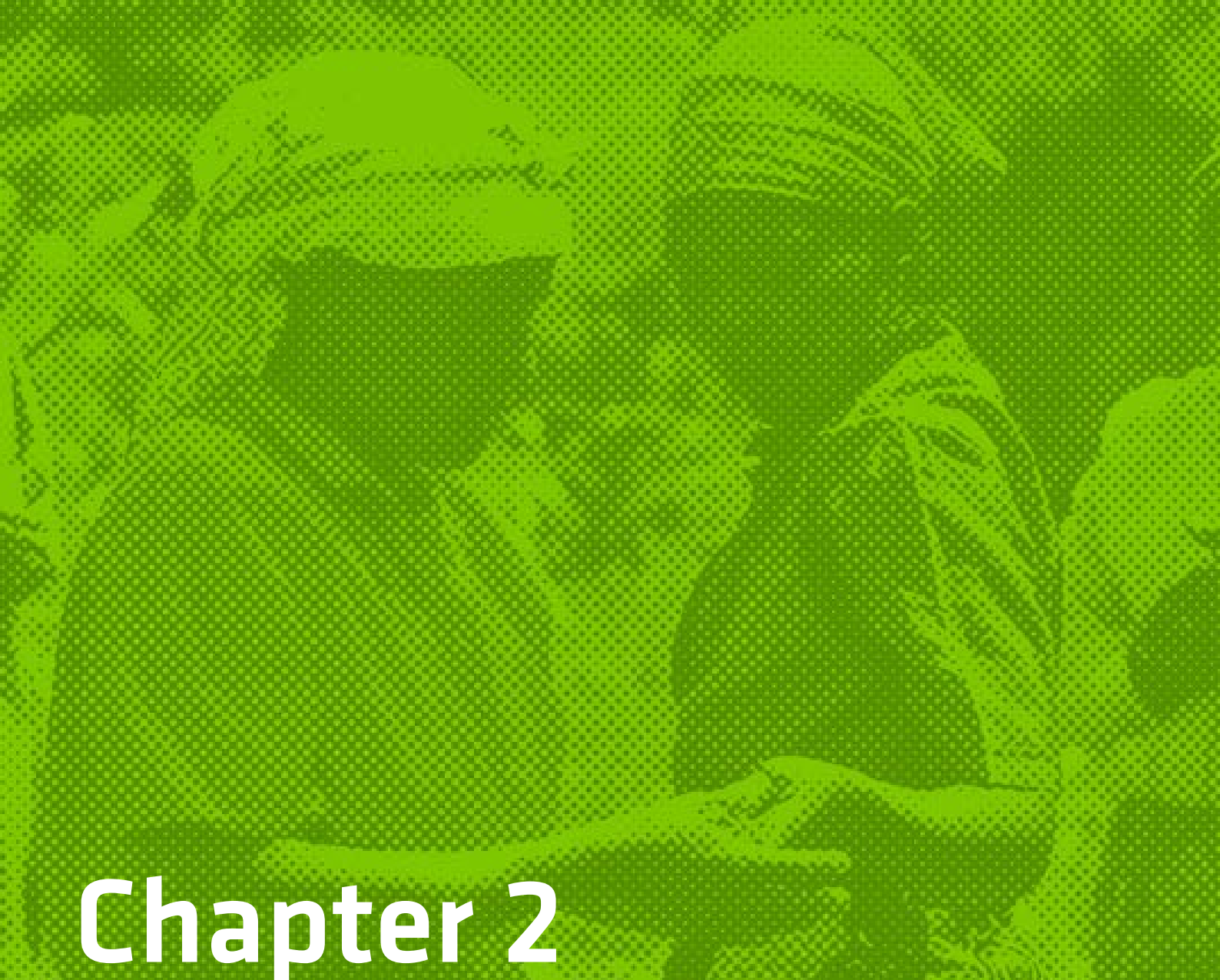
2.1. Epidemiology of pest populations

Epidemiology is defined as the study of the development of a pest population (insects, acarids, nematodes, rodents, birds) within a host population (plants cultivated within a plot or an orchard).

International trade and air transport have also encouraged the introduction of a large number of pests in new areas of the world. In the absence of natural enemies associated with these pests considerable damage to crops is caused in their new habitat.

This is why international regulatory measures have been adopted to limit the spread of potentially dangerous pests: There are lists (Lists A1 and A2 produced by the EPPO,[1] *European and Mediterranean Plant Protection Organization)*, or organisms which appear in European Directives [2]) of '**quarantine organisms**' (e.g.: *Helicoverpa armigera*, with regard to exports of fruit and vegetables to Europe) for which special precautions are required on the part of growers (e.g.: **Plant health certificates**[3] **issued by the relevant authorities in the exporting country**).

> **Detecting these quarantine** organisms (insects, bacteria, fungi, and so on) **in batches of vegetables may lead to their immediate destruction.** Some organisms are not present in Europe, others are present in Europe but in order to limit their spread, the destruction of infested batches remains obligatory.

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[1]   *EPPO A1 and A2 Lists of pests recommended for regulation as quarantine pests as approved by EPPO Council in September 2009*, at: http://www.eppo.org/QUARANTINE/quarantine.htm.

[2]   Consult the Annexes to Directive 2000/29/CEC (and its modification Directive 2002/89/EC) on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community, *OJEC*, L169 of 10 July 2000, p. 1.

[3]   Model of Plant Health Certificate in Annex VII of Directive 2000/29/EC.

2.2. Dynamics of pest populations

While some species appear regularly each year, in the same quantities, there are others, on the other hand, which after seeming to disappear, suddenly re-emerge but then become rare again after one or several years. The danger represented by a pest depends on the species and the host plant and its population number is the outcome of two groups of antagonistic factors: firstly, **biotic factors** (fecundity, number of generations per year, possibilities of developing on host plants in the region in question; secondly, **abiotic factors** (climate, competition for food, enemies such as parasites, predators and diseases).
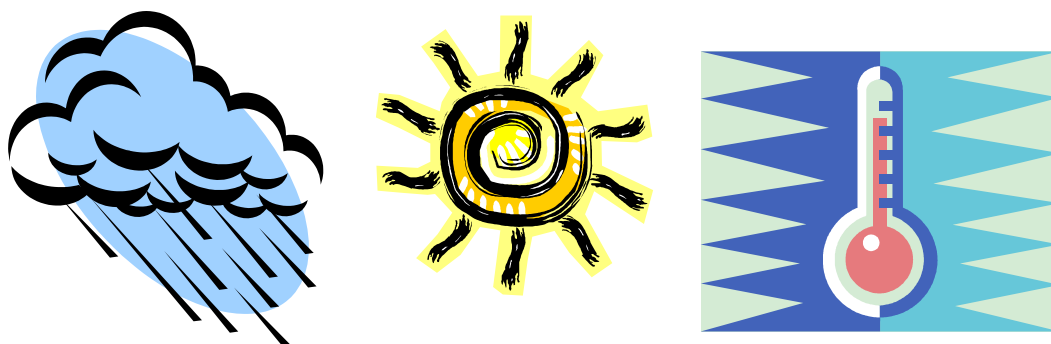
The abundance of rainfall, the date on which it begins, and its distribution have a direct influence on the pest, its enemies and on the plant. The role of temperature is less important than in temperate regions.

The greater or lesser abundance of a predator species therefore depends on the various parameters that are involved and often make estimating infestation in the long term very random and very tricky.

The presence of adventitious plants ('weeds') or new growth, at the edge of plots which are cultivated or even within a crop, may constitute a reservoir of infestation (viruses, fungal diseases, insects, acarids, nematodes etc.).
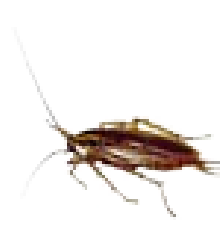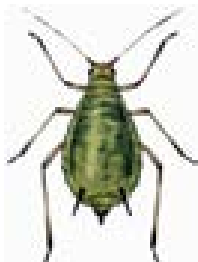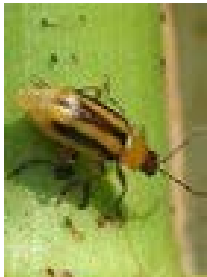
2.3. Biology and identification of insect pests

Insects belong to the branch of Arthropods characterized by individuals with a segmented body. The class of insects is remarkably vast. Nowadays, insects account for +/- 800,000 species (there are probably several million), that is 80% of animal species currently described. They occupy every environment since they can adapt to the most difficult conditions. Their prolific nature is remarkable.

The main pests for crops belong to different orders and sub-orders, which break down into families (See table below).

Main orders and families of pests

Orders	Characteristics	Families	Examples	Crops
Dictyoptera	Large, flat insects Prickles on the tibia Triangular head Spindly antennae Gnawing, strong mouth parts Light-avoiding	*Blattidae*	Cockroach or roach 	Pests in stored foodstuffs of all kinds
Orthoptera	Wings which can be placed on the top of the back Rear wings folded in a fan-shape Rear "thighs" inflated and suitable for jumping Chirping organs Gnawers	*Gryllotalpidae* *Gryllidae* *Acrididae*	Mole cricket Cricket 	Potato, millet, maize, sorghum and various cereals

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Orders	Characteristics	Families	Examples	Crops
Homoptera	Small insects Long mouth pieces (in stylet form), sucking Transparent membranous wings Polyphagous larvae and adults (injection of corrosive saliva, absorption de sap, transmission of viral diseases)	*Aphididae* *Aleyrodidae* *Jassidae*	Bug White fly Leaf hopper	Diakhatou (bitter aubergine), cabbage Tomato Aubergine, diakhatou, gombo
Heteroptera	Medium-sized insects Injecting-sucking mouth parts Front wings with one part chitinous and one part membranous	*Pentatomidae* *Miridae* *Reduviidae* *Coreidae*	Bug	Manioc, rice, banana, millet, sorghum
Coleoptera	Chitinised head with 2 large eyes Laterally-inserted antennae Chitinous front wings, encased over membranous rear wings which are the only functional ones Gnawing mouth parts Walking feet	*Chrysomelidae* *Cantharidae* *Coccinelidae* *Cerambycidae* *Scolytidae* *Bruchidae* *Curculionidae*	Chrysomelid Blister beetle Ladybird Longhorn beetle Bark beetle Seed weevil Weevil	Tomato Cucurbitaceae Peanut, pea Sweet potato

Orders	Characteristics	Families	Examples	Crops
Lepidoptera	Four wings covered in scales forming patterns which are often coloured Sucking tubes Nocturnal (spindly antennae) and diurnal (antennae in the form of a club) Phytophagous, leaf miners	*Tortricidae* *Pyralidae* *Noctuidae* *Pieridae* *Nymphalidae*	Codling moth Webworm Owlet moth Cutworm Defoliating caterpillars and army worms	Apple tree, apricot tree Tomato, cotton, melon Potato Cotton Aubergine Capsicum, chilli pepper
Diptera	Vast and varied order Stinging or sucking mouth apparatus 1 single pair of functional wings Complex wing nervation	*Nematocera* (short and ringed antennae: *Cecidomiidae, Agromyzidae*)	Cecidomyia Cabbage, carrot, mango fly Leaf miners etc.	Cereals Vegetables Fruit trees Citrus fruits

Insects possess some very specific characteristics. Like all Arthropods or Vertebrates, they possess a **rigid outer covering** in the form of a series of segments, which are modified to a greater or lesser degree. This tegument, consisting of strong, jointed plates **based on chitin,** is an external skeleton, which provides **protection against aggression from the environment.**

The body of the adult is divided into three very distinct parts: the **head**, which carries the mouth parts, the antennae and the eyes; the **thorax** to which the **three pairs of legs** characteristic of insects **and the wings are fixed**; the **abdomen** is **segmented and does not have any legs**. Their size can vary from a few millimeters to several centimeters in length.

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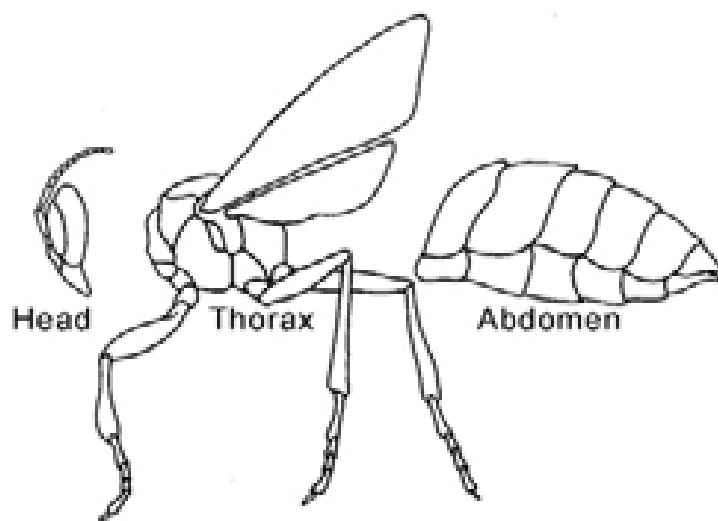
Diagrammatic representation of the body of an insect

In the course of their development cycle, insects undergo varying degrees of transformation called metamorphoses. Their successive stages are: **the egg**, **the larva**, **the nymph**, **the adult** (Figure below).
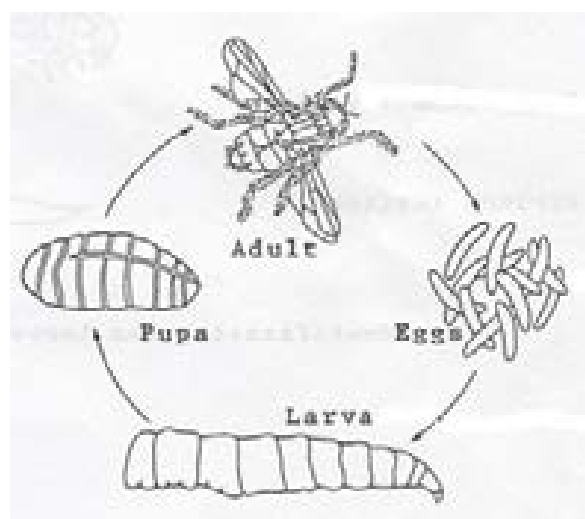
Illustration of the life cycle of an insect

Insects may cause damage at different stages but **the most harmful are generally the larval stages** (caterpillars which eat leaves, larvae which dig tunnels in the plant or in the fruits). At the adult stage, damage also occurs through the transmission of disease. It is their **method of feeding** which is responsible for the damage caused!
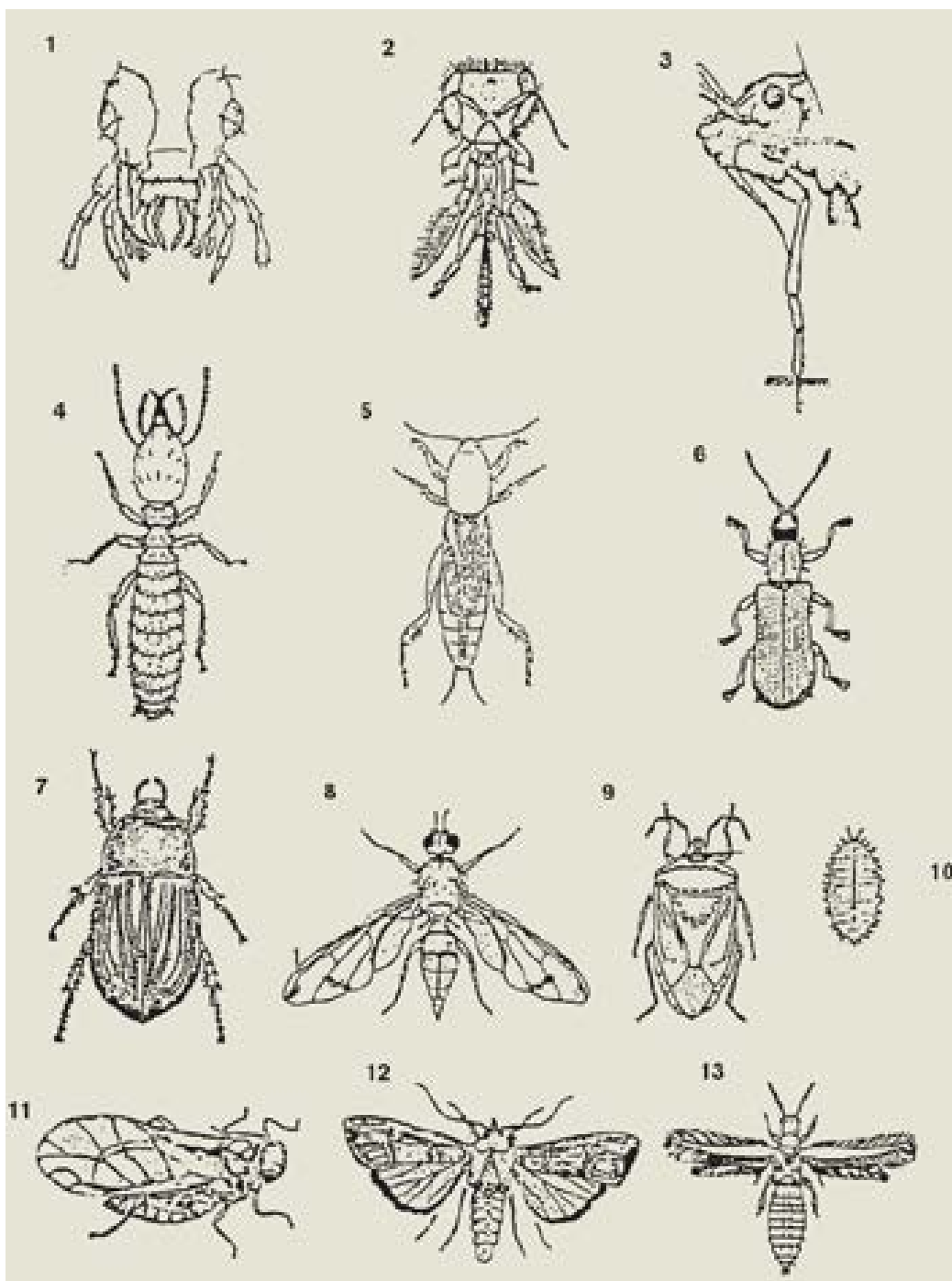
Mouth pieces and drawings of some insects that are important in agriculture (illustration of major orders of insect pests).

1) Grinding mouth apparatus
2) Licking-sucking mouth apparatus
3) Stinging mouth apparatus
4) Isoptera (termite)
5) Orthoptera (*Gryllotalpidae*)
6) Coleoptera (*Chrysomelidae*)
7) Coleoptera (*Scarabeidae*)
8) Diptera
9) Heteroptera
10) Homoptera (mealy bug)
11) Homoptera (greenfly)
12) Lepidoptera
13) Thysanoptera (Thrips)

The method of nutrition of the insect determines the appearance of the damage (stinging, biting, cutting etc.), hence the importance of also knowing the system, the feeding characteristics and the biology of the insects.

- In insects that undergo a **complete metamorphosis** (Coleoptera, Diptera, Lepidoptera), presenting *four stages which are clearly different one from another*, it is more often **the mobile larva stage** (caterpillar in the Lepidoptera, the maggot in Diptera) which **causes the damage** to cultivated plants, as the adults are not generally harmful to crops except in the case of certain Coleoptera.

- In insects that undergo an **incomplete metamorphosis**, *the larva already closely resembles the adult* except it is smaller and has no wings: **all the stages are mobile and can be harmful** to crops. This is the case with zig-zag leaf hoppers, greenfly and white fly (Homoptera), grasshoppers (Orthoptera) and thrips (Thysanoptera). It is possible to fairly easily identify the larvae of insects from these three main orders of pests.

Recognizing pests and an effective **diagnosis** are based on several elements including monitoring the crops and therefore observing the infestation directly in the field, looking for signs of attacks on the plants at all their stages.

Example of damage caused by insects:

Damage caused by leaf miners (tunnels)
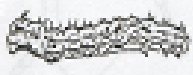
Colonies of mites invading leaves
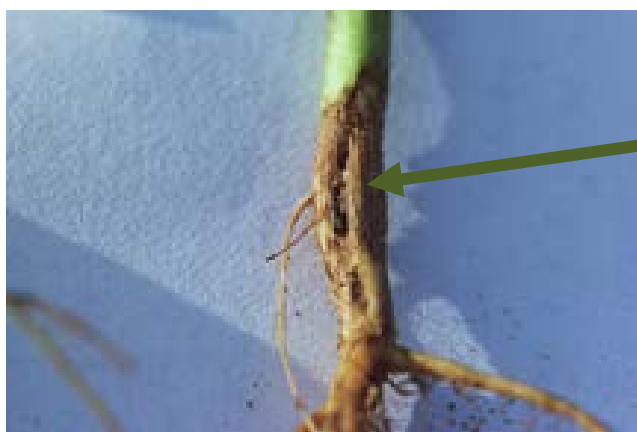
Fly maggot in the stalk of a bean plant

Identification of larvae of insects

Order	Types of larvae	Characteristics
LEPIDOPTERA: **'Typical' caterpillar**		4 pairs of false abdominal legs and 1 anal pair 3 pairs of legs on the thorax
'False looper'		2 pairs of false abdominal legs and 1 anal pair 3 pairs of legs on the thorax
COLEOPTERA: **'Larva'**		No abdominal legs 3 pairs of legs on the thorax
DIPTERA: **'Maggot'**		No legs (apode)

2.4. Mites (Acarids)

2.4.1. Characteristics of mites

Mites **are not insects** even though they belong to the division of Arthropods. They are part of the Class of *Arachnids*.

They generally have **four pairs of legs** instead of the three present in insects. They are very small (0.20-1 mm in length) and often invisible to the naked eye. They have neither **wings, nor antennae**; the head, the thorax and the abdomen are fused together.

Reproduction is sexual: it is oviparous or viviparous.

They undergo a complex development and often pass through 6 larva stages and 2-3 nymph stages; their development is considerably favored by hot, dry weather; heavy rain quickly reduces their population. The **larvae**, **nymphs** and **adults are mobile** and feed by sucking the cell content from the organs attacked resulting in malformations, discoloration, browning of leaves and generalized weakness of the plant (example of tomato **russet mite**).

Tissue boring mites often have **a real economic importance**. Their cycle is often complicated and the reproductive potential of these pests is very high because of their great fecundity.

Damage caused by an attack of mites

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Damage caused by an attack of mites

We find the main market garden pests within **three families of acarids**:

2.4.2. Tetranychidae

These mites have an oval, convex and sclerified body. They move quite quickly over the surface of the leaves. They also have 4 pairs of legs and reproduce continuously in hot climates.

The main species found on plants are: *Eotetranychus telarius, Tetranychus urticae, Tetranychus neocaledonicus, Panonychus ulmi, Paratetranychus pilosus*.

Tetranychus urticae
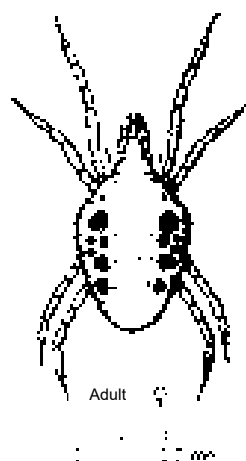
2.4.3. Tarsonemidae
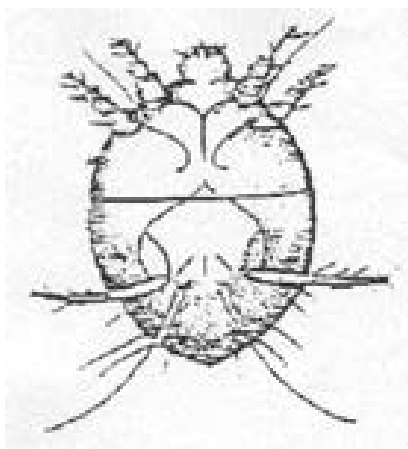
Acarids from this family also have an oval body and are smaller and barely visible. They also have 4 pairs of legs.

Common species are *Tarsonemus pallidus* and *Polyphagotarsonemus latus*.

Tarsonemus pallidus

2.4.4. Eriophyidae

These, on the other hand, have a long, narrow and soft body; 2 pairs of legs and are also **invisible to the naked eye**.
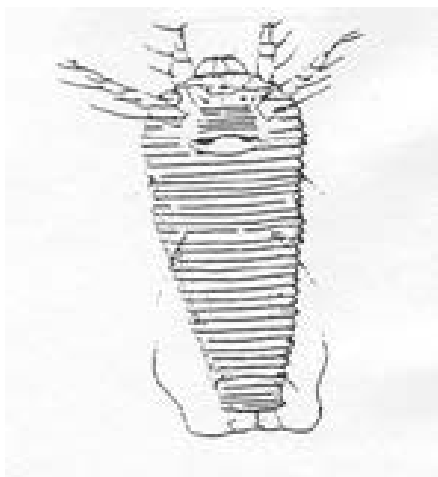
E.g.: *Aculops lycopersici,* tomato rust mite.

Among the species that are harmful to crops are: *Eriophyes pyri, Eriophyes vitis, Eriophyes ribis, Eriophyes tiliae*. Flour acarids *Tyroglyphus farinae* belong to this group.

2.5. Myriapods

Myriapods or **centipedes** are invertebrate arthropod animals whose body consists of similar segments, each of which have one pair of legs (chilopods) or two pairs (chilognathes or diplopods). They do not have wings and possess one pair of antennae. Males are rarer than females. Phytophagous species can be found in **three orders**:

2.5.1. Lulidae

These are long and rolled up into a spiral; the body has over 30 segments. These pests **destroy sowed seeds before harvesting** by devouring the kernel by penetrating the teguments of the seed at the hilum. They can damage the seedling by taking away food. These lesions can give rise to the development of micro-organisms, resulting in the death of the seedling.

Diplopods are numerous if the previous crop has been a fallow field of elephant grass (*Pennisetum purpureum*), a crop of peanuts or rain-fed rice.

2.5.2. Polydesmidae

Their bodies have 20 rings. The harmful species *Polydesmus angustus* **attacks seedlings** of bean, carrot, onion etc. Avoid sowing wheat after maize, sorghum on wet land.

2.5.3. Symphylae

These are myriapods with 12 pairs of legs. The *Scutigerella immaculata* species is very harmful as it **devours seeds** of maize, bean, broad bean, pea and cucumber. Avoid using manure containing straw, which encourages the pest to reproduce freely.

2.6. Plant parasitic nematodes
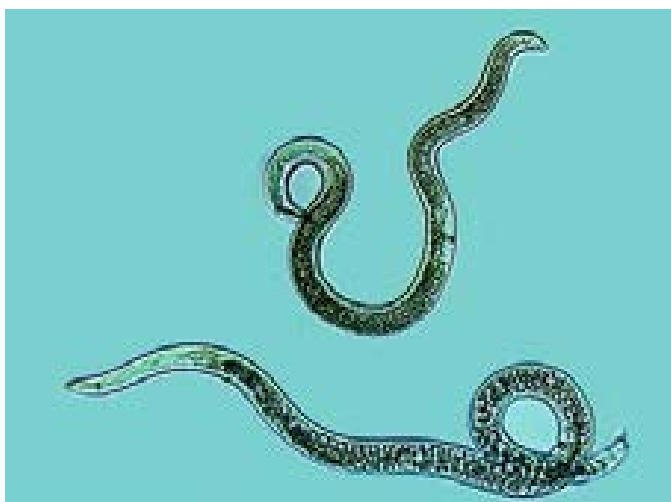
Nematodes are **microscopic worms** usually long and cylindrical (*nema* in Greek = hairs), without a clearly defined head, with bilateral symmetry contained in a fairly resistant cuticle which is decorated or ringed.

This **girdling is completely superficial** and does not correspond to any division inside the organism, unlike other worms (*annelidae*).

The size of the nematodes is very variable: The horse ascaris can be as long as 30 cm, with some species reaching a meter in length, although this is not the case with phytophagous species of nematodes, whose diameter varies between 10 and 40 microns and whose size oscillates between 200 microns and 1 cm.

The sizes and diameters vary a great deal depending on the stage (larva or adult) or the sex of the animal. These animals are therefore small and difficult to detect without accurate observations (rarely visible to the naked eye, they require special detection techniques).

Their body can be considered to be **three tubes slotted** into one another: an external sleeve or cuticle, a digestive tube and the reproductive organs.

The **first tube** is an external sleeve comprising the external cuticle, the epidermis and the muscle system (4 longitudinal, muscular sleeves). We can also distinguish the head of the animal, the cephalic capsule where the cuticle is thicker; the head is flattened, more or less truncated or slightly elongated. In nematodes we can talk about the hydrostatic skeleton; there is a high pressure inside the body that keeps the body turgescent. The cuticle must therefore be sufficiently thick and inelastic to resist this internal pressure.

The **second tube** basically consists of the digestive tube; the digestive system is simple and consists of the following organs: mouth, often surrounded by sensorial bristles or papillae and chemo-receptive organs (amphids). After the mouth comes the buccal cavity with a stylet of varying lengths, the esophagus with the three perioesophageal glands and the median bulb. Lastly comes the intestine, which ends in the rectum and the anus.

Alongside the digestive tract, **the third tube** or general body cavity holds the gonads (reproductive system). The females have 1 to 2 'ovaries'; the vagina is located either midway down the body (in a ventral position), or in the terminal part of the body (the position of the vulva is one way to recognize the genders). The nervous system is

rudimentary; a ring of nerves surrounds the esophagus. The nerves leave here and make their way through the epidermis. There is no circulatory system.

The evolutive cycle of all phytophagous nematodes involves **five different stages**: four larva stages which end with casting the skin (L1, L2, L3 and L4) and an adult stage. Between stage L4 and the adult stage the sexual organs appear (ovary[ies] and spicules). With the exception of sedentary nematodes, in other species, the larvae stand out mainly because of their respective sizes; but, apart from the sexual organs, they possess all the other characteristics of the adult nematodes, meaning that the specialist can identify them.

The systematic naming of nematodes has recently been revised so it is unstable and constantly called into question. Phytoparasites are limited to 15 families containing 111 types. Nematodes form one class among the Nemathelminthes.

The class of Nematodes is divided into two subclasses:

- The subclass of **Phasmidia** contains the order which interests us: the TYLENCHIDA. This order contains nematodes whose development has reached a higher stage than that of the RHABDITIDA whose representatives are saprophages, bacteriophages, mycophages, phytophages.
  Examples:
    - *Tylenchus: fungus parasite*
    - *Anguina: parasite of the respiratory organs*
    - *Ditylenchus: parasites of the aerial parts of plants and bulbs.*
    - *Belonolaimus (migrating ectoparasites of roots)*
    - *Scutellonema*
    - *Helicotylenchus*
    - *Rotylenchus*
    - *Pratylenchus (P. vulnus, penetrans, thornei, neglectus, etc.)*
    - *Radopholus (R. similis)*
    - *Globodera (G. rostochiensis, punctata, pallida)*
    - *Heterodera (H. schachtii, avenae, carottae, etc.): females forming cysts*
    - *Meloidogyne (M. arenaria, javanica, hapla, incognita, javanica, etc.) : females forming galls*

- The sub-class of **Adenophorea** (= **Aphasmidia**) contains in particular the order of DORYLAIMIDA whose representatives do not have any phasmids (sensory organ) and are (the only nematodes) **vectors of viruses**:
    - Longidoridae: *Xiphinema and Longidorus*
    - Trichodoridae: *Trichodorus and Paratrichodorus*

The nematode, guided by its amphids (chemo-receptors), approaches the root and with its stylet perforates one of its cells. It injects it with secretions from the esophageal gland: these lysate the content ('digest' it) which is then aspirated by the lumen of the stylet towards the intestine via the median bulb (which acts as an aspirant-delivery pump). This is how all migrating nematodes feed.
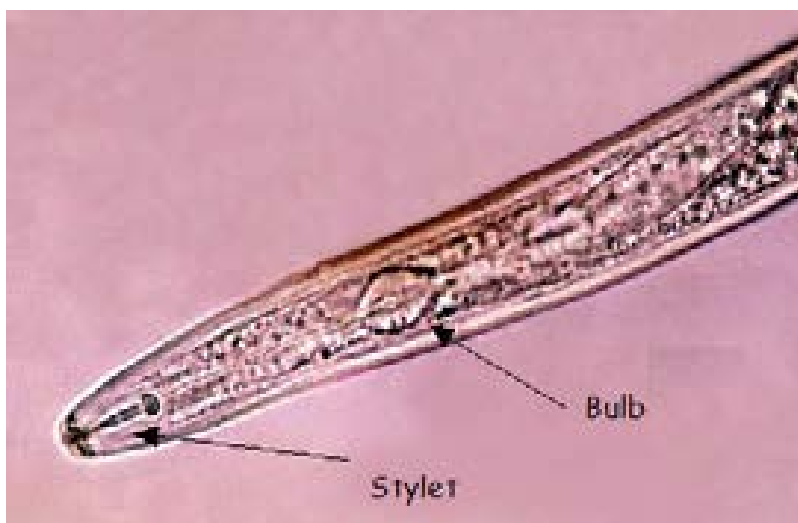
Front end of a plant parasitic nematode: the presence of a stylet is characteristic.

Secretions from the nematode can also lead to the formation of special nourishing structures (case of sedentary nematodes – e.g.: Heterodera or Globodera), or even galls on roots (e.g.: Meloidogynus).

It is rare to be able to link a particular symptom to a nematode disease. An accurate diagnosis – through extraction and identification – is always essential.

A soil analysis is requred in order to identify and count the number of nematodes per gram of soil (**determine whether the threshold of infestation has been crossed**).

In the case of nematodes which cause galls (*Meloidogyna*), counting the **number of galls** on the roots is sufficient (and possibly masses of eggs).

In the case of nematodes with cysts (*Heterodera* or *Globodera*), counting the **number of cysts** present in the soil is not sufficient because some of the cysts may be empty. In the case of an old infestation of the plot, the number of larvae which may really infest the plants will be less than that estimated by counting the cysts (over-estimation of the risk).

From the point of view of their behavior towards plants, nematodes can be separated into **two categories** of unequal importance:
- firstly, those which spend their whole cycle in the ground and only attack the roots. These are the most numerous;
- secondly, those which attack the aerial parts of the plants: bulbs, stalks and sometimes leaves.

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➢ **Nematodes of the roots**: there are external parasites which never penetrate the inside of roots, but are content with damaging them with their stylet (migratory or sedentary ectoparasites) and internal parasites which dig cavities into the cortex of the roots by destroying cells and feeding on their content and who spend their cycle entirely or partly in plant tissues; they are migratory (if all the stages - larvae and adults – remain vermiform in general) or sedentary (if the females swell up and remain fixed to one place where they take their nourishment): These are sedentary endoparasites. In these nematodes, the penetration of the plant takes place during the first stages of development (usually at the second larva stage or D2). The larvae lodge themselves in the parenchyma and establish themselves on a feeding site by inducing in the host the formation of transformed cells, which are larger and polynuclear, and which are used to supply the nematode with the necessary nutritional elements ('giant cells' from the syncytium). After the last casting, the female gets fatter and fatter which makes it immobile; it changes into a cyst (**nematodes with cysts**, *Globodera* or *Heterodera*) or triggers the formation of galls on the roots **(nematodes with galls**, *Meloidogyne*).

**Root infested with galls
(*Meloidogyna* spp.)**

The cyst can survive for a long time in the ground, even in the absence of host plants. Secondly, even under favorable conditions, a fraction of the cysts (between 10 and 40%) do not hatch, which maintains a potential infestation in the ground.

➢ **Nematodes on the aerial parts**: certain species of phytophagic nematodes are capable of migrating out of the ground and of attacking the aerial parts of the plants. They move to the surface of the stalks and the leaves in the film of water which covers them when it rains or there is a dew. When this film of water disappears, they switch to a slowed down state of life (anabiosis) and only begin their activity again when it reappears. An example of this is:

  • the nematode of the stalks and bulbs (*Ditylenchus dipsaci*)
  • nematodes of the leaves (*Aphelenchoides* spp. and *Anguina tritici*, agent of wheat 'blight'): *Aphelenchoides besseyi* (on rice).

Following attacks, generally we only see **zones where the vegetation is less dense, smaller plants split into patches of unequal size**. Often **the infested plants wither in the sun** as water absorption is slowed down by the change in the root system. In the root system, the damage ranges from surface necrosis, due to stings from ectoparasitic nematodes, to complete deformation of the root through the production of galls through the action of endoparasites (example: the various *Meloidogyna*). Water absorption is very often impaired. Assimilation of potassium is reduced, as well as that of sodium, at times.

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Damage caused by Radopholus similis*: infected seedlings fall in the wind, municipality of Ajoupa Bouillon, Martinique.*
(Photo IRD - Patrick Quenehervé).

Interactions between the nematodes and the pathogenic organisms exist: synergic effect between the virus and nematodes; action of *Globodera rostochiensis* aggravated by the presence of *Rhizoctonia solani* or *Verticillium dahliae*, etc. Varieties of tomato resistant to *Fusarium oxysporum* f. sp*. lycopersici* became sensitive to this pathogen in the presence of *Meloidogyne incognita*. *Meloidogyna* seem to break down resistance by causing profound changes in the physiology of the plant: these are likely to predispose it to attacks of *Fusarium*.

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2.7. Rodents and harmful birds

Essentially a few mammals and species of bird. Among the harmful mammals, we need to make a distinction between the occasional ones (members of the deer family, boars, elephants, rabbits) and those we need to eradicate in order to protect crops or harvests (**rodents**: field voles, field mice, rats).

Birds may become dangerous on account of their numbers and justify implementation of means of protection for crops.

2.7.1. Rodents

In intertropical zones, the huge variety of rodents amplifies the potential danger they present to crops. Many rodents eat the same food as humans and so are their direct competitors. Everywhere, crops are attacked by rodents and losses can be high; damage can be occasional, or generalized. We need to remember that some rodents may be vectors of diseases with serious effects for humans.

It is **essential to identify the rodents** responsible for agricultural damage as knowing about the characteristics of each species means we can conduct a rational struggle (diurnal, nocturnal animals, granivores, herbivores, land animals, tree animals, etc.).

We also need to **be aware of the reproductive periods** of these small mammals and the breeding cycle in order to be able to intervene with maximum effect avoiding any wastage. That is why a basic understanding about the biological system of these small mammals is essential to anyone wanting to control them on the land.

The order of rodents contains over 1,700 species of Mammals which is 40% of the 4200 known mammal species. The most common and most abundant rodents on the African continent belong to 3 families: the **Sciurideae**, the **Gerbillideae** and the **Murideae**.

Thick tail
- Length of head + body > 20 cm → **SCIURIDAE (squirrels)**
- Length of head + body < 15 cm → **GLIRIDAE (dormice)**

Rodents which attack crops

No hairs or few scattered hairs on tail
- Animal with a russet back and flat stomach, large, round, prominent eyes, tail with some hairs and a bushy end → **GERBILLIDAE (gerbils)**
- Grey or brown animal generally with a grey stomach, small eyes, scaly-looking tail ringed with a few scattered hairs → **MURIDAE (rats & mice)**

The Sciurideae (squirrels) are strictly land animals which burrow, such as the 'striped ground squirrel', *Xerus erythropus* and other tree-inhabitants like the Gambian sun squirrel, *Heliosciurus gambianus*

The Gerbillideae are mainly present in the savannahs of Sudan and the Sahel as well as in the deserts. Their pelt is light-colored, their eyes relatively large and their legs long. The main types represented in Western Africa are *Gerbillus*, *Taterillus* and *Tatera*.

The Gerbillus

The Muridae group together 'rats' and 'mouse'; some 'rats' are cosmopolitan such as *Rattus norvegicus* or the Brown rat, and the *Rattus rattus* or black rat.

Rattus norvegicus

Rattus rattus

The problems posed by rodents in crops are mainly due to the way they feed. The damage can take various forms that are both **quantitative** and **qualitative**, with some rodents selecting a particular organ of a cultivated plant; on the other hand, other species only appear after the appearance of a clearly determined stage of the plant: for example, tomatoes are only eaten after they have ripened. Most tropical crops can be attacked but economically significant damage relates to cereals, palm trees, sugar cane, newly planted market garden crops: tomatoes, peppers, melons etc.

The main methods of control recommend destroying rodents at the time of year when their population is lowest. In tropical regions with a single rainy season, the most favorable period is at the end of the rainy season, at the beginning of the agricultural campaign. In regions with two rainy seasons, rodents reproduce continuously. Preventive treatment is rarely undertaken in dry regions for material and psychological reasons, the farmer not acting until he sees the first signs of damage two or three months later.

Curative treatment is usually carried out with rodenticides on bait (cereal grain, artificial support, etc.) which act on the blood clotting of these small mammals. There are also asphyxiating gases that can be used on rodents in their burrows.

Indirect control is possible by modifying the environment by looking after crops, by destroying all the wild plants and any potential shelters for the rodents, making the environment hostile to these animals around the edges of the fields: keeping embankments and watercourses permanently clean. Farmers are also advised to follow the crop calendar in order to avoid the combination of a sensitive stage of the plant and high densities of rodents. Finally, the fields must be protected using metal, electrified or flexible plastic anti-rat barriers, or screens, and the population of natural predators must also be encouraged (diurnal birds of prey, nocturnal ones such as owls, surfbirds such as herons, egrets and cattle egrets).

2.7.2. Birds

In many tropical zones all over the world, birds (especially seed eaters) cause losses which can be considerable to cereals and to fruit and vegetables. The extent of this plundering and the identity of those responsible are not always properly understood.

Relatively few families of birds include pests, but families such as **Sturnids** (starlings) or **Ploceidae** (weaver birds) ravage almost all cereal crops and market garden crops (tomatoes, peas, beans, etc.). These crops (flowers, fruits) are attacked by starlings and sparrows often because of the attraction of irrigation water.

The main species of pest are the red-billed quelea *Quelea quelea*, the black-headed weaver *Ploceus cucullatus*, the golden sparrow *Passer luteus* and the red-headed quelea *quelea erythrops*

Ploceus cucullatus

Quelea erythrops *or Red-billed quelea*

Passer luteus *or golden sparrow*
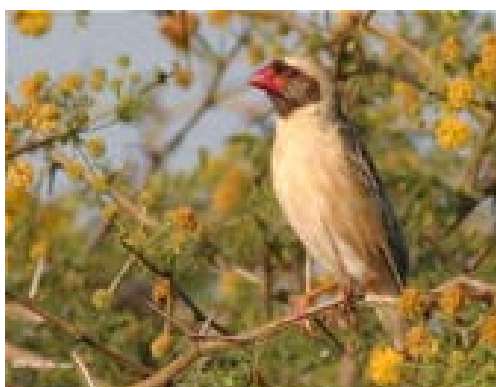
Quelea quelea *or black-headed weaver*

The struggle to control birds has always existed. Traditional control is characterized by cutting down trees carrying quelea nests in order to protect harvests in advance against attack by young birds. Having children look after the fields by throwing projectiles at birds or frightening the birds with noisy objects is also used. Using physical protection such as nets or fiber barriers is recommended. The cleanliness of the fields and the absence of perches near the fields or in them reduce attacks by birds. Using auditory or visual repellents and traps remains the best means of protection.

Without wishing to overlook the fact that significant occasional and/or seasonal damage can be caused by birds, **it is also helpful to remember the essentiel role played by birds as crop helpers**!

Birds consume considerable quantities of insect pests, and birds of prey limit the populations of some rodents, etc. So protecting their habitat is often beneficial to the farmer.

Chapter 3

Development and identification of plant diseases

3.1. Introduction

An important yield-reducing factor: diseases that destroy tissues needed for the photosynthesis of plants!

Disease is an **anomaly in the structure** or **the function** of a plant caused by a continuous irritating factor (causal agent or **pathogenic agent**). This means that, contrary to an injury, it is not a process that appears instantaneously.

Diseases can be divided into two main groups: **infectious** (or biotic) and **non infectious** (or abiotic).

3.1.1. Infectious (biotic) diseases

Infectious diseases are caused by micro-organisms (**fungi**, **bacteria**, **viruses**, mycoplasms and rickettsias) which can be transmitted by various vectors (wind, water, contact between plants, nematodes, insects, etc.) to other healthy plants, or be present in the soil, thus causing disease in the new **sensitive hosts**. A pathogenic germ is therefore a living organism, which may be virulent, *i.e.* which may cause a disease in the plant.

Infectious diseases in plants only develop if the following **3 conditions** are fulfilled:
- the host plant must be **sensitive** (and/or 'sensitized'),
- the pathogenic agent must be **virulent** and capable of attacking the plant,
- the **environment** must favor the development of the disease (*i.e.* favor sensitivity and virulence).

Conditions influencing the development of diseases
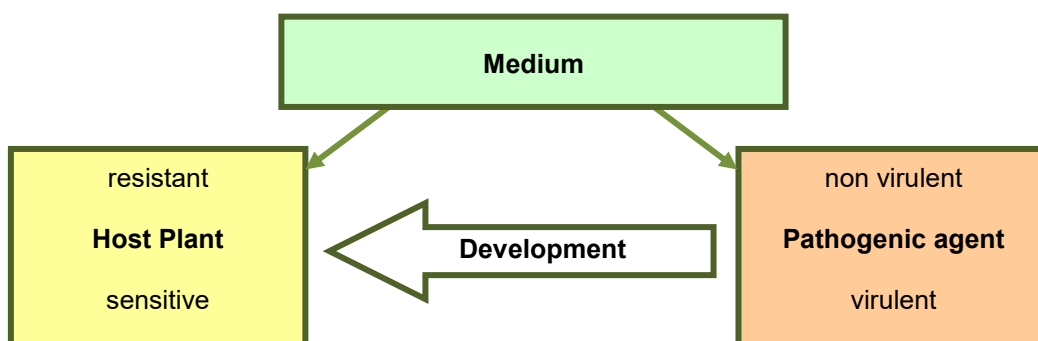
❑ **Sensitivity (or resistance) of plants**

The sensitivity of a plant depends on 2 parameters:
- the **conditions (the state) of the cells and the tissues** of the plants prior to the infection: the factors of **passive resistance** include the resistance of the cell walls (and the cuticles) which can make it difficult or impossible for the pathogen to penetrate from the exterior and propagate inside the tissues. The viability of a pathogenic agent also depends on the metabolic activity of the cells. Passive resistance can be reinforced by improving cultivation methods.
- **the ability of cells to react** to a pathogenic agent in a particular way: **active resistance** only appears from the point when the infection begins. Two types are well known and apparently widespread in nature:
  - **a plant's hypersensitivity** to an infection, which results in rapid necrosis, isolation of the affected cells, and rejection of the source of infection. By selecting a particular variety of plant to encourage hypersensitivity, the factors of output, crop quality, etc. must be taken into consideration (e.g.: resistance to attacks from Fusarium, but also nematodes).
  - **induced resistance**, another form of response to the infection by the plant, with the production of phytoalexins which have a fungistatic or fungicide activity (these phytoalexins, which accumulate in the tissues, may be toxic for consumers).

❑ **Virulence of the pathogen**

The most important factor of the virulence of a pathogen is **its ability to produce enzymes and toxins**, and to transmit them to the plant. Depending on the type of disease, the infection may take place:
- through the intact cuticle,
- or by mechanical penetration,
- or through cuts,
- or through natural holes in the plant surface: stomata in the epidermis, lenticels of the phellem (cork), hydathodes (aquiferous stomata) at the edge of the leaf.

❑ **The environmental influence**

Factors in the surrounding environment (temperature, light, nutritional elements - and particularly the nitrogen available in the ground - , density, bearing of the plants, etc.) strongly influence both **the plant's sensitivity** and **the virulence of the pathogen**. None of these factors influences all plants in the same way. This is why it is important to familiarize oneself with these environmental effects which encourage the development of a specific disease considered significant in the region concerned.

3.1.2. Non-infectious (abiotic) disorders

Non-infectious diseases are caused by a range of unfavorable environmental factors, nutritional, mechanical or other (e.g.: soil compaction, air pollution, herbicide post-effect, unsuitable fertilizer, nutritional shortages, excessive manure, unsuitable irrigation, apical end rot on tomatoes, sunburn frequent on the melon for example etc.) and cannot be passed on to healthy plants.

*Apical rotting
(or 'Blossom end rot')
in the tomato.
This affliction is caused by insufficient and irregular irrigation, which disrupts the assimilation of calcium.*

Among the non-infectious diseases which are harmful to plant development and production, affecting the quality of products, the **deficiencies in major nutritional elements** (N, P, K, Ca, Mg) or minor ones (the 'oligo-elements') play an important role.

Examples of deficiencies on bean

Phosphorus deficiencies manifest themselves in the form of a dark green color of the leaf blade, an upright stance and the browning of old leaves followed by falling.

Potassium deficiencies cause a dark green color and inter-rib discoloration, with the base of the leaves curling downwards
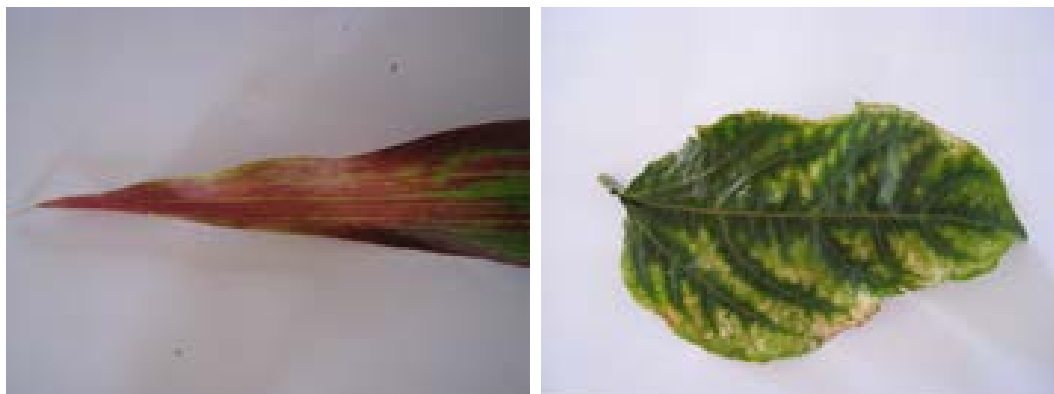
Examples of manifestations of deficiencies

Some elements present in the soil can be clearly toxic for crops (e.g.: chlorides in the case of the green bean). Healthy plants and production therefore depend on **fertilization suitable** for the crop, added at the right time (it is often a good idea to divide up doses) and in a suitable form (chemical nature of manure, solubility, etc.) (e.g.: avoid manure containing KCl on beans).

3.2. Diseases caused by pathogens

Even though we use a whole range of ways to control them, plant diseases due to fungi, bacteria and viruses still cause significant losses. In industrialized countries, these **rise to almost 40%,** involving every stage in the food chain from production to industrial processing and commercialization. Their level is even higher (over 50%) in ACP (*African, Caribbean and Pacific*) countries which pay the heaviest price for this wastage of food resources. Hence the need to understand the epidemiology and biology of the various pathogens in order to be able to **make the most accurate diagnosis** on the basis of the symptoms observed in the field or in the laboratory.

Prior knowledge of main diseases known in a given geographical zone

Entry of data relating to circumstances surround onset

Formulation of a hypothesis relating to the primary cause of symptoms
- Abiotic disease
- Biotic diseases
- Viruses, viroids
- Bacteria, phytoplasma
- Protozoans
- Fungi
- Angiosperms

Possible transfer to laboratory to validate the hypothesis

Koch's postulates if a case of an unknown agent

Identification of the cause

*Main stages of diagnosing a plant pathogen
(Source: P. Lepoivre. Phytopathologie – Plant diseases 2003)*

The two figures show, respectively, the main stages of diagnosing a plant disease as well as all the elements to be analyzed when diagnosing a disease.

Topographic distribution of diseased plants

Species and variety cultivated

Growing methods:
• working the soil
• sowing system
• mineral fertilizer
• organic fertilizer
• amendments
• pH of the soil

Parameters relating to crop rotation, establishing the crop (dates, sowing, etc.), for irrigation

• Location of the plot
• Properties of the soil
• Climatic conditions
• Spatial distribution of diseased plants

Plant health treatments

applied :
- Active substances
- doses/ha
- methods and dates of application

All the elements to be analysed in the diagnosis

3.3. Fungi responsible for plant diseases

3.3.1. General characteristics of fungi

Fungi form an **extremely heterogeneous group** whose main shared characteristic is their heterotrophic nutrition through absorption. This can take the form of saprophytism, parasitism or symbiosis.

Uni- or pluri-cellular fungi come under the kingdom of *Fungi* which consist, on the one hand, of four phyla (***Chrytidiomycota, Zygomycota, Ascomycota*** and ***Basidiomycota***), and *secondly*, the group of **Deuteromycetes** (fungi without sexual reproduction). The number of fungal species is estimated at 1.5 million, approximately 100,000 of which are described. Among these known species, **over 10,000 are responsible for plant diseases.**

The vegetative organ is known as the **thallus** which may be unicellular (yeasts) or filamentary. All the filaments or **hyphae** form the **mycelium**.

The filamentous thallus is able to diversify into different organs: the **appressoria** or pressing and penetration organs in the form of a sucker, the **houstoria** forming in the plant cell and taking up nutritional substances and exchanging different molecules and the **loops** which capture prey (fungi which are predators of nematodes).

Most fungi have **two methods of reproduction**: **asexual** (or vegetative) reproduction and **sexual** (or perfect) reproduction.

- *Sexual spores* are frequently able to store pathogenic fungi during periods of plant growth stoppage in the cold or dry season and constitute the sources of primary inoculum (infection) ensuring the recurrence of the epidemic.
- *Asexual reproduction* is rapid and repetitive; it is able to produce a large number of spores ensuring the secondary extension of diseases during the explosive development of epidemics in crops in which the plants are growing actively (Table).

Characteristics of forms of sexual and asexual reproduction associated with the storage and spread of fungi (Source: P. Lepoivre. Phytopathologie. (Plant diseases) 2003) 2003)

Dispersion spores which are asexual in origin	**Survival** spores which are sexual in origin
• Extremely variable (transporting) forms of spores • Produced in very large numbers • Small size • No reserve substance • No dormancy	• Limited number of forms • Produced in small numbers • Large size • With reserve substance • Dormancy

3.3.2. Taxonomic characteristics of fungi and main fungal diseases (*according to Lepoivre, 2003*)

There are different classification systems, one of which is **based on morphological characteristics** which go right down to the species and the specialized form ('f.sp.') (This indicates a parasitic specificity of the fungus towards a particular host species: for example *Fusarium oxysporum* f.sp. *Lycopersici*, a fusarium pathogenic for the tomato). There are also molecular classifications obtained by **analyzing the genome** of the pathogens.

Fusarium oxysporum on the tomato (Photo P. Jones)

Taxonomic key for fungi responsible for plant diseases:

Characteristics: *Phyla:*

```
Compart-
mentalised ──── Endocellular
(or plasmodial)     plasmode      ──▶ PLASMIDIO-
                    (parasite)         PHOROMYCETES

                    Presence of
                    biflagellate  ──▶ OOMYCETES
                    zoospores

          Non       Presence of
          compart-  uniflagellate ──▶ CHRYTIDIOMYCETES
          mentalised zoospores
          hyphae
                    Absence of
                    zoospores     ──▶ ZYGOMYCETES

Unicellular or
filamentous
thallus             Spores of
                    sexual origin
                    that are 8 in  ──▶ ASCOMYCETES
                    number in an
                    ascus
                    (ascospores)

          Compart-  Spores of
          mentalised sexual origin
          hyphae    that are 4 in  ──▶ BASIODIOMYCETES
                    number on a
                    basidium
                    (basidiospores)

                    Spores of
                    asexual origin ──▶ DEUTEROMYCETES
                    or
                    sterile mycelium
```

A simple observation, under the microscope, shows whether or not the thalli and the hyphae are compartmentalized.
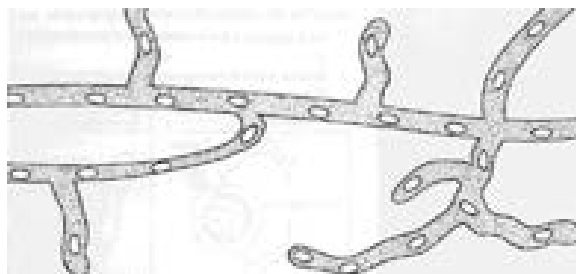
Non-compartmentalized hyphae
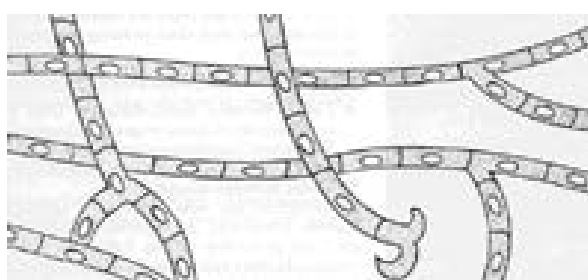
Compartmentalized hyphae

*Detailed characteristics of the various fungi
and the main fungal diseases*
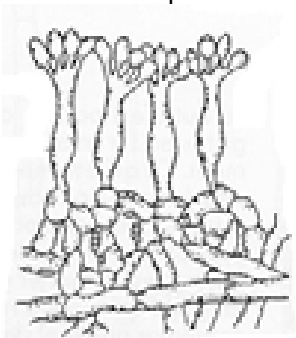
Phyla	Characteristics	Plant parasites (examples)	Diseases (examples)
Plasmodio-phoromycota	Obligate parasites of underground organs and stems of plants (hypertrophy and hyperplasia of infected tissues) with sexual reproduction. Dissemination by zoospores (irrigation), contaminated tools, soil, organs.	Fungi from the species *Plasmodiophora Polymyxa and Spongora*	Sugar beet rhizomania (transmitted by *Polymyxa betae*)

Oomycota	Asexual reproduction (zoospores) and sexual reproduction (oospores). Saprophytes in the soil and seedling parasites. Preservation in soil	Fungi from the class of Oomycetes in which 3 main families of Peronosporals are found: Pythiaceae, Peronosporaceae and Albuginaceae.	Damping off (*Phytium* sp.) Potato mildew (*Phytophtora infestans*). Mildews (*Peronosporaceae* family) White rust (families of *Albuginaceae*).
Chrytidiomycota	Mobile spores: monoflagellate zoospores	Fungi from the class of Chrytidiomycetes, 2 species of which (*Olpidium* and *Synchritium*) are a combination of plant parasites.	Viruses
Zygomycota	Division of the class of Zygomycetes into 3 large orders: Mucorales, Entomophthorales and Glomales. The Mucorales are saprophytes, on fruit, with sexual and asexual reproduction (sporanges disseminated by the wind) The Entomophthorales are animal parasites (insects, such as aphids for example).		Rotting on fruit (Mucorales)

Ascomycota	Sexual reproduction (asci). Classification based on asci, ascocarps and ascospores. Ascospores Parasites internal to the aerial apparatus and fruits (Order of Taphrinales). Obligate parasites developing on leaves, young shoots, flower buds and fruits (Order of Erisyphales). Saprophytic phase in decomposing plant debris (Genera *Monilinia* and *Brotryotinia*)	Fungi from the genera *Taphrina, Erysiphe, Claviceps, Mycosphaerella, Venturia, Sclerotinia, Monilinia*	Distortions of organs through hyperplasia and hypertrophy (curling leaves, witch's broom branches, pockets in fruits) caused by the genus *Taphrinia.* Mildew or whites (Order of Erysiphales). Ergotism of grains (*Claviceps purpurea*). Rotting and mummification of fruits (*Monilinia and Botrytis* spp.)
Basidiomycota	Production of basidiospores Obligate parasites attacking leaves and stems (rusts and smut on cereals). Basidiospores	Fungi from the class of Uredomycetes (Order of Uredinales), and Ustilaginomycetes (Order of Ustilaginales)	Rusts (Order of Uredinales), Smut (Order of Usteginales),

| Deuteromycetes | « Imperfect » fungi with asexual reproduction (spores generated by mytosis).

Parasites of leaves and stems of annual or perennial plants.

Formation of conidia dispersed by the wind, water, insects and tools. | Fungi in the class of Hyphomycetes, Coelomycetes and Agonomycetes | Malformations of organs, maculicole agents (on foliage).

Damping off (anthracnosis of the bean and pea (if transmitted by seeds of annual plants).
Cankers (penetration through damage).

Vascular diseases (Fusarium spp., Verticilium spp.) on protected crops, market garden and ornamental plants, cotton, banana tree and forest trees. |

The extended storage of fruits and vegetables prior to their consumption poses numerous and specific plant health problems. Amongst the fungi responsible for post-harvest diseases, we note wound **parasites** (entering through accidental breaks in the cuticle), such as *Botrytis cinerea* and *Penicillium sp.*, and **latent parasites** entering through natural openings (such as lenticels and only showing symptoms after a latency period which varies in length).

> The contamination of fruits or vegetables by wound parasites may occur in the orchard or field but mainly come from an **inoculum present in the storage premises** (in the collection crates, on the storage equipment and in the rooms at the packaging station).

Contamination of fruit by latent parasites **occurs in the orchard before the fruit is gathered** and is caused by conidia which come from infectious tissues on the fruit trees themselves (cankers and necrosis on the branches).

The fungi present on the fruits may produce toxins ('**mycotoxins**') which pose a significant health problem to the consumer (e.g.: the 'aflatoxins', mainly released by *Aspergillus flavus*) as many are recognized carcinogens. The fungus *Alternaria* is often present on fruits and vegetables and may release mycotoxins.

3.3.3. Parasitic cycle of plant pathogenic fungi

For an epidemic to develop, a number of events must take place. The epidemic begins with a **primary inoculum** which is responsible for the primary infection of the crop (e.g.: **infected tubercles**). The tissues which are infected at that point in turn become infectious thus triggering the epidemic dynamic in the course of which the basic cycle will repeat itself a number of times.
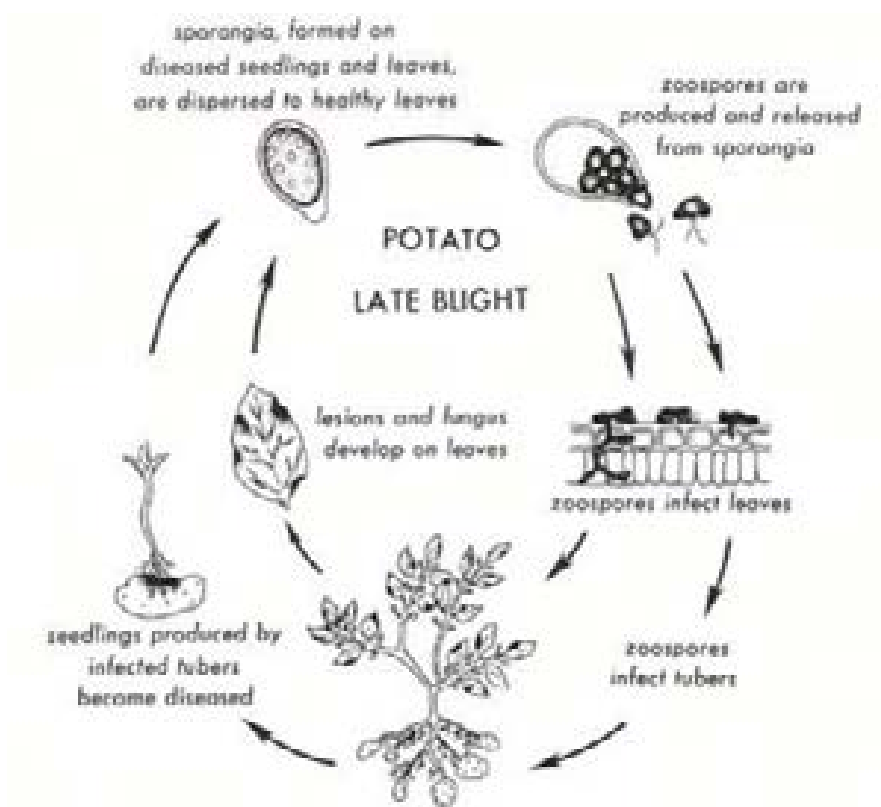
Hence, the progress of the epidemic requires the existence of an inoculum **conservation phase**, followed by a succession of **phases of infection** and **phases of dispersion**. If the disease is to be controlled, this cycle must be interrupted!

❑ **Storage**

A number of plant pathogenic fungi have specialized structures which are resistant to unfavorable environmental factors. Some form **sclerotia**, whose germination produces the mycelium or the sexual organs of carpophores; others form **rhizomorphs** which develop from an infected site capable of colonizing new hosts or new substrates. Finally, the **spores** which are sexual in origin (and sometimes asexual in origin) may also constitute forms for storing the inoculum in unfavorable environmental conditions. The

resistant spores of Plasmodiophoromycota, the oospores of the Oomycota and the chlamydospores of *Fusarium oxysporum* are **capable of surviving in a latent state** for numerous years **in the soil** in the absence of a host plant. The teliospores of Basidiomycota also ensure the conservation of the parasite between two or several growing seasons.

Basic cycle of a disease caused by plant pathogenic fungi
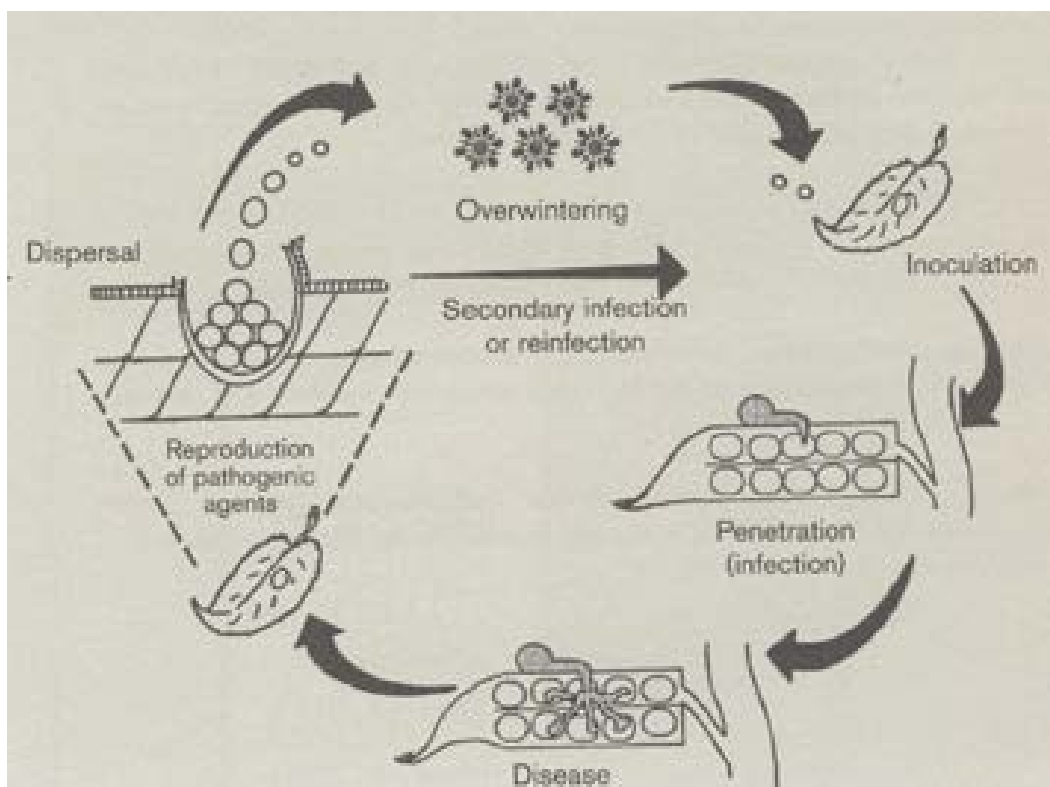
Natural vegetation, **weeds** and organs for propagating plants (tubers, cuttings, sowing, and so on) help to store and disseminate parasites with a broad spectrum of hosts.

❑ Infection

The infection of a plant by a fungus usually involves the stages of germination of the spore and penetration of the germinative tube before establishing a trophic relationship. There are different stages when a pathogenic plant is infected by plant pathogenic fungi and these are: **fixation to the cuticle, germination of the spores, the formation of the *appressorium*, and piercing of the cuticle and the periderm**.

When **fixing to the cuticle**, on the surface of the leaves, as a very general rule we can see that the spores of pathogenic fungi become rapidly fixed to the cuticle of the host and are resistant to washing the surface on which they have lodged.

Phase 1 - Contact with the host

← spore

Phase 3 - The leaf is penetrated with the "tip"

Germinative tube

The "tip"

Phase 2 - The germinative tube develops

Germinative tube

spore →

Phase 4 - The haustorium develops

haustorium

Phase 5 - The penetrating hypha branches out Haustorium

penetrating hypha

haustorium

1 Haustorium: a simple or complex structure, formed through the interaction between fungus hypha ramification and a host cell in which the hypha has penetrated without causing total damage. The haustorium acts as an absorptive organ for fungi to absorb nutrients from the host cell.

Germination of a fungus spore generally ends in the formation of a **germinative tube** which appears a few hours after the spore has come into contact with the plant. Most of the spores germinate in the presence of water and oxygen without requiring external food sources. Germination begins with swelling which corresponds to the penetration of water.

The formation of the **appressorium** is the third stage of the infection. When penetrating the leaf (by piercing the cuticle or by moving between the guard cells of stomata), the germinative tube forms a fairly differentiated structure, the appressorium.

The phytopathogenic fungus penetrates an intact leaf by **piercing the cuticle**. However, this penetration may also take place via the stomata. As the periderm is generally resistant to all the enzymes from the microorganisms, the suberized tissues constitute a natural obstacle the phytopathogenic fungi meet during the first stages of the infection in the branches, the stems and the roots.

Once all these stages have been passed, a trophic relationship sets in between the fungus and the plant affected by the parasite within which the fungus uses the plant cells as a food source.

❑ **Dispersion**

The release and dissemination of the fungi's organs of propagation are provided by a wide range of mechanisms:

- In Peronosporales, a considerable reduction in humidity quickly dries out the axis of the sporangiophore, which contorts violently throwing out spores.
- The conidia of numerous Deuteromycetes are thrown out by a similar mechanism.
- In numerous *Ascomycota*, the ascus encloses a liquid which allows the violent discharge of germs 2 or 3 cm away from the initial point.
- In certain fungi, mucilages enclose the spores and allow them to extrude from the pycnidia in the form of long columns which can reach 1 cm when humidity is high

Although the release of spores is frequently the result of active phenomena, their dispersion is generally passive. In many fungi, dispersion is anemophilic (by the wind), or it takes place by means of droplets of water in suspension (fog). The shock of the droplets of water may cause the carpophores to burst with full force (irrigation by aspersion).

Workers' tools as well as living vectors (animals, humans) are also possible agents for the dispersion of fungal particles. The mucilages in fungal particles help them to adhere to insects or acarids or sometimes even attract vectors (as in the case of rusts).

1. Overwintering (= dry season on tropical regions)

The fungi survive between most crop rotations. During this inter-season, they can be active or latent. The fungi survive in association with other plants, inside or on the seeds, on waste, or in the soil. Overwintering could not take place if the crop continued to grow.

7. Reproduction

Can return to overwintering conditions, or reinfect plant parts.

Different types of spores:
Asexual: zoospores, conidia, etc.
Sexual: ascospores, basidospores, oospores, etc.

2. Primary inoculum

The inoculum (usually spores) can cause primary infections in the host population.

6. Infection and appearance of the symptoms.

Infection of the plant parts.

Infecting hyphae mycelium, with or without haustoria*

Production of inoculum in or on the host plant.

*typical only for parasites

3. Dispersal

The forces of nature disperse the inoculum: wind, rain, etc....

5. Penetration

Direct or indirect penetration in the host, under favourable conditions.

4. Contact with one or several sensitive hosts.

3.3.4. Structure of populations of phytopathogenic fungi

The structure of a fungal population characterizes:

1) **the genetic variability** existing within it,
2) the phylogenic relations between individuals within the population and sub-populations,
3) the manner in which **this variability develops** in **time** and **space**.

Some mechanisms increase the genetic variability (genetic recombination of sexual and parasexual origins, mutations and genetic flows due to migrations). Secondly, selection pressures operate on the pathogen (resistance genes, biotic and abiotic environments, etc.) and limit this variability.

The characterization of the structure of the populations makes it possible **to evaluate the relative weight of the different factors of development of a pathogen** and constitute an important parameter in **the resolution of numerous phytopathological problems** (choice of resistance genes, deployment of resistant varieties, and so on).

3.4. The phytopathogenic prokaryotes (bacteria and mycoplasmas)

3.4.1. General characteristics of prokaryotes

The prokaryotes group together all the **unicellular organisms** which do not possess a differentiated nucleus. Amongst the phytopathogenic prokaryotes, we can distinguish the **bacteria** *sensu stricto* **with a wall** and the mollicutes (phytoplasma and spiroplasma). In bacteria, this wall is rigid and surrounded by a layer of mucus (**capsule**). It plays an important role in the recognition process which determines the future of the parasitic relationship.

Phytopathogenic bacteria have a cytoplasmic membrane. Their chromosome material comes in the form of an irregular plaque in the cytoplasm and they have circular fragments of DNA. They also have structures external to the wall (capsules, polysaccharides, etc.) which play a fixative and protective role or which are necessary for movement. The mobility of these cells is provided by **flagella** which respond to an external chemical stimulus (chemotactism).

There are phenotype classifications and molecular classifications of procaryotes, based on morphological and biochemical characteristics.

> The first subdivision established within the bacteria is based on **Gram** staining (staining of the walls of the bacteria:
> if yes, « Gram+», if no «Gram-»).

3.4.2. Classification systems

There are phenotypical classifications and molecular classifications. The first are traditionally based on morphological and biochemical characteristics but the fact that they are not very discriminating reduces their practical use. The physiological and metabolic properties are more widely used if the microorganism can be cultivated in the culture media required. The molecular techniques targeting the sequences in nucleic acids are increasingly being used to resolve problems with identification.

Taxonomic levels are also used in the classification of phytopathogenic prokaryotes (see Table below).

Taxonomic levels used in the classification of phytopathogenic prokaryotes (Source. P. Lepoivre, Phytopathologie (Plant Disease) 2003)

Levels	Taxonomic rank	Nomenclature
Supraspecific levels	Domain Kingdom Section Class Order Group Genus Species	*Bacteria (Eubacteria)* *Proteobacteria* *γ-Proteabacteria* *Zymobacteria* *Pseudomonadales* *Pseudomonadales* *Pseudomonas* *Pseudomonas syringae*
Intraspecific levels	Pathovar Race (or biotype)	*Pseudomonas syringae* pv. *tabaci*

3.4.3. Principal taxons and diseases caused by phytopathogenic bacteria

Within the **Gram⁻** bacteria, the **Proteobacteria** constitute an extremely diversified group. It contains **4 sections** (α, β, γ, and ε), comprising phytopathogenic agents:

1. The section of **α-Proteobacteria** contains the genera ***Agrobacterium*** and ***Rhyzobium*** (group of **vascular bacteria** responsible for **withering** due to the occlusion of vessels by the bacteria themselves) When it comes into contact with the wound of a sensitive host plant, *A. tumefasciens* introduces a fragment of DNA into the cells of the plant which provides a code for the proliferation of plant cells (tumours on fruit trees and in the nursery garden).

2. The genera ***Burkloderia*** and ***Ralstonia*** are classified in the section of **β-Proteobacteria**. Bacteria from the first genus, induce symptoms of **rotting,** withering or necrosis. Amongst these bacteria, *Ralstonium solanaceae* is responsible for vascular diseases on numerous crops in tropical regions.

3. The section of **γ-Proteobacteria** contains the genera ***Pseudomonas, Erwinia, Pantoea*** and ***Xanthomonas***. Bacteria from the genus Pseudomonas are responsible for **leaf necroses or blight on branches.**
   The genus *Erwinia* is responsible for significant plant diseases (the group of agents causing **soft rotting** and the 'amylovora' group, fire blight).
   The species ***Xanthomonas campestris*** is ubiquitous and contains over a hundred pathovars. Finally, this section contains the species ***Xylella fastidiosa,*** which cannot be cultivated on a medium and which **colonizes the xylem.**

Pseudomonas syryngae pv. phaseolicola on the bean

4. The section of ε-**Proteobacteria** contains several species of bacteria subservient **to the phloem**. This is the case of the *Liberobacter* responsible for the 'greening' of *Citrus* in South Africa in particular and transmitted by psylla.

The **Gram⁺** bacteria contain the section of ***Clostridia*** (anaerobic bacteria) and the section of mollicutes containing the **phytoplasms** and the **spiroplasms**. Diseases caused by **phytoplasma** are particularly widespread in tropical countries because of the uninterrupted activity of the vector insects. The phytoplasma cause **symptoms** affecting the reproductive apparatus as well as the plant apparatus (soft rotting). The main symptoms caused by **spiroplasma** are **nanism, chloroses, jaundices, a reduction in the size of fruits and leaves as well as withering**. Two types of spiroplasma are known; in nature the first type has a limited number of host plants and the second type has a very wide spectrum of host plants.

We also find within these Gram⁺ bacteria the **Corynebacteria** whose most damaging species are *Clavibacter michiganense* sbsp. s*epedonicum* causing ring rot disease in the potato whereas *C. michiganenese* sbsp. *michiganense* causes withering (bacterial canker) in the tomato. This group also contains the genus *Streptomyces*.
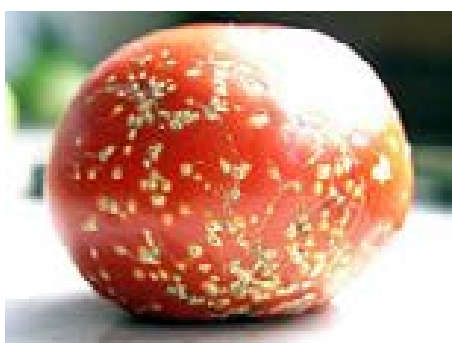
*Bacterial canker on tomato
(C. michiganenese sbsp. Michiganense)*

3.4.4. Parasitic cycle of bacteria

Bacteria establish with plants a range of relationships from symbiosis to parasitism but the distinction between parasitism and saprophytism is not clear cut.

The epidemic dynamic requires the sequence of several events which constitute the basic cycle of infection: phase of conservation of the inoculum, phase of infection and phase of dispersion (figure below).

The essential phases of the basic cycle of infection in phytopathogenic bacteria.

Conservation

Infection   Dispersion
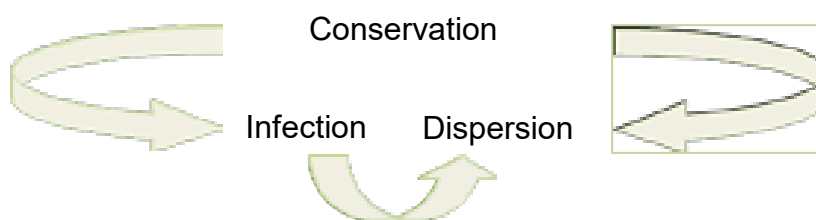
3.5. Plant pathogenic viruses and viroids

3.5.1. General characteristics of the phytovirus

*Melons infested with a virus
(Photo B. Schiffers)*

Plant viruses are infectious entities which carry genetic information (DNA or RNA) **obligate parasites** of living cells of a host plant whose metabolic machinery they use to carry out their own protein synthesis.

The inoculation of a healthy plant with a virus first of all requires a cell to be damaged by rupturing the wall, followed by the transfer of the inoculum when in contact with the cytoplasmic membrane.

The infection of a plant with a virus is the result of the infectious entity passing from cell to cell through the plasmodesmata. This movement involving a short distance involves the formation of a movement protein. Once the infection (local or systemic) has begun, the **symptoms** can be **diversified**, going from **changes of color** to **stunting** or **malformations of plants.**

The plant virus takes the form of an isometric structure, comprising rigid or filamentous, rods and bacilliform particles. The different types of viral genomes are divided into 7 basic groups depending on the type of nucleic acid (DNA or RNA) contained in the virion (viral particle) and the strategies used for their replication. An analysis of the virus populations containing RNA shows a wide variability resulting from either the reassortment of genome fragments or recombinations, occasional mutations, deletions or insertions. Viroids consist exclusively of a circular monocatenary RNA virus.

3.5.2. Transmission of viruses and viroids

We can make a distinction between: **(1) vertical transmissions** on the descendants of the infected plant by generative or plant propagation; **(2) horizontal transmissions** to other plants of the same species or other species through mechanical injury by means of contact between protoplasms and animal vectors (aphids, nematodes, grasshoppers, etc.), plant or fungal vectors.

❑ **Vertical transmission**

Most plant viruses are not transmitted by sowing or by the pollen from infected main shoots. On the other hand, the **vegetative multiplication of the infected plants** leads to **generalized infection of the descendants**, hence **the considerable practical importance of the production of virus-free material.** The viruses are mainly eliminated by growing meristems and/or heat therapy.

❑ **Horizontal transmission**

The horizontal transmission of a virus may be carried out via **mechanical transmission, via grafts, by cuscuta, by fungi and animal vectors (acarids, nematodes and above all by biting-sucking insects)**.

> Viruses transmitted by animals may be classified into 2 major categories: non-circulating viruses and circulating viruses:
> - Non circulating viruses are transported by the mouth pieces during transmission; they contain 'non persistent' viruses and semi-persistent viruses (acquisition sting and short-term inoculation).
> - Circulating viruses circulate in the vector via the alimentary canal, the digestive system, the haemolymph, salivary glands and the salivary canal through which they are introduced into a new plant. They are of a 'persistent' type.

3.5.3. Epidemiology of the transmission of plant viruses

The epidemiological parameters of the extension of viral diseases transmitted by vectors depend on **various factors relating to the vector itself and its hosts, as well as their respective relations with the pathogenic agent in question, or with the environment.**

An accurate knowledge of these parameters may lead to **provisional systems being set up which can lead to effective control.** The behavior of **insect vectors** under natural conditions determines the control strategies used against the extension of the viruses: elimination of sources of viruses carrying the inoculum during intercropping, interference with the behavior of the vectors and close protection of crops.

Courgette (zucchini) seedling with virus
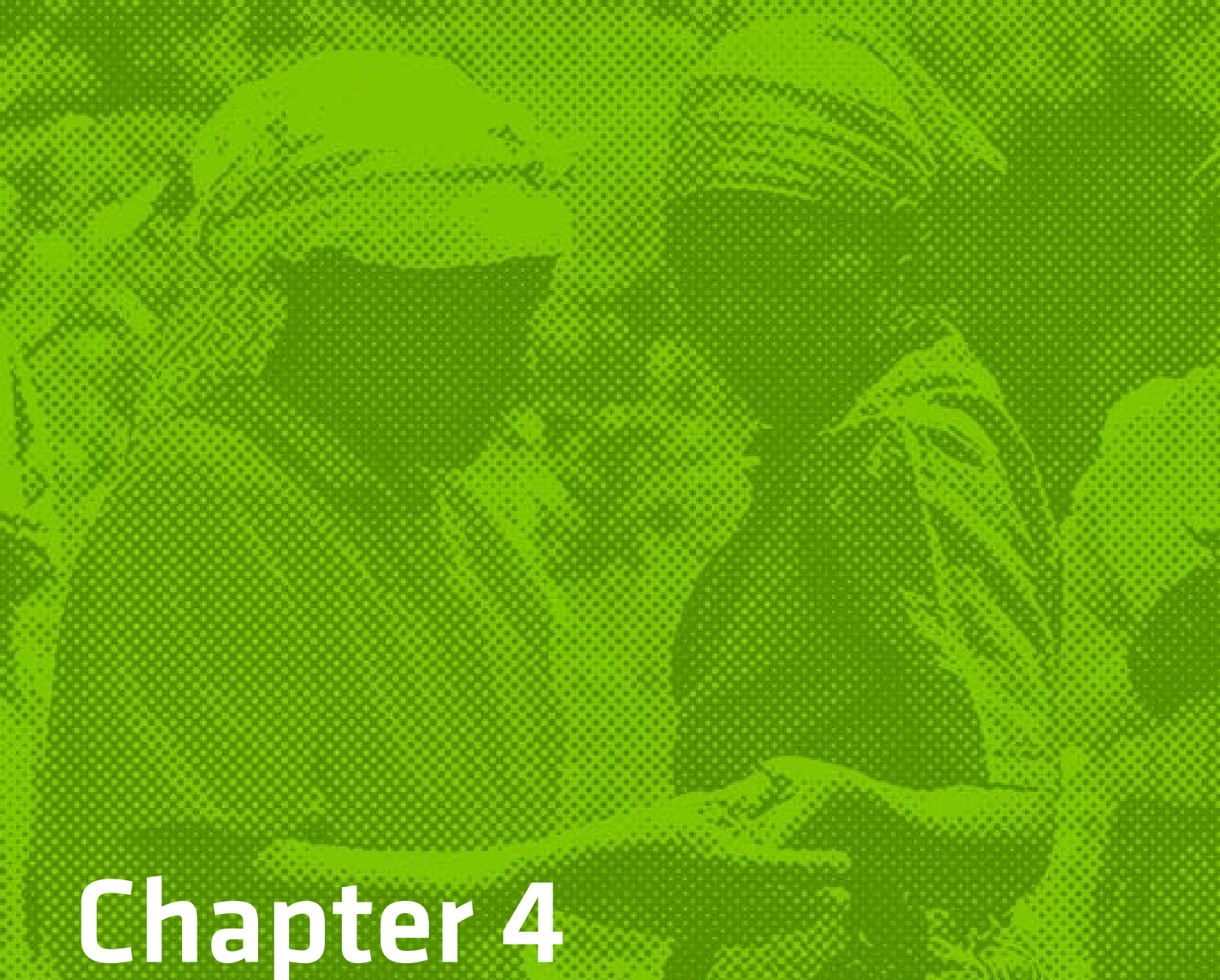
Chapter 4

Competition and identification of weeds

4.1. General information about the biology and harmfulness of weeds

4.1.1. General information about weeds

A weed is an **herbaceous plant** or, by extension, a **ligneous plant** that is **undesirable** at the point where it is found (thus, it is frequent to have to eliminate certain trees that adversely affect a new plantation). Apart from cultivated fields, orchards, plantations, pastures, etc., some plants are undesirable in particular cases: banks of irrigation channels, lakes and rivers overrun by aquatic grasses and algae, fire-break in a forest, brambles invading young plantations, industrial land (around industrial buildings), some cemeteries, car parks, railway tracks, turf on golf courses, tennis courts, roads and edges of roads, airports, storage areas, containment basins etc.

Amaranth shoot in beans (Photo B. Schiffers)

The close relationship between weeds that are «good» and those which are «bad», in particular **when they belong to the same genus,** makes weeding particularly difficult. This is the case with cultivated rice (*Oryza sativa*) with the adventitious species *Oryza longistaminata* and *Oryza brevigulata*, cultivated oats and wild oats, cultivated carrots and wild carrots, etc.

Harmful plants and useful plants share common **ground**, the soil in which they grow. When their relationship with the soil is examined (or even better a certain 'volume of soil'), there are very significant differences between the useful plant and the harmful plants. When introduced in a field deliberately, the stages in the life of the cultivated plant are well known in advance (there are even 'keys' showing the different growth stages).

On the other hand, harmful plants are more of an unknown entity: **how can we predict how a weed flora will develop in a field** containing 10, 20 or even more species which will appear and develop with the crop?

> For example, a crop of winter wheat will suffer attacks from **several waves of weeds**: after sowing, during the winter, during tillering, during stem elongation and from heading to harvesting.

The **abundance of seeds**, the **capacity for reproduction** and **propagation** are significant advantages of weeds. In fact, they reproduce either through seeds, or through vegetative multiplication: rhizomes, bulbs, suckers, fragments of roots or stems. The latter method of reproduction is fairly common in certain annual plants and especially in numerous perennial plants (e.g.: couch grass).

Weeds multiply and spread for various reasons: abundance of seeds and long dormancy in the soil, seeds transported by the wind, which definitely appears to be the most common way of spreading seeds, through water, which has an essential role (whether rainwater or ditches or rivers as far as the dissemination of aquatic species is concerned), by animals, which also play a part in this propagation by carrying away or fixing fruits or seeds to the surface of their bodies or when seeds of weeds are expelled with excrement.

When manure is inadequately decomposed, it can constitute an excellent means of dissemination. Sowing badly graded seeds, use of the combine harvester, cultural methods that facilitate the multiplication of certain perennials and using herbicides that are ineffective and to which some weeds are resistant also aid dissemination.

Lastly, weeds benefit from the progress made in agriculture: rational use of fertilizer, irrigation, especially for species which are resistant to herbicides which benefit equally well as the crop from reduced competition. Not only are there large numbers of weeds but they are actually **more resistant** to destruction; in fact, the degree of impermeability of their seed coat allows them to resist prolonged desiccation and burial in deeper layers of soil with little air.

This impermeability makes the seeds hard, i.e. they do not germinate, even in favorable conditions of humidity and heat. Some are able to conserve their germinating powers for a very long period of time which, in certain species, can be as long as around ten years. Some plants even germinate relatively badly in the year of their production and it is only when they are 3 to 5 years old that their germinating power is the greatest.

4.1.2. Direct harmfulness (competitive effect)

Weeds are formidable competitors for crops, mainly when they are **beginning their development**.

Even in a field that has been well prepared and dug over, weeds will germinate and be competitors for cultivated plants. The requirements of weeds can exceed those of cultivated plants, i.e. the soil reserves are truly depleted by weeds.

*Competition between cultivated plants (Bean) and weeds (Cyperus)
(Photo B. Schiffers)*

What is more, numerous weeds **develop faster than the crops** and smother them. Yield falls and sometimes the harvest is destroyed. The number of weeds required to see a significant effect on yield can sometimes be fairly small: for example, in crops of sugar beet, the presence of 6 to 7 chenopods per m² in the crop is sufficient to affect production.

Sometimes, weeds quite simply take over from cultivated plants, if they are slow to occupy the ground (onion). Different elements must be taken into consideration to explain the competition crops face from weeds. These include: well-adapted morphology and a very active or specific physiology. Other plants excrete substances which are toxic to crops, either through their roots, or through their leaves.

It is important to underscore the fact that **weeds start competing with crops as soon as they start to emerge. W**eeds will have an effect on the future yield of the crop even at seedling stage.

Harvesting loss (as a %) in maize with known populations of untreated annual dicotyledons that emerged at the same time as the crop

Annual dicotyledons	% with 1 plant/m²	% with 5 plants/m²
Great ragweed	13	36
White chenopod	12	35
Amaranths	11	34
Cocklebur	6	22

Centella erecta	5	21
Charlock mustard	5	18
Abutilon	4	15
Redshank	3	13
Black bindweed	2	10
West Indian Nightshade	2	7

Crops   **Weeds**

The thresholds of economic loss will help to determine whether the population density and repercussions of weeds on yield justify recourse to control measures, i.e. whether the value of the loss of yield avoided compensates for the cost of the envisaged treatment.
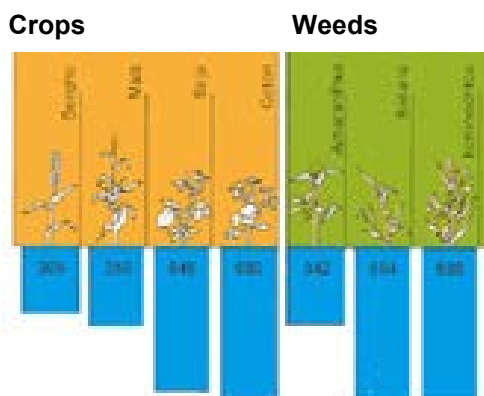
Water consumption of cultivated crops and weeds

Weeds absorb some of the **water** and **nutritional elements**, and partially deprive cultivated plants of **air** and **light**. A reduction of water resources, which transports nutritional elements, has a direct effect on the **assimilation of chlorophyll**.

The periods of germination and development for graminae such as *Digitaria horizontalis* and *Rottboellia cochinchinensis* coincide with the period for sowing cotton and become direct competitors of the cotton plant in their quest for water, nutrients (nitrogen, potassium, phosphorus) and light. Trials have shown that losses of yield are proportional to the delay in hoeing and may vary from 7% (for a delay of 12 days) to 45% (for a plot left unhood). The cotton harvest may be difficult and polluted, leading to a **downgrading of fiber** in a plot thickly infested with weeds. Finally, we can point out that crops with a strong vegetative development, such as maize, do not escape competition from undesirable plants.

4.1.3. Indirect harmfulness

- Weeds are home to numerous pests, as well as diseases harmful to crops. They are secondary host plants to **aphids**, numerous types of **rust**, for some **nematodes**, and for numerous **viruses** (transmitted by aphids and nematodes in particular), **acarids** (*Tetranychidae*), snails. Their presence provides cover for harmful **rodents**, which brings about a drop in yield and quality. Crops full of weeds offer conditions which are favorable to the development of certain diseases.

- The presence of weeds does not assist with harvesting work (the weed growth may be such that mechanical harvesting is impossible!), as well as thinning, earthing-up etc. which increases losses and production costs.

- The moisture content of the grains harvested may be increased (need for drying after harvesting).
- The unwanted seeds and the plant debris in the crop devaluates the harvest and may even lead to it being rejected if the crops are earmarked for seed-production or for the canning industry (weed seeds being toxic).
- In grassland and other fodder crops, some plants may **cause problems** or be **toxic** for humans and/or animals (e.g.: corn cockle, colchicum, field buttercup, common and field sorrel, St John's wort etc.). Finally, the roots of some weeds obstruct drainage during irrigation (invasion of irrigation channels, obstruction of drains). In **pasture land**, some species of weed are not eaten by cattle which results in a loss of surface area useful for production.

Hypericum perforatum, CIUSIACEAE, St John's wort is sensitive to light.

4.1.4. Particular case of 'invading species'

An invasive species or exogenous invading species is an exotic living species which becomes an agent of **harmful disruption to the native biodiversity** of the natural or semi natural ecosystems amongst which it has established itself. The phenomena of biological invasion are now considered to be one of the major causes of reduction in biodiversity, along with pollution, ecological fragmentation of the ecosystems and the generalized hunting, fishing and over-exploitation of some species.

The deliberate introduction of new species is often justified by the services these can offer us (dietary value, aesthetics, the fishing industry, and so on). However, if by chance they become invading, the importance of these services rapidly lessens when compared with the disadvantages of their uncontrolled development. The negative effects of biological invasions fall into four groups:

- Impacts on health. Often transported completely accidentally, some undesirable exotic organisms are important **vectors of disease** and cause new diseases to emerge (mosquitoes, rats, etc.). Some invasive plants such as ragwort, hogweed and the tree of heaven are also responsible for triggering strong **allergic and inflammatory reactions**;

- The socio-economic impacts. The introduction of exotic species may cause **significant economic damage**. They are the result of the development of various organisms: Insect pests, pathogenic fungi and rodents which cause significant damage to crops and forests, aquatic mollusks which encourage the corrosion of ships' hulls and block filters and the pipework of thermal plants or even plants with a powerful root system capable of damaging the surface layer of roads and of deteriorating infrastructures.

- The effects on the way in which ecosystems function. The development of invasive species often has significant repercussions on the stability and productivity of ecosystems. They can bring about a far-reaching **change to the functioning of the food chains** and biogeochemical cycles, impair the hydro-morphological characteristics of waterways, etc. Consequently, these malfunctions may in turn cause damage to the ecosystems and have major financial and ecological repercussions (see insert);

- The **impact on indigenous species**. Some introduced plants which have become extremely invasive have a significant impact on biodiversity, either because of the competition they exercise for the space in which they grow (e.g.: *Caulerpa taxifolia* in the Mediterranean) or indirectly through ecotoxic or inhibiting substances they emit for other species, or simply because they cannot be consumed by native herbivores or other native animals.

4.2. Classification and identification of weeds

4.2.1. Reminder of a few definitions

'Weeds' are also designated by the following terms:

- adventitious plants (from the Latin *adventicius*: foreign) which appears accidentally, without being introduced deliberately;
- commensal plants (from the Latin *cum*: with, and *mensa*: table) who eats at the same table, which lives alongside;
- messicole plants (from the Latin *messis*: harvest, and *colere*: to live) the name used for any annual plant which grows in fields of cereals.

Scientifically, the plant kingdom is divided into two subkingdoms:

- *Cryptogams* (plants without a flower);
- *Phanerogams* (plants with flowers), which in turn are subdivided into two sub-kingdoms:
  - the *Gymnosperms*;
  - the *Angiosperms* (approximately 250 000 species) comprising two classes, *i.e.*: **Monocotyledons** and **Dicotyledons**.

The distinction between these 2 classes, as well as the **accurate recognition** of the species concerned is generally a requirement when choosing a suitable means of control, particularly to **guide the choice of effective herbicide**.

Location of the meristems

Monocotyledons   **Dicotyledons**
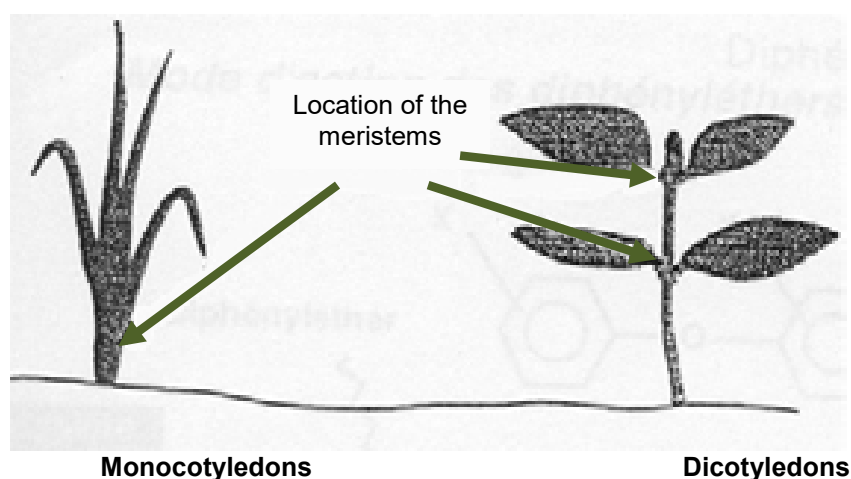
Comparison between Monocotyledons and Dicotyledons

MONOCOTYLEDONS	DICOTYLEDONS
One cotyledon, dispersed bundles without cambium, extra bundle cambium.	*Two cotyledons, bundles of conductors in a circle with a cambium.*
These are the 'graminae'.	**The plants have broad leaves and leafstalks.**
A few important families:	*A few important families:*
Poaceae (or Gramineae) (meadow foxtail, common wild oat, meadow grass, bent grass, ray-grass, couch grass, panic, hairy brome grass, etc.)	Asteraceae (yarrow, milkweed, groundsel)
• narrow, lengthened leaves, with the veins all parallel • the base of the leaves is differentiated into a sheath which envelops the stem • the sheaths begin at node level	Renonculaceae (buttercup) Chenopodiaceae (chenopod) Polygonaceae (knot grass)
Cyperaceas (Cyperus)	Euphorbiaceae (dog's mercury)
• leaves are arranged in a tristic way, the limb is folded lengthways in a V shape • the sheaths effectively form a tube; the stems are short and remain hidden in the sheath • the axes which emerge from bunches of leaves are prismatic pedicles with inflorescences at their tip.	Crucifereae (senna) Urticaceae (nettles) Papaveraceae (poppy) Fumariaceae (fumitory) Convolvulaceae (bindweed)
Liliaceae	Labieae (dead-nettle)
Alliaceae	Scrophulariaceae (speedwell)

4.2.2. Classification according to their vegetative cycle

In practice, weeds are generally separated according to their vegetative cycle and we can distinguish between:

❑ **Herbaceous plants** comprising:

- **Annual plants**: these are plants which only live one year: they germinate, produce flowers and fruits during the same year (e.g.: poppy, chenopod). These plants generally produce vegetation rapidly and last for a short time and in all cases, they mature and disseminate their seeds prior to harvest time. They are mainly found in crops of vegetables, cereals, sugar beet etc.

- **Biannual plants**: these are plants whose complete development takes two consecutive years. They germinate and develop during the first year, but only produce flowers and fruits the next year. This category is quite small (wild carrot, spear thistle, burdock).

- **Perennial plants**: this is the name for plants which are able to produce flowers and fruits for several consecutive years; they generally possess other means of dissemination. It is in the prairies and pastures that most perennial species are to be found. Amongst these are:
  - plants with rhizomes,
  - stoloniferous plants,
  - plants with bulbs,
  - plants with root strains,

Invasion of the crop by Oxalis (Photo B. Schiffers)

- **Annual plants with rhizomes and stolons are the most invasive**, as they can colonize fairly large surface areas without producing seeds (Cyperus, couch grass, coltsfoot, field thistle, buttercup, colchicum, plantains, dandelion etc.).

❑ **Ligneous plants** (generally perennials)

4.3. Cultural factors encouraging the development of weeds

4.3.1. Factors influencing weed populations

Shortened periods of rotation, **reduced cultivation** (even sowing without ploughing), **spray or bed irrigation**, the absence of effective herbicide or one at an affordable price, the absence of associated crop, and so on. All these practices will favor the development of populations of weeds in plots, and, because of the competition, have a negative effect on the yield.

Two other important points can be added here:
- an inadequate choice of the time of intervention (intervening too late!);
- treating crops with an ineffective herbicide or one made ineffective because of the resistance of the weeds.

Losses in yield largely depend at what point in time the weeds emerge compared with the crop. The **choice of the moment of intervention** is consequently a key element in weed control. The **critical period** is defined as the interval in the biological cycle of the crop during which it must be kept weed-free, to avoid the risk of a drop in yield.

Horticultural crops are very sensitive to competition exercised by weeds. They need to be kept weed-free from sowing, to emergence or flushing, right to the end of the critical period for the absence of weeds.

Establishing a critical period helps to determine the optimum moment for interventions, which reduces the need to have recourse to herbicides with a residual effect which lasts the whole season and late applications of herbicides. Given the variations in soil type, climate and advancement of the season, the critical periods are defined according to the growth stages of the crop. Establishing the critical period aims to maintain the drop in yield attributable to weeds under 5%. In other words, this is the period during which the crop must be kept weed free in order to avoid being exposed to a drop in yield of more than 5%.

If controlling the weeds during the critical period proves successful, the weeds which emerge subsequently will not damage the yield and if necessary can be destroyed before the harvest by a treatment intended to desiccate the crop and facilitate the harvest.

4.3.2. Origin of the phenomenon of resistance to herbicides

Resistance to an herbicide provides a sign of the capacity of a population of weeds to survive an herbicide treatment which, under normal conditions of use, would manage to control it effectively. Resistance to herbicides is an example of evolution at an accelerated rate and illustrates the principle of the 'law of the strongest'. An herbicide can destroy all the weeds in a population of one particular species, with the exception of a few specimens with the genetic potential to survive the herbicide.

The seeds of resistant weeds increase and sooner or later dominate the population. This means that this weed is no longer effectively controlled by the herbicide responsible for the selection.

The plant health and cultural practices which lead to the appearance of populations of weeds resistant to the herbicides in the treated plots are not very different from those which lead to resistance in pests or in pathogens. For example:

- Repeated use of the same active substances or active substances with the same action targets on the same plot (amaranths resistant to atrazine may also be resistant to metribuzine as well as simazine (cross resistance). If the same population of amaranths is resistant to imazethapyr, it displays multi-resistance);
- Monoculture or short rotation;
- Species of weed present in each crop in the rotation;
- Weed with a strong potential for reproduction.
- Resistance has more risk of appearing amongst annual species of weeds, because they produce a large number of seeds (amaranths, white chenopod and foxtail grass are good examples).
- Resistance often appears towards the herbicides which are the most effective at combating certain species of weeds. This phenomenon can be explained by the intense selection that these herbicides impose on the species that they are very effective at combating. Thus, only the specimens which are resistant see their genes transferred from one generation to another.

> Once we see that treated plants are not completely destroyed amongst others with the symptoms characteristic of plants poisoned by the herbicide, it is highly probable that resistance has set in!

4.3.3. Particular case of plants which have been genetically modified

We often read that **genetically modified plants** (**GMP**)[1] have been made « resistant » to herbicides. However, this expression, common even amongst professionals, is not correct: these plants are made « **tolerant** » to herbicides. The plant assimilates and converts the molecule which is normally harmful to it. It becomes quite simply insensitive to the effect of the herbicide (*i.e.* 'physiological resistance/tolerance').

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[1] We also refer to GMO (genetically modified organism).
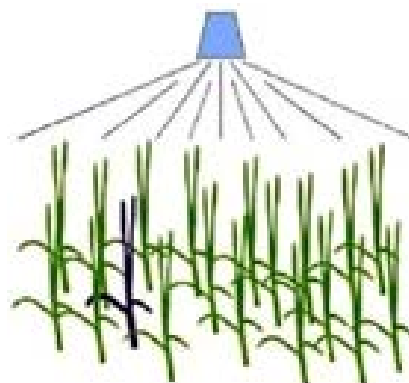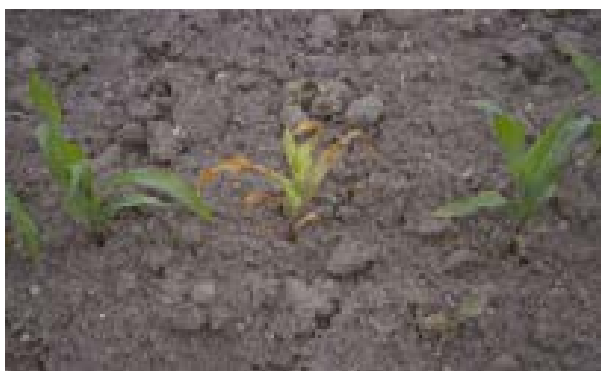
Several types of tolerance are proposed by genetic engineering, but they all use one of the following strategies (or a combination of both) in a tolerant genetically modified plant (GMP):

a) the GMP produces a new protein which « detoxifies » the herbicide;

b) the protein which is the target for the herbicide is replaced in the GMP with a protein which is insensitive to the herbicide.

There are basically **four types of herbicide** which are involved in this genetic engineering technique:

1. glyphosate (in maize, soya, cotton, colza and sugar beet),
2. gluphosinate (in maize, soya, cotton, colza, rice and sugar beet),
3. bromoxynil (in cotton) and
4. sulfonylurea (in cotton and linen).

Crops of transgenic plants represented 114 million ha in 2007, which is 8% of the cultivated surface area world-wide (1.5 billion ha) 93.3% of which is on the American continent. These four species represent over 99% of surfaces cultivated with transgenic varieties. With 59 million ha, transgenic soy is the most widespread. These are resistant varieties which simplify cultivation a great deal. It is cultivated above all in the United States (81% of American soy) and in Argentina (90% of Argentine soy). Its more recent development in Brazil is associated with the competitiveness of the Argentine economy.

Transgenic maize is resistant to the corn borer and, to a lesser extent, demonstrates resistance to herbicides (especially to glyphosate). It is also most developed in the United States (40% of maize-growing surfaces according to the USDA - *United States Department of Agriculture*). Transgenic spring colza (canola GMO, 14 varieties resistant to herbicides) in 2009 represented 55% of surfaces planted with colza in the United States and 77% in Canada.

4.4. Examples of harmful weeds

4.4.1. The fight against Striga (witches weed)

Example of infestations by Striga
Photos: Sara, Montreal, ABC Burkina & CIRAD)

❑ **Biology and harmfulness of Striga**

Waongo in the Moore language, *Sigè* in Dioula or witches weed in English, and Striga in French is a plant from the family of *Scrophulariaceae* (family of *Orobanchaceae*) and is a parasite of annual crops of major importance. It is well known to producers in the semi-arid zones of Africa. According to different reports, the loss caused by Striga to agricultural production in Africa is more than 1,000 billion FCFA per annum. For decades already, research has been conducted across Africa in order to introduce technological advances designed to combat Striga.

Two species are a particular threat to crops in the intertropical zone:

- *Striga asiatica*, with red flowers, measuring 13 to 30 cm. It is the most widespread in East Africa as well as worldwide;
- *Striga hermontica*, which measures approximately 50 cm, with pinkish-purple flowers (see photos below). This is the species found most frequently in Africa and more particularly in the Sahel, where it causes estimated losses in yield of 30 to 75% nationally, although this percentage can be 100% in a plot. The plant is particularly well suited to **zones with low rainfall**, with a clear dry season and high annual temperatures.

The main **host crops** of Striga are: **maize**, **rice**, **sorghum**, **millet**, finger millet and sugar cane. Spontaneous graminae also act as alternative hosts for Striga: *Heteropogon contortus, Cynodon dactylon, Rottbelia exaltata, Echinochloa colona, Brachiaria distachya, Brachiaria erecta, Stenotaphrum dimidiatum, Setaria sphacealata* etc. so it is

fairly common to see the parasite flowering in the middle of fallow-land. Another species of Striga (*S. gesnerioides*) causes damage to **black-eyed peas**.

Seeds of Striga go through a period of dormancy, which allows them to avoid germinating after light rainfall during the dry season. After a period of dormancy of 4-8 months, the seeds go through a phase of pre-conditioning (rehydration) prior to germination. The biological cycle of Striga can then begin with an underground phase which lasts almost 50 days. First of all the plant develops a sucker (called haustorium) which **penetrates the host tissues and branches out into its vascular system**. During this underground phase, Striga takes from its host all the substances it needs for its metabolism (water, carbohydrates and other nutritional elements) and is at its most harmful, as it depends entirely on its host to be able to develop (exclusive parasite).

This parasitism means that the infested plant **develops poorly**, suffers chlorosis (yellowing) followed by **progressive desiccation of leaves**, reduction in the size of the crop, poor seed set, and therefore a significant drop in yield.

These symptoms are associated with a significant lack of nutritional elements and a lack of water in the host, but there are probably other reasons for the poor development of the host (change in hormonal balance, toxins, disturbance of photosynthesis).

*Significant damage caused by Striga on rice in the underground phase
(Photo: Rakotondramanana)*

After emerging, the leaves develop and become photosynthetic. The plant becomes hemiparasite, capable of supplying some of its own needs. The stem develops rapidly and produces a shaft which will carry the flowers. Flowering begins five to six weeks after the seedlings have emerged. Strigas produce minuscule seeds, in a gigantic quantity (10,000 to 100,000 seeds/plant). These seeds take the form of a blackish dust, which means that they are easily disseminated by the wind, run-off water, cattle, agricultural equipment and humans when sowing crops and contaminated straw.

❑ **Conditions favorable to Striga**

Striga is a **plant which is often associated with poverty**. It develops in environments where rainfall is low and irregular, on poor soils, with a low content of organic material and nitrogen. The increase in cultivated surfaces and the reduction of fallow land, cultural practices (ploughing, monoculture), poor returns and intense erosion, repeated bush fires

and the spread of cereal production (host plants of the parasite) lead to rapid deterioration of soils and favor the development of Striga. Its method of reproduction (multitude of small seeds which are easily transported) allows it to rapidly infest large surface areas. Small underprivileged farms are the most badly affected. They enter a **vicious circle of deterioration** which favors the development of Striga, further aggravating their precarious position: small plots which do not allow crop rotation (need to ensure a supply of basic cereals), no access to farming input, sometimes not even manure, no fallow land, little labor force etc.

❑ **Methods of control**

Even if farmers are familiar with this parasite, they have much more experience of its consequences on yield than its cycle of development. The behavior of this parasite is virtually unknown to peasant farmers, which explains their great difficulty in controlling it. The traditional methods of curative control of Striga are very often not very effective (ploughing, mineral fertilization, staggering the time of sowing crops to reduce infestation etc.) or unsuitable and very difficult to implement (pulling up plants and straw after the harvest, repeated herbicide treatments on 2,4-D, flooding lasting several weeks, mechanized trap crop, fumigation). We can quote a few methods used with varying degrees of success:

➢ *Trap crop:*
This technique consists of growing crops whose root exudates are capable of germinating parasite seeds, without however allowing the parasite to develop. This results in failed germinations and a drop in the seed stock of the Striga. The most interesting examples are those of the cotton plant, soya, Bambara groundnut (*Voandzeia subterranea*), the pigeon pea (*Cajanus cajan*), the peanut (*Arachis hypogea*), the bean (*Phaseolus vulgaris*) and the black-eyed pea (*Vigna unguiculata*) which allow the germination of seeds of *Striga hermonthica* without being parasited. However the use of « plant traps » must not be carried out to the detriment of the crop.

➢ *Agronomic practice*
This is the simplest controlling technique and does not require any sophisticated equipment. The strong recommendation is to use fire to destroy the parasites which have been pulled up, as fertilized flowers of Striga are capable of reaching maturity even after they have been pulled up. To obtain a significant effect on the harvest, the weed must be pulled out regularly for several years.

➢ *Sowing date*
Early sowing allows the host plant to escape the attacks due to Striga right from the first rains, when the conditions for the germination of the seeds of the parasite are not yet in place.

➢ *Fertilizer*
The appearance of Striga in crops is generally associated with poor soils which comes from monoculture practiced for too long and the absence of any inputs. Perfectly naturally, we imagine that supplying fertilizer should improve the situation. In Togo, supplying 120 kg of urea per hectare from the outset up to a few days before the flowering of the male of the maize crop is able to reduce the risk of a parasitic attack of *Striga asiatica*.

➢ *Crop rotation*
The practice of the continuous crop is very well developed in subsistence agriculture in Africa. It leads to a regular and spectacular increase in the stocks of seeds of Striga in the soil. **The first measure to be recommended is crop rotation** so that the sensitive crop only returns every 4 or 5 years. Crop rotation can be optimized if a false-host plant such as cotton, peanut, soya or black-eyed pea is introduced into the cycle of rotation.

➢ *Crop association*
This technique, which consists of combining, in the same field, a cereal with a leguminous crop (peanut, soya or black-eyed pea), is able to significantly reduce the pressure from Striga on the cereal. Trials carried out in Togo have shown that the combination of millet/soya reduced the number of seedlings of *Striga hermonthica* from 100 to 70%.

➢ *Mulching and sowing directly on permanent plant cover*
Mulching leads to a reduction in the temperature of the soil which reduces the germination of the parasite). However, the difficulty lies in the implementation of this technique as mulching requires biomass (often used to feed animals, which is rapidly decomposed by termites and/or lost in bush fires) and may be long and laborious to transport. As an alternative, a technique of direct sowing on permanent plant cover can be used (SPP) which allows **the simultaneous implementation** of trap crops, mulching and improvement of soil fertility, with limited means. Very good results have been obtained using this method to control Striga.[2]

In future, the use of the fungus *Fusarium oxysporum*, which can damage the development and reproduction of Striga, should permit the biological control of this formidable parasite.

4.4.2. Control of dodder

❑ **Biology and harmful nature of dodder**

Dodder (*Cuscuta* spp.) is a genus containing between 100 and 170 species of parasitic plants. Dodder are yellow, orange or red, and rarely green, plants. They can be recognized by their fine, spindly stems, apparently without leaves, with these being reduced to minuscule scales. They have very little chlorophyll.

Dodder seeds are relatively small (1 to 1.5 mm in diameter). They are produced in large numbers (2,000 to 3,000 per stem) and covered by a brownish and very tough multilayer seed coat whose impermeability is responsible for profound dormancy of the seed cover. The seeds germinate on the surface of the soil or slightly below. Germination may take place without a host, but the seedling must reach a green plant within 5 to 10 days after germination to survive. Before reaching a host plant, the seedling lives on the reserves of the seed, just like other plants.

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[2]   See Husson, O. *et al*. (2008). *Le contrôle du Striga par les systèmes SCV (Semis direct sur Couverture Végétale permanente)*, Manuel pratique du semis direct à Madagascar (*Controlling Striga using SPP [Direct sowing on permanent plant cover]*.Practical manual of direct sowing in Madagascar), vol. I. Chapter 3, CIRAD (Agricultural Research for Development), TAFA (Tany sy Fampandrosoana), FOFIFA (National Agricultural Research System), GSMM, AFD [*French Development Agency]* Madagascar).

After dodder has reached a host plant, the stem forms non photosynthetic filaments which wrap themselves around the stems of the host plant and push in suckers (haustoriums) which insert themselves into the vascular system of the host. The original root then dies. The severity of attacks of dodder is very variable depending on the species, the host, the duration of the attack etc.

Market garden crops (tomato, carrot, eggplant) are particularly susceptible.

Dodder may develop and become a parasite on several plants. In tropical regions, dodder develops more or less continuously up to the tops of trees and bushes.

The parasitic plant diverts the sap produced for its own benefit; the host branch located above the insertion point of the parasite is always stunted. Drops in yield are noted because of the reduced development of the host which results in a reduction in flowering, fruiting and production, or even the complete drying out of the host prior to flowering. By weakening the host plant, dodder reduces its ability to fight viruses; thus dodder can be involved in the transmission of pathogens from one plant to another, if it establishes on several plants at once.

❑ **Methods of controlling dodder**

- Use certified seeds and clean tools. Many countries have legislation prohibiting the importation of dodder seeds, obliging farmers to obtain seeds from crops which have not been contaminated by dodder seeds.
- Burn the areas invaded by dodder. It is also possible to use glyphosate on the stains of dodder on crops of alfalfa by applying 60 ml of the commercial product (Round-up) in 500 liters of water (slit nozzle or using an impact plate).
- If a field is infected, it is a good idea to plant non-host plants for several consecutive years.
- Apply an anti-germinative herbicide.

Chapter 5

Techniques of observation and sampling methods

5.1. Methods of observing and sampling pest populations in the field

The word 'population' is used to refer to all individuals of the same species that occupy a territory (the biotope). The limits of this territory are generally the local geographic region to which this species belongs.

The populations possess a set of characteristics such as the spatial distribution of the individuals, the density, the structure, and so on. The **density of a population** is the number of individuals present per unit of surface area or volume.

Determining population density is important as **the damaging effect of a species in an environment largely depends on its density**… with notable exceptions such as virus vectors!

The methods of evaluating the density of populations, essential for establishing a control strategy, are extremely numerous and may be grouped under 2 main headings: **direct counting** and **indirect methods** (**trapping, extraction etc.**), not forgetting the techniques of diagnosis and sampling.

Choosing a sampling method is a complex process which must be adapted to suit the type of crop being observed. The main stages the observer must carry out are as follows:

1) planning the regularity of recording in line with the pest, the disease or the weeds being targeted and keeping to a schedule of observation and sampling activities;

2) determining the units (e.g.: plants, leaves, roots, etc.) and drawing up a plan of the farm's plots (in order to determine the areas to investigate);

3) determining the pest counting, evaluation and location techniques to be used. Three techniques are mainly used:

  - counting the pests present according to the different stages of development;

  - observing the damage caused by pests and/or the symptoms caused by diseases;

  - counting the number of seedlings with insects, acarids, nematodes, etc., or that show damage, or symptoms;

4) determining sampling procedures by planning the testing method and by determining the number of samples to be screened:

- if you are trying to detect pests or problems suspected to be **uniformly distributed** or whose distribution pattern is unknown, spread out the sampling points uniformly:
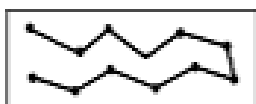
- if your aim is to detect pests or problems suspected of arising **from external rows**, spread out the sampling points uniformly around the field:
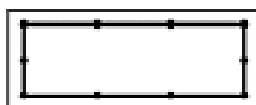
- if you are looking for pests or problems suspected of being located **in certain portions of the plot**, the sampling points must be concentrated in these sectors:
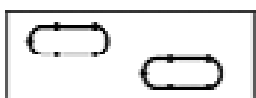
5) data recording allowing the observer to quantify the populations of pests present and to follow the progress and distribution of parasites during one single season and subsequent growing seasons (particularly with regard to the 'threshold of intervention').

5.1.1. Direct observation and counting

This method consists of selecting seedlings at random or a particular number of plants along a row of seeds and observing the presence of the pest or the disease on all parts of the plant. This method can be used early in the season and can be applied to the first stages of vegetative development. It has the advantage of not being destructive as no sample of plant material needs to be taken. However, it can only be applied when there is little wind (under 12 km/h). It also requires a good knowledge of the insect system, and the symptoms of the diseases.

In an open environment or one with little plant cover, direct counting can be carried out. You may need to use a magnifying glass for close observation. In addition, this method can be used for counting birds' nests or breeding pairs.

5.1.2. Trapping and capturing techniques

❑ **Ground cover**

This method of sampling consists of making the pests fall onto a **piece of light-coloured fabric** measuring approximately 20 cm pegged out **on the ground** at the foot of the plant

between two adjacent rows of seeds in order to collect the insects and count them. Obviously, this method is not applicable for insects that fly away rapidly and at the slightest contact (crickets, for example). It is well suited for the Coleoptera, which often let themselves drop when they sense danger and for the caterpillars of Lepidoptera.

Use of a piece of fabric for soil collection

Once the pests have been collected, the species can either be identified and counted in the actual field, or be transferred in a suitable container (glass bottle, small plastic tubes) and then taken to the laboratory to be analysed at a later point. This method is suitable for pests with slow movements but is limited by the size of the seedlings. If they are too small or in senescence, the technique becomes unsuitable. In addition, shaking the seedling can cause leaves to fall outside the perimeter delimited by the piece of fabric and it becomes difficult to count them correctly.

❑ **The sweep net**

For over a century, this method has been the most widespread for capturing Arthropods harmful to crops. This can be explained by the fact that, in spite of difficulties with standardization, there is no other method capable of capturing so many insects per head and per hour without increasing the cost of the equipment and damaging the crop.

This net consists of three basic elements: the actual **conical net**, the ring which keeps the net open as well as the handle, joined to the ring, made out of aluminium or wood.
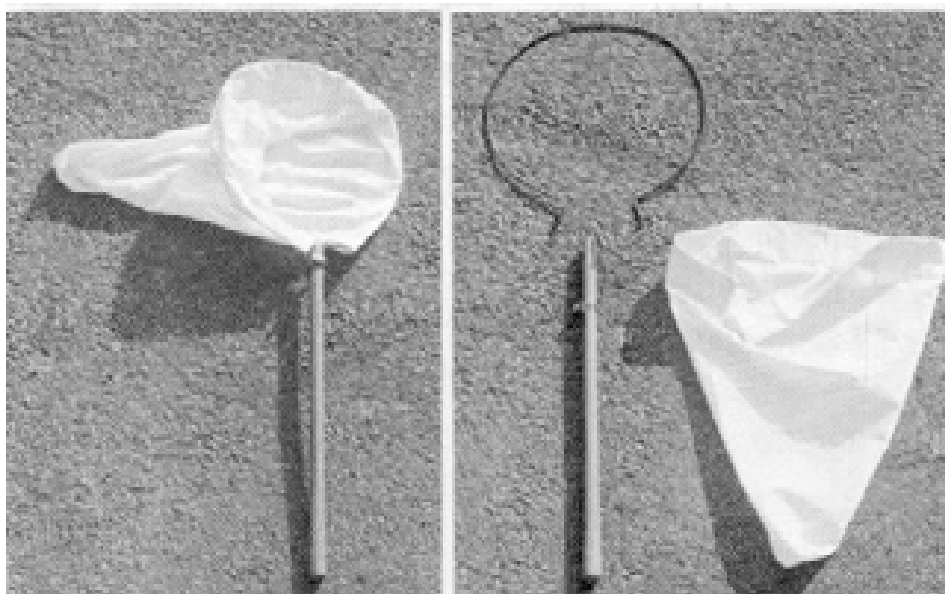
Sweep net

Sampling can be carried out **all along a row of plants** by holding the net by the handle and passing it through the foliage. It is also possible to sample the adjacent row as well, by using a zigzag movement. In spite of the fact that this method is very suitable for trapping Arthropods, its results are often variable because of environmental factors such as temperature (which influences the metabolism of insects and therefore their ability to escape), humidity, which has an effect on the microclimate and the location of insects, the position of the sun (the shadow cast by the operator may chase away the insects), the size of the seedlings (which are fragile when small) and the density of the vegetation, which may have a degree of mechanical resistance to the net. When the foliage is wet after rainfall, the net becomes difficult to use.

In order to convert the number of insects trapped into absolute estimates of the population, regression methods are used by comparing the population estimates based on insects captured with population densities determined on the basis of an absolute method of sampling such as cage fumigation or collecting the entire plant.

❑   **Suction nets**

These function by **suction** as fixed or mobile traps for sampling pests within a crop. They have a draft tube (portable fan), a gasoline tank, a flexible air pipe, a collection bag, a small cone and a control.

The sample must be taken in the opposite direction to the direction of the wind. It is possible to take samples over a clearly determined length all along a row by holding the head of the cone horizontally with the rounded part of the net forming an angle of 45° with the row and the top part of the plant.

Diagram of a suction net:
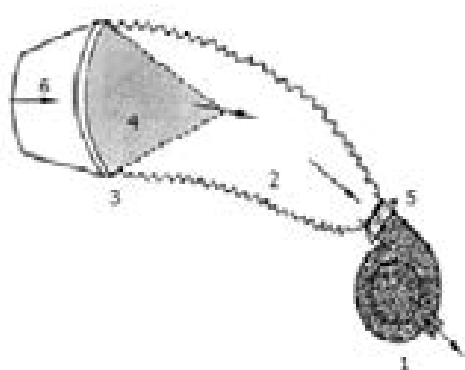
1: fan
2: flexible air tube
3: ring to hold cone
4: net made of tulle
5: filter protecting fan
6: cone adjusting the diameter of the net

Using a suction net

This tool is useful for **small-sized pests** capable of being sucked up by the current of air and not frightened by the noise of the apparatus and the movement of the operator. This technique produces good results for flies, some small larvae of Lepidoptera, nymphs and adults of some Hemiptera.

Using this trapping method, the surface of the conical head corresponds to a zone of the field being sampled. The residual population may be determined by direct observation, but better calibration is produced by comparing the results with those of a more absolute method.

❑   **Pheromone traps**

In market garden crops, fruit and vegetable crops, the caterpillars of butterfly pests and other insects which are parasitic on crops can cause considerable damage. The pheromone trap is a useful tool for detecting insect pests, provides information about the extent of the attack and helps the grower to determine the right time to destroy them.

Pheromones are **chemical signals exchanged between the individuals of the same species** and influence their behaviour. For example there are sexual pheromones which

attract male butterflies located a long distance away from female butterflies. The pheromone trap makes use of this phenomenon to attract insect pests.

The type of trap which gives the best results in practice is the 'Delta' trap. This trap consists of a sticky base and a top in hard-wearing, water-resistant material. The trap is hung from a hook placed in the middle of the top. The capsule, containing the pheromones, is located between the top and the sticky base. Males, attracted by the female pheromones, are trapped and remain fixed to the sticky base. By examining this base, the pests can be identified. Counting allows us to obtain an idea of the size of their population and their distribution. Once a certain number of males are trapped, control methods must be started. Pheromones are specific to each insect pest. How long a pheromone's activity lasts depends on its composition, the number of traps used, its concentration and the climate.

Sexual traps are another type of pheromone trap, which use capsules impregnated with a pheromone similar to the pheromone of the female of the pest sought. There are sexual traps for Lepidoptera, but also for other pests, such as certain Diptera.

There are two main categories of trap: *traps for detection* and *traps for extensive trapping*.

- **Traps for detection** (or 'monitoring') are used to **indicate when a pest is beginning to fly**. Hence the user is able to use a sustainable approach when applying chemical or biological treatments (for the introduction of trichogram wasps for example). They are mainly sticky traps, so the males attracted by the synthetic pheromone become trapped. This type of trap may be used for numerous pests in tree crops, field crops, market garden and ornamental crops, viticulture, and so on.
- **Traps for extensive trapping**, consisting of a funnel and a receptacle which holds the butterflies, are used to **capture large quantities** of Lepidoptera. Using a synthetic attractant, the aim is to capture and destroy a large number of insect pests on crops. This method is specific and environmentally-friendly. This method of control via extensive trapping is able to control pest populations in the medium term, but is not effective against all species. It is of particular use against Lepidoptera pests.

❑ *Sticky traps*

- Delta traps

The delta trap, generally made from recyclable plastic or cardboard, is impregnated with sexual pheromones but also with glue which traps the insects. This trap has a small entrance to prevent insects from escaping.

- Wing traps

The wing trap is also made of paper resistant to bad weather, with sticky internal surfaces, wide openings for increased diffusion of the pheromone in the surrounding environment and bait with pheromones inoffensive to other insects. However, the efficiency of these traps is poor.

- Cone traps

This trap uses synthetic pheromones fixed to the base of a cone net as bait. This cone is placed at ground level in high grass and the insects which are trapped in it accumulate in a reservoir on top. These traps are the most effective on the market, although the trapping period is 4 to 8 days longer than that for light traps. They are almost 4 times as effective if placed in the middle of the vegetation and not above it. They are also effective outside the plot, during the pest's first cycle (Lepidoptera).

❑ **Water pan traps**

A capsule containing pheromones is fixed to a string above a container holding a 'wetting agent'. This liquid, consisting of soapy water, reduces the water repelling nature of the cuticle of insects, which can no longer remain on the surface and hence sink more easily to the bottom of the container. The liquid in the container must be changed regularly (every week) for an optimum yield. They are as effective as light traps, but unfortunately they are very dependent on atmospheric conditions, either evaporating in dry conditions or becoming diluted in rainy conditions.

❑   **Other traps**

- **Black light traps** are especially effective for Lepidoptera and other nocturnal insects. The light produced by a 15 W bulb attracts butterflies or other insects which fly into the metal plates impregnated with soap. The insects then slide into a container full of soapy water and remain trapped there. These traps are among the most effective where there are high densities of insects. However, they do not contain pheromones, so are not very selective. They actually attract not only the female Lepidoptera of a given species but also other species, or even other insects. These traps can therefore make counting the insects difficult if similar species are mixed together.

- The most effective trap is still **the coloured bowl** (**yellow**) **full of soapy water** (**water traps**) which collect the insects attracted by the colour. Water has an attractive effect in the sense that the insects move towards places where humidity indicates the presence of water. The reflections from solar and atmospheric light on its surface also have an effect of attraction and finally this hides the walls of the dish to an extent and the

insects focus on the water. The insects are attracted over a distance of 30 to 40 cm. These traps have numerous advantage**s such as their si**mplicit**y and low cost, the e**ase **of collec**ting the insects (the contents of the dish are poured into a funnel with a removable plastic tube at the end. The contents of this are then collected in a container and alcohol is squirted in). This keeps the insects in good condition (apart from butterflies). Finally, they do not require any source of energy. The specific nature of the captures should be noted, as the insects are usually attracted by specific wavelengths.

- The **Malaise trap** resembles a canvas tent in which flying insects 'are lost'; passively directed to the higher end of the "roof" before being collected in a container fixed to this end.

- The **emergence trap** is able to collect populations of ground Arthropods. It can be used in a *dry extraction* form or a *wet extraction* form :
  - **Dry extractors** (Berlèse apparatus; Tullgren apparatus;Tullgren apparatus combined with repellents such as naphthalene) use a source of heat and are suitable for micro- and macro-arthropods.
  - **Wet extractors** (Barmann, Seinhorst or Milne apparatus) often consist of a sieve containing the sample of earth onto which *water* is poured, with the entire mixture then being heated by a lamp placed over it. The oxygen content drops and the animals fall down a tube to escape from the heat, reaching a container of cold water where they are collected. These wet extractors are suitable for samples of nematodes.

  There are also mechanical methods **of extraction by directly examining samples of earth** with or without colorant (nematodes), by means of the **direct examination of sections of soil**, by means of extraction by **dry sifting** (Coleoptera), by means of extraction by **floating** (nematodes, acarids, molluscs), by **wet sifting and flotation** (Ladell, Aguilar, Bernard and Bessard methods, Salt and Hollick method), by means of **centrifuging and flotation**, by **sedimentation**, by **elutriation**, and by **maceration of the substrate**.

5.1.3. Absolute sampling methods

Accurate methods of estimating population densities are needed to produce management programmes for pest populations. The methods described above depend on environmental and human conditions and other biological factors. The validity of the data collected using these techniques can only be judged on the basis of their efficacy when these are compared to a more reliable and less costly sampling method. The two methods described below are based on isolating a population over a known surface area.

The first method is **cage fumigation** (cage made from wood, plastic or lightweight metal). The cage must also have a very small opening at the top in order to allow the application of the fumigant as well as a collection plate at the bottom. An aerosol pack containing 20% of a pyrethrinoid makes an excellent fumigant. 5 to 8 seconds of spraying are often sufficient to have a 'knock down' effect on Arthropods inside the cage. Without removing the cage, the operator inserts an arm through the injection cylinder and energetically shakes the plant. The cage is then removed and the insects are collected at the base.

Sampling by fumigation (A: Choice of plant, B: Sample)
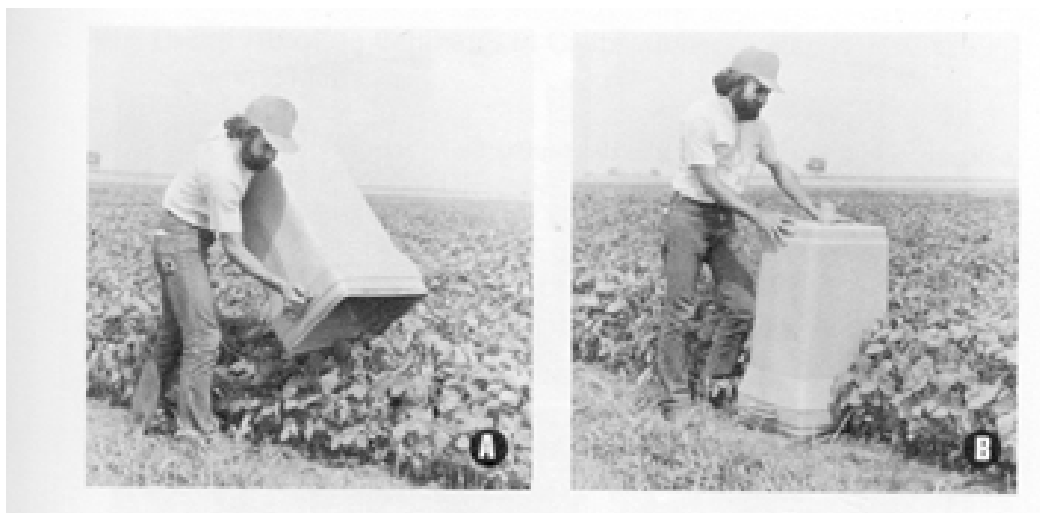
The second method consists of **collecting the whole plant** using a sampling cage measuring 1.8 x 1.8 x 1.8 metres, made of net and mounted on a cubic support. An opening which can be closed is made on one of the sides of the cage. This allows access to the inside of the cage. The cage is placed over the sampling location by two operators one of whom goes into the cage with an aspirator, labels and plastic bags. The aspirator is used to suck out the insects from plants, which are then pulled out and placed in bags provided for this purpose. The plant debris (leaves, branches) are also collected and placed in separate bags. The cage is left in place for 1 to 2 hours in order to collect the individuals that have fallen into holes or have been enveloped in dust when moving towards the edges of the cage. The methods of dry extraction allow the insects to be 'removed' from the plant debris and the soil.

Using a method of statistical regression, in the form of $y = \beta x + \alpha$ is used, with y corresponding to the number obtained using the sampling method employed and x the number obtained using the absolute sampling method (fumigation or collection of plants), the efficacy of the sampling method selected is tested.

Illustration of the sampling method for the whole plant (sampling cage):

1: Transporting the cage to the field
2: Putting the cage in place
3: Collecting the insects that have fallen to the ground after sampling and bagging up
   the plants
4: Removing the cage and sampling surface

5.2. Methods of observing fungi and bacteria

5.2.1. Methods of observing symptoms

Accurate observation of symptoms and their development in time and space constitutes the first stage of the diagnosis. The symptoms are sometimes sufficiently defined and specific to allow the cause of a disease to be correctly identified without requiring other analyses: this is the case with certain traditional afflictions such as rust, mildew and smut.

However, more often than not, the situations encountered are complex: different agents may induce similar symptoms while, on the other hand, the same agent may produce symptoms which vary according to the situation. In addition, the most visible symptoms do not necessarily appear at the primary site of infection; for example, certain pathogenic agents responsible for necrosis of the radicular system or of vascular tissues (**primary symptoms** or **causal symptoms**) cause secondary withering or shrivelling of the aerial parts (**secondary symptoms** or **consequential symptoms**).

The period when symptoms appear, as well as the **climatic circumstances** which preceded their appearance, is extremely important when diagnosing a disease caused by a fungus or bacteria.

The **previous cultivation** as well as the different **operations carried out within the crop** may interfere with the initiation and development of symptoms; mineral fertilisers (doses and dates of application), plant health treatments (doses, commercial names, equipment and spreading techniques), work on the soil, the date of sowing or planting and the origin of batches of seeds or organs of propagation will be taken into particular consideration.

The history of the field may reveal circumstances which favour the appearance of symptoms, even after several years. Likewise, demarcation between symptoms may correspond, after several years, to the boundaries of plots with a different history. Spatial distribution may provide elements which are useful in the diagnosis: valley bottoms and sides of hills with a Northern exposure are locations which are particularly favourable to damage by fungi developing in rather more humid and cold conditions. Dips are often areas where symptoms of root asphyxia are seen.

The way in which diseased plants are distributed in the crop is also able to shed light on the way in which the causes of the infection are transmitted or on their transmission. Distribution in lines parallel to the seeds reflects human origin (compaction of the soil associated with the passage of machines, overdoses of manure or plant health products, linear distribution of an inoculum by tools). Diseased plants in an area at the entrance of a field may correspond to deposits from bags of manure (scabies caused by *Streptomyces scabies* in areas where calcium-containing fertiliser is stored); diseased plants distributed in small groups forming spots distributed at random in the field may reveal that the virus has been transmitted by aphids. On the other hand, a disease that appears year after year, in the same place and whose affected surface area is mainly

increasing in the direction in which the soil is worked suggests a microbial origin or transmission of the virus by nematodes or by fungi.

> At this stage in the diagnosis, it is important to pick up on every clue that will make it possible to determine the biotic or abiotic nature of the problem, by taking samples. When the cause of the disease cannot be established on-site, samples need to be taken for subsequent analyses.

This sampling must be carried out with the greatest of care, as its quality will determine the success of the later stages (observations under the microscope, isolation, etc.). It is always preferable to **sample entire plants** (including roots), rather than limiting the sample to the parts which seem damaged in order to identify the causal symptoms. It is also a good idea to take samples at various stages of progress of the disease, particularly in plants showing early symptoms (with a view to isolating the pathogenic agent and of observing its fruiting bodies) or showing an advanced stage of the infection (presence of the parasite's survival structure).

5.2.2. Methods of diagnosis in the laboratory

Various laboratory methods are used to make the diagnosis. They are the reserve of specialists and of well equipped and, if possible, certified laboratories.

The laboratory techniques can be split into **three categories** depending on their aim:
- detecting infectious parts of the pathogenic agent (**biological methods**);
- revealing immunogenic molecules synthesised by the pathogenic agent (**immunological methods**);
- detecting sequences of nucleic acids that are specific to the genome of the pathogenic agent (**molecular methods**).

❑ **Biological methods**

A simple close examination of the surface of the samples of diseased plants using a **binocular magnifying glass**, or of a sample under the **microscope**, is sometimes sufficient to reveal carpophores of fungi or bacterial exudates whose presence may be grounds for diagnosing a parasitic disease.

Practical example: the 'exudates method' to confirm the presence of *Ralstonia solanacearum* (Brown rot).

This method is used for certifying potato seedlings.

Ralstonia solanacearum is a soil bacterium, a Gram-negative plant pathogen, responsible for brown rot. Present on every continent, particularly in tropical and subtropical regions, the bacterium is stored in the soil where it can survive for several years. It penetrates through the roots and propagates through the vascular system; it is spread by irrigation water (surface water) or by the seedlings. It colonises the xylem, causing bacterial rot or vascular bacteriosis in numerous host plants from the Solanaceae family (tomato, nightshade, pepper, aubergine, tobacco, etc.) and other plants as well.

White filaments escaping from the section of stem

Method of detection (*(extract from: Draft of the plan to control the certification of potato seedlings, CDE- Lux Development – AIDCO, 2009* :

Pull up the plant and check whether:
- the main stem and/or the roots are being attacked by an insect,
- the stems are rotting around the neck (Erwinia),
- the main stem is giving off an exudate:
  - equipment: transparent glass + knife + bottle of clear water
  - method: cut off the main stem 5 cm above the neck and soak it in a glass of water. Wait 1 to 3 minutes to check for the presence of white filaments coming out of the vascular tissue.

Result:

If filaments are observed, the plant is definitely suffering from *Ralstonia solanacearum*, which means that the soil, tubercles and nearby plants must be removed.

In more complex cases, a procedure will be used to **isolate the agent**; the different stages of this work involve: (1) choosing a plant sample; (2) disinfecting its surface, depositing it in a nutritional environment and (3) observing the growth of the uncontaminated culture.

The final identification can extend as far as inoculation of the agent which has been isolated. This method only applies to the pathogens capable of multiplying on the medium in vitro (fungi, bacteria).

Biological methods of diagnosing **obligate parasites** (viruses, phytoplasma, etc.) are based on a series of operations: descriptions of the symptoms observed, **transmission of the infectious agent to host plants** and symptoms, determination of the range of host plants and the symptoms they express, observation under the microscope (possibly electronic), extraction and purification (in the case of viruses and viroids).

❑ **Immunological or serological methods**

Numerous molecules of a pathogenic agent may behave like antigens by causing, in the lymphatic tissues of warm-blooded animals, the formation of antibodies with which they react specifically. Several serological techniques make use of this property; they use both polyclonal antibodies, and monoclonal antibodies.
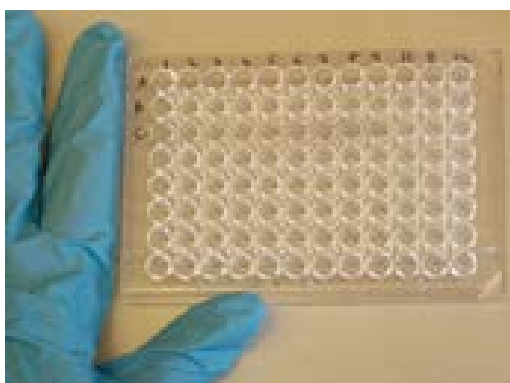
Enzymatic marking of these antibodies has allowed the development of protocols capable of detecting phytopathogenic agents and quantifying them (**ELISA test**).

The ELISA (acronym for *Enzyme Linked ImmunoSorbent Assay*) test is an immunological test intended to detect and/or assay a protein in a biological liquid.

The main advantages of immuno-enzymatic tests are their **sensitivity** and their **ease of use**. However, it may be difficult to obtain antibodies in the case of diseases with an ill-defined aetiology, or disorders whose agent cannot be cultivated in vitro or purified easily.
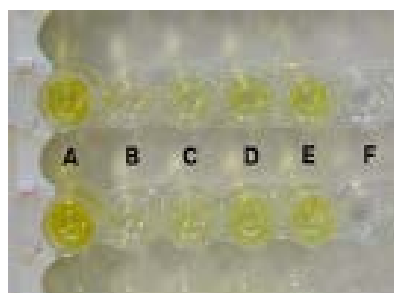
❑ **Molecular methods**

Serological methods cannot be used to diagnose diseases caused by viroids. In this case, diagnostic techniques are used based on **the analysis of sequences of nucleic acids** from infected plants using electrophoresis in polyacrylamide gel or on the characterisation of nucleic acids by molecular hybridation.

Recourse to **molecular amplification**, via chain polymerisation (**PCR** – Polymerase Chain Reaction), has made it possible to push back **the boundaries of sensitivity** of diagnostic techniques based on the detection of specific sequences of nucleic acids. The aim of the technique is to make a large number of copies of a given segment of DNA (e.g.: amplifying a specific region of a nucleic acid of the virus to be detected, in order to make the virus 'visible'). In order to make this possible, a series of reactions allowing the replication of a matrix of double-stranded DNA is repeated in a loop. In the course of the PCR (polymer chain reaction), the products obtained at the end of each cycle act as a matrix for the next cycle, so the amplification is exponential.

This amplification produces a **band on a gel** (see figure) that is specific, on account of its size, to the virus we are trying to reveal. If this technique is properly developed, it is both very sensitive (amplification possible as soon as there are a few cells infected with the virus alone) and very specific. The PCR reaction is extremely rapid and only lasts a few hours (2 to 3 hours for a PCR involving 30 cycles).

PCR reaction in a « thermocycler »

Reaction mixture

PCR (*polymerase chain reaction*)

Expected size of « PCR » fragment
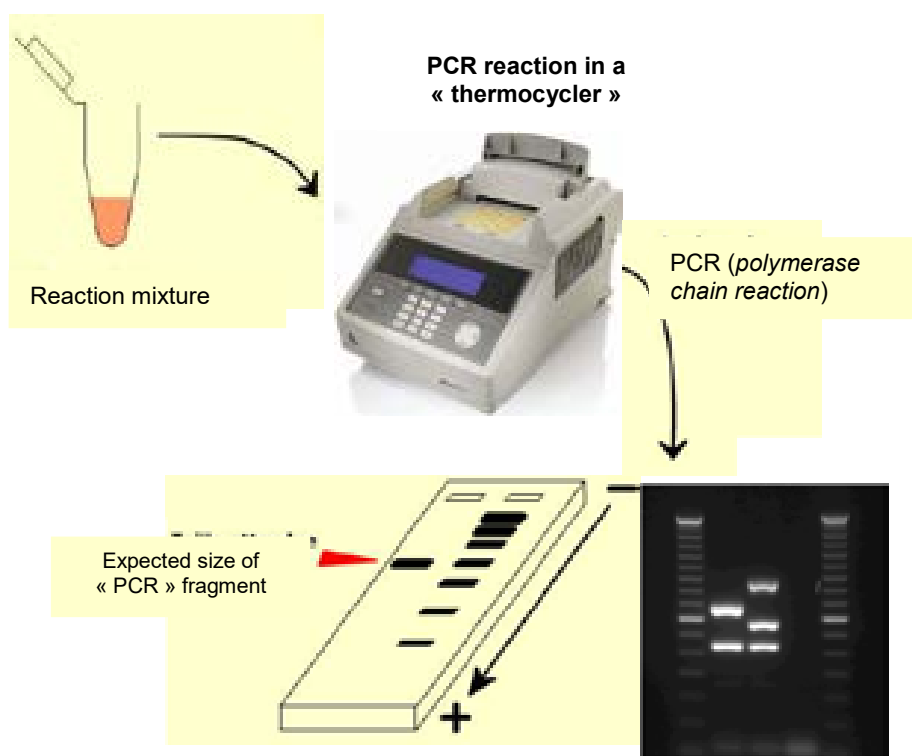
Reading results on the polyacrylamide gel

5.3. The thresholds of risk, the estimation models and agricultural warnings

5.3.1. The thresholds of risk

As a general rule, a crop can withstand a certain level of infestation by insects, diseases, and so on, or competition with weeds: there are actually compensation phenomena which mean that, up to a certain level, damage to part of the production apparatus does not reduce the value of the product. Simply detecting a disease, a pest or a weed in a plot must not therefore automatically prompt the grower to make a decision to intervene to eliminate it at all costs.

One of the principles to follow within the framework of integrated crop management is to use pesticides only when pest density is such that they risk causing harvesting losses whose cost is likely to be higher than the cost of a treatment: this is the 'threshold of economic harmfulness' (or 'Economic Threshold').
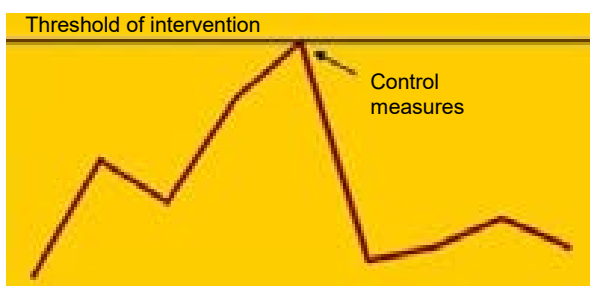
In fact, as from a certain level of infestation, the loss of yield justifies an intervention. The 'intervention threshold' (or treatment threshold) is therefore the value at which the abundance of pests justifies, on account of its damage, recourse to control measures.

Development of infestation over time

These thresholds are not simply 'number of individuals' or '% of damage', as they may be much more precise. In the case of weeds, the threshold of harmfulness is based on the number of plants/m² which might lead to a significant drop in yield.

Example of thresholds of harmfulness of some pests

Pests	Threshold of harmfulness
Crops of sugar cane	3-4 white worms/stock
Winter colza	8 heads out of 10 showing traces of bites from flea beetles, from emergence to the stage of 3 leaves
Canning peas	1 Thrips on average/plant

Example of thresholds of harmfulness of weeds in cereal crops

Weeds	Threshold of harmfulness (plants/m²)
Foxtail	30
Agrostis (bentgrass)	20
Galium aparine (goosegrass)	0.1 – 0.5
Viola tricolor (heartsease)	5 - 10
Polygonum (knotweed)	2

It is important to note that **this general rule does not apply in the case of vectors of viruses** (just a few insects or nematodes can infect a large number of plants), nor in the case of quarantine organisms, for which **a zero risk threshold can exist** (their mere 'presence' being prohibited).

In order to intervene at the right time, particularly **to rationalise the use of pesticides**, the notion of threshold of intervention, adapted to actual pest pressure, is recommended. These levels of thresholds of intervention can be varied by **incorporating in the decision-making** parameters:

- agronomic data (growing methods, growth stages of the crop, variety sensitivity);
- climatological and geographic elements;
- biological, entomological, pathological or general weed science data;
- data relating to the control methods available (alternative methods) and properties of the plant health product (method of action, persistence, selectivity, methods of use, etc.);
- economic data (economic value of the crop, cost of different control methods).

In practice, the **threshold intervention** is not easy to set up as it involves:

- evaluating the degree of infestation of the crop correctly (sampling?);
- estimating the extent to which this infestation could develop;
- estimating the risks to the crop or harvest according to the extent of infestation, the growth stage of the crop, its sensitivity and climatic conditions;
- evaluating the relationship between the expected revenue (depending on the monetary value of the crop or harvest) and the cost price of the intervention (e.g.: product applied or technique used + cost of application);
- evaluating, depending on the technique envisaged, whether one intervention will be sufficient or whether several interventions will be necessary.

We should be aware of the fact that it is not simple to fix thresholds of intervention, and that each case is individual. It is a good idea to pay a great deal of attention to the knowledge and control of **population dynamics**, especially pests and beneficials. The perception of this dynamic, as well as the estimation of the number of pests a crop is likely to withstand, make use of biological studies which supply growers with simple decision-making tools: methodology and techniques for evaluating population levels and modelling infestations.

In the field, **these complex parameters are difficult to evaluate** and require knowledge, training and supervision that growers do not always have at hand. In addition, **the relationship between symptoms, damage and losses is complex**. Likewise, the financial evaluation of losses involves numerous economic factors which are difficult for farmers to control (evolution of the prices of agricultural products and the influencing factors).

As trials are conducted, these thresholds are therefore **reviewed periodically** as they have to adapt to the changes in growing techniques and in the sensitivity of the varieties grown.

Hence, if these evaluations are not made, we are in the field of preventive (or 'safety') treatments, *i.e.* the '**calendar treatments**' (systematic treatments, carried out on the basis of a calendar). Nevertheless, these planned interventions may be rationalised by using products that are effective against the target pest, selective, respectful of humans and the environment. Programmes for protecting the transition are therefore proposed, which progressively integrate the threshold interventions.

5.3.2. Agricultural warnings

By being aware of the biology of the enemies to control, their population dynamics according to the environmental conditions as well as the thresholds of harmfulness, it is possible to construct a large scale (regional) system to control the pests by broadcasting '**alert bulletins**' aimed at growers (radio messages, e-mails, text messages etc.).

These bulletins are often subject to a charge, sent to subscribers, issued by organisations that monitor agricultural health over a given region, regarding the emergence, expected or unusual, of crop parasites or pathogens (fruit trees, vines, major crops, vegetables, green spaces).

A network of experts and stations check, in real time, the development of diseases (bacterial, fungal, parasitic, etc.) as well as the contents of insect traps scattered over the area in question and in the principal types of crop. When a pathogen, a crop pest, or a species which is undesirable for agriculture is present in proportions posing an immediate problem, or **conditions judged to be favourable to its development** are all present (temperature, humidity), **measures (alert messages)**, sometimes based on mathematical models, are sent to the growers who have subscribed to this monitoring service.

On the other hand, if a pest disappears from the environment, warnings tell the subscribers to avoid unnecessary treatments. The data from quarantine parasite surveillance plans are also used successfully.

Advice on strategies and methods of control can be added by specialists.

Without going as far as setting up sophisticated surveillance networks and sending out experts, it is not complicated:
- to make systematic observations and to make a note of the results in order to try to reveal a progression of symptoms, the number of insects, etc;
- to put butterfly in the pupa or chrysalis stage in outdoor cages in order to detect the emergence and egg-laying period of pests;

- to set up traps to capture insects;
- to measure temperature, humidity and rainfall to detect periods that are favourable to a potential infestation.

The Mills curves or tables, first published in 1944, were the first attempt to use « forecasts » in order to help growers to synchronise the application of sulphur on their crops according to the potential appearance of scab on apple trees (Venturia inaequalis).

They actually link the necessary hours of humidity of the leaf, according to temperature, the probability of their infection by the disease.

The first fungicide treatment is applied as soon as the conditions for the infection are present, and the following applications are applied according to the residual activity of the pesticide and the other forecasts of infection.
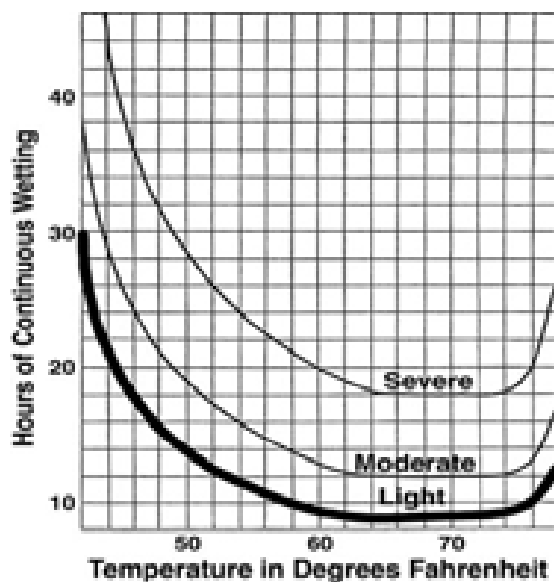
Infection of leaves by scab.

5.4. Detection of quarantine organisms (sampling) and plant health certificates

Protecting crops against their enemies is a **question of general interest**, which requires an **organisation** capable of **preventing the introduction** of a plant pathogen into a given country or area and of issuing the certificates required to market plant products.

In the first case, **the crops in unaffected countries or regions are the priority** of the regulations. In the second case, the main aim of the regulations is to **protect the product being marketed and its user**. The merchandise may not constitute a risk to plant health as such, but it may be a carrier of harmful organisms.

Since March 2005, new European regulations and new obligations imposed on **wood packaging** have come into force.[1] The Directive aims to bring European legislation in line with the provisions of the "International Regulation for phytosanitary measures - NIMP N° 15" of the FAO relating to the "Directives on the Regulation of Wood Packaging Material in International Trade". From now on, any wood packaging material originating in a third country used in the export of foodstuffs to Europe must be the subject of plant health certification. The targeted products are mainly wood packaging material in the form of bins, boxes, crates, as well as pallets, bin-pallets and other loading stations. The third-party countries which carry out the export are therefore obliged to carry out a plant health examination of the wood products they use and to provide proof that the wood has been stripped, has undergone an appropriate thermal treatment at 56 °C, or appropriate fumigation, or even chemical impregnation under pressure.

5.4.1. International Plant Protection Convention (IPPC)

The International Plant Protection Convention (IPPC) was signed in 1951 under the aegis of the FAO. The convention was reviewed in 1997 in the wake of the Agreements of the Uruguay Cycle of the World Trade Organisation (WTO), particularly the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement). The convention is the result of international collaboration on plant protection and the prevention of the dissemination of agents harmful to plants (animals, viruses, prokaryotes, fungi, weeds). It reaffirms the need for plant health measures which are technically justified, transparent and compliant with the SPS Agreement and it supplies a framework which guarantees that the plant health regulations put in place have a scientific basis justifying their application and that they do not constitute a hidden restriction on international trade.

One of the most important measures as far as the IPPC is concerned consists of drawing up the inventory of harmful organisms which are particularly dangerous, whose

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1   Directive 2004/102/EC of 5 October 2004, amending Annexes II, III, IV and V of Council Directive 2000/29/EC on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community.

introduction to the Community must be prohibited, and harmful organisms whose introduction through certain plants or plant products must also be prohibited.

5.4.2. Risk evaluation procedures

Any plant health regulation must be based on a **risk evaluation** in accordance with a procedure which the FAO has codified (**PRA procedure**). The 'Pest Risk Analysis' is a process consisting of **evaluating biological evidence** or other scientific or economic data to determine whether a harmful organism should be regulated, and the severity of any plant health measures to be taken against it.

This procedure concerns harmful agents which meet the definition of a quarantine organism. According to the IPPC definition, a quarantine organism is a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled.

The risk evaluation procedure will take into consideration criteria of a geographical, biological and economic nature into consideration such as the probability of establishment of the pathogen, its potential spread and the economic consequences of its introduction in a geographical region in which it is absent. Once the level of risk has been evaluated, all the means likely to reduce this risk to an acceptable level are envisaged. The principle of the « minimum impact » recommended by the IPPC is to adopt quarantine measures whose restricting nature is proportional to the level of risk.

One of the essential requirements of a risk evaluation is to be able to have available accurate and reliable information about the geographical distribution of the agent under consideration. In this respect, the FAO, the RPPO (Regional Plant Protection Organisations) and various international organisations (CAB, EU etc.) publish documents that make it possible to monitor the emergence of pathogenic agents and their distribution world-wide.

5.4.3. Monitoring quarantine organisms

Inspecting consignments is an essential element of managing plant health risks, and it is the plant health procedure most frequently used to establish whether or not harmful organisms are present and/or their compliance with the plant health requirements of the destination market.

❑ **Basis for sampling**

Each batch must be checked. A whole dispatch cannot always be inspected, which is why the phytosanitary inspection generally involves samples from the dispatched lots.

A '**dispatch**' may comprise one or several batches of products. When it involves more than one batch, the inspection aimed at establishing compliance will possibly give rise to several different visual examinations, which involves **sampling the batches separately**. In this case, the samples relating to each batch must be isolated and identified so that the batch concerned can be clearly identified if a subsequent inspection or analysis shows that it does not comply with plant health requirements.

Sampling within a batch begins with **identification of the most suitable sampling unit** (e.g.: *n* fruits, unit of weight, bag, carton) depending on the product.[2] As a rule, fruits or vegetables are inspected during sorting in the station or during packaging.

When compiling the sampling plan, the level of acceptance for a quarantine organism must be fixed at **zero**, and the **calculation of the number of samples** must be carried out on this basis.

In order to calculate the number of samples to be examined (**n**) out of a population (= one batch) of fruit/vegetables (**N**), 2 possibilities must be taken into consideration:

- Sampling of **small batches**: the size of the sample (n) > 5% of the size of the batch (N).
  In this case, when a unit from the batch is sampled, **the probability** that the next unit sampled will be infested changes. Sampling, without any replacement in a small batch, is based on a hypergeometric distribution.
- Sampling of **large batches**: the size of the sample (n) < 5% of the size of the batch (N).
  In this case, for large size batches which have been adequately mixed together, sampling is based on a binomial distribution or a Poisson distribution.

> **Please note!**
>
> Even if no individual (egg, larva or adult) is detected in the sample examined, the probability that an organism is present, even at a very low level, remains. The threshold of monitoring in principle is not in itself a guarantee of plant health compliance.

Simple random sampling is used. In practice, the **operator uses Tables from Standard ISPM No. 31** (*Methodologies for sampling of consignments* (FAO, IPPC 2008).

❑ **Calculating the number of units to examine in small batches**

In **Standard ISPM No. 31** – *Methodologies for sampling consignments* (FAO, IPPC 2008), the operator will find 4 tables[3] indicating the minimum number of samples to be examined according to the number of fruits/vegetables in a batch and the confidence level selected (80%, 90%, 95% or 99%). As a general rule, a confidence level of 95% is deemed to be sufficient.

The size of the sample is determined from the level of detection and the degree of efficacy.

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2   Distribution not approved.

3   The Tables are available on the IPPC site (www.ippc.int) on the welcome page: Click on "Adopted Standards" to obtain the ISPM No. 31 standard.

Minimum sizes of the sample for a 95% confidence level, according to the size of the batch, with the level of acceptance being 0:

Number of units in the batch	P = 95% (confidence level) % level of detection × efficacy of detection				
	5	2	1	0,5	0,1
25	24*	-	-	-	-
50	39*	48	-	-	-
100	45	78	95	-	-
200	51	105	155	190	-
300	54	117	189	285*	-
400	55	124	211	311	-
500	56	129	225	388*	-
600	56	132	235	379	-
700	57	134	243	442*	-
800	57	136	249	421	-
900	57	137	254	474*	-
1,000	57	138	258	450	950
2,000	58	143	277	517	1553
3,000	58	145	284	542	1895
4,000	58	146	288	556	2108
5,000	59	147	290	564	2253
6,000	59	147	291	569	2358
7,000	59	147	292	573	2437
8,000	59	147	293	576	2498
9,000	59	148	294	579	2548
10,000	59	148	294	581	2588
20,000	59	148	296	589	2781
30,000	59	148	297	592	2850
40,000	59	149	297	594	2885
50,000	59	149	298	595	2907
60,000	59	149	298	595	2921
70,000	59	149	298	596	2932
80,000	59	149	298	596	2939
90,000	59	149	298	596	2945
100,000	59	149	298	596	2950
200,000 and over	59	149	298	597	2972

Example of application:

For a batch of approximately 2,000 fruits, if we estimate that on average the percentage of infested fruits is 2%, 143 fruits must be sampled (approximately 7% of the fruits).

The confidence level of 95% means that on average only 5% of infested fruits will not be detected.

❑ **Calculating the number of units to examine in large batches**

In **Standard ISPM No. 31** – *Methodologies for sampling of consignments* (FAO, IPPC 2008), the operator will find 2 tables (one according to the binomial law, the other according to the Poisson law) indicating the minimum number of samples (n) to be examined in the large batches depending on the confidence level chosen (95% or 99%). The size of the sample is determined from the level of detection and the % of efficacy.

Minimum sizes of the sample for 95 or 99% levels of confidence, according to the values of efficacy, with the level of acceptance being 0:

n according to the binomial law				
% of efficacy	**P = 95% (confidence level)**			
	% level of detection			
	5	2	1	0.5	0.1
100	59	149	299	598	2995
99	60	150	302	604	3025
95	62	157	314	630	3152
90	66	165	332	665	3328
85	69	175	351	704	3523
80	74	186	373	748	3744
75	79	199	398	798	3993
50	119	299	598	1197	5990
25	239	598	1197	2396	11982
10	598	1497	2995	5990	29956

n according to the binomial law				
% of efficacy	**P = 99% (level of confidence)**			
	% level of detection			
	5	2	1	0.5	0.1
100	90	228	459	919	4603
99	91	231	463	929	4650
95	95	241	483	968	4846
90	101	254	510	1022	5115
85	107	269	540	1082	5416
80	113	286	574	1149	5755
75	121	305	612	1226	6138
50	182	459	919	1840	9209
25	367	919	1840	3682	18419
10	919	2301	4603	9209	46050

Minimum sizes of the sample for 95 or 99 % levels of confidence, according to the values of efficacy, with the level of acceptance being 0:

% of efficacy	n according to the Poisson law				
	P = 95% (confidence level)				
	% level of detection				
	5	2	1	0,5	0,1
100	60	150	300	600	2996
99	61	152	303	606	3026
95	64	158	316	631	3154
90	67	167	333	666	3329
85	71	177	353	705	3525
80	75	188	375	749	3745
75	80	200	400	799	3995
50	120	300	600	1199	5992
25	240	600	1199	2397	11983
10	600	1498	2996	5992	29958

% of efficacy	n according to the Poisson law				
	P = 99% (confidence level)				
	% level of detection				
	5	2	1	0,5	0,1
100	93	231	461	922	4606
99	94	233	466	931	4652
95	97	243	485	970	4848
90	103	256	512	1024	5117
85	109	271	542	1084	5418
80	116	288	576	1152	5757
75	123	308	615	1229	6141
50	185	461	922	1843	9211
25	369	922	1843	3685	18421
10	922	2303	4606	9211	46052

Example of application:

For a batch of approximately 400,000 fruits, if we want to be able to detect with 95% confidence an infestation of 1% of fruits with an efficacy of 80%, 353 to 375 fruits must be sampled, i.e. approximately 0.1% fruits to be examined. The 95% confidence level means that on average only 5% of infested fruits will not be detected.

5.4.4. Plant health measures implemented

❑   **Quarantine and eradication measures**

Plant health regulations may prohibit importation, submit their authorisation to a prior plant health inspection or make disinfecting of the merchandise obligatory. Once the first source of a quarantine agent has been declared, we can try to prevent its spread by means of a regulation imposing the detection of the disease, the application of certain measures with a view to eradicating or limiting it, or sometimes even abandoning growing some sensitive species or varieties.

❑   **Certification**

The plant health certificates are **issued by a qualified authority** which must guarantee that the product is free from any disease covered by quarantine laws. Issuing plant health certificates is therefore entrusted to technically qualified operators duly authorised by the national organisation for the protection of plants to act on its behalf and under its control, possessing the necessary knowledge and information so that the importing authorities can accept the plant health certificates of other States as reliable documents. For Europe, the Plant Health Certificate must be compiled according to the Model shown in Annex VII of **Directive 2000/29/EC**.

For the so-called 'quality' organisms, certification guarantees the user a product suitable for the use for which it was purchased.

❑   **Cost/benefit of regulatory measures**

A preventive plant health regulation will only be adopted after having compared the cost of applying these administrative measures and whichever of the means of control which must be implemented if the disease has been introduced to the country.

Chapter 6

Developing a crop protection strategy

6.1. General aims and principles of plant health control

6.1.1. Foundations of plant health control

In the long term, plant health control is pointless unless adopted as part of an overall approach, a **well-thought out strategy**, which can only be constructed on the basis of firm, fundamental knowledge:

- crop management (agronomics) and **awareness of biological data** about pests (including harmfulness of parasites and action of parasitoids);
- knowledge and study of the agro-ecosystem (including **crop sensitivity** to pests according to their stages, the variety, and so on);
- awareness of all the **environmental and cultural factors** that encourage or discourage not just diseases, pests and weeds, but also their antagonists;
- knowledge of **non-chemical methods of protection** and alternative products;
- knowledge of biological and physical-chemical properties of **crop protection products** (including method of action, effective dose, persistence and side effects, formulations);
- **knowledge of regulations**: substances that are authorized and those that are prohibited, restrictions of use, authorized dosage, pre-harvest interval (PHI), maximum levels in authorized residues (MRL) in relation to destination markets of products;
- competence in **good plant protection practices** (GPPP) and application techniques;
- knowledge of **commercial requirements** relating to authorized practices within the crop in order to obtain certification.

There have been many changes in the field of plant health control:

- **'Blind' chemical control:** based on a calendar of treatments, established by estimating a recurrent risk (but one not specific to the production plot); is disappearing as not profitable.

- **'Recommended' chemical control:** avoiding systematic insurance treatments based on advice, organized warnings, proven crop protocols.

- **'Directed' or 'rational' chemical control:** risk incurred at plot level, calls upon the notion of "economic threshold of damage" and selectivity of the pesticides towards the auxiliaries; it requires qualified growers and technical assistance.

- **'Integrated control':** based on the management of populations of harmful organizations through integration, and not on the juxtaposition of all the preventive and control techniques, whether cultural, genetic, mechanical or biological, in order to reduce recourse to chemical control; it involves taking into account, and knowledge of the whole agro-ecosystem and of the products introduced within the framework of the intervention; it requires highly qualified operators.

6.1.2. Plant health control and sustainable agriculture

In 1987, the Brundtland Report emphasized that deterioration, pollution and absence of growth go hand in hand in developing countries. It came out in favor of a growth policy which took into consideration the constraints of the environment and defined the concept of '**sustainable development**'.

> In the report entitled *Our Common Future*, the United Nations Commission on Environment and Development provides the following definition:
>
> "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".
>
> Brundtland, G., *Our Common Future: The World Commission on Environment and Development,* Oxford, Oxford University Press, 1987.

Sustainable development in agriculture means being aware of **and limiting the impact on the environment of the inputs used**, and particularly that of pesticides on the health of operatives and on the environment. This calls for a thorough understanding of the agro-ecosystem, and then knowledge of the toxicity, the degradability and the mobility of the pesticides used in the soil, water and air and their effects on biodiversity, with a view to using every means possible to reduce the undesirable side effects of treatments.

Integrated agricultural production represents the final stage of a strategy aimed at optimizing, under conditions which are economically satisfactory for the grower, each of the elements of the polynomial "*quality/quantity/cost of production/environmental protection/compliance with standards*". All the impacts of agricultural activities on the environment are taken into consideration when assessing the integrated agricultural production of an undertaking.

As such, the burning question is how to protect crops and harvested products when introducing practices that fit into this scheme of things. Integrated agricultural production associates the notion of **integrated regulation** of pests and diseases within a rational system of fertilization and a selection of varieties appropriate to the crop protocols proposed. However, it is important not to lose sight of the fact that the final 'judge' remains the consumer who wishes to purchase **a healthy**, good **quality** and **financially affordable product**.

The aim is to bring about a competitive agriculture that finds the right balance among the following factors: the economic goals of the growers, environmental respect, consumer expectations, requirements of distributors and those of the processing industries. For growers, the reward for these efforts must be their continued presence on international markets, and, if possible, the growth of their market share (e.g.: growth of the 'organic' banana market).

6.2. The various stages of intervention

6.2.1. Principle of the procedure

The procedure to be followed in order to establish effective plant health control therefore involves a series of stages which can be roughly simplified as follows:

Identifying

Diseases, pests, weeds

Insects/acarids, both useful and antagonistic

Defining

Level of infestation compared with threshold of intervention

Deciding

Ways of intervening
Alternative methods
Chemical methods as required

Evaluating

All the impacts of the intervention:
- Production
- Operator health
- Health quality of products
- Effects on the environment
- Profitability

6.2.2. Stage No. 1: Identification

- Identification and inventory of pests (biology, ecology, aetiology).
- Evaluation of the growing system: genotypes, economic value, role in the agricultural undertaking, system of rotation, sensitivity according to stages.
- Relations with the natural enemies present, firstly, and with their host plants, secondly.

6.2.3. Stages Nos 2 and 3: Evaluation and comparison with the threshold of intervention

Evaluating whether the intervention or treatment envisaged is necessary implies awareness, in terms of potential production loss, of the respective harmfulness of the identified pathogenic agents, pests or weeds, according to the crop in question and its stage of development and environmental factors.

Depending on the types' pest problem, there are several methods of identifying them and evaluating their populations:

- **For insects:**
  The methods of observation, counting and trapping (visual trapping, colored trapping, olfactory trapping based on the use of pheromones)

- **For pathogenic agents:**
  Direct observation (bacteria, viruses, fungi). It must be possible to recognize the emergence or the development of abnormalities, and to identify the exact cause of the symptoms observed (modifications to color, damage to organs, anatomical modifications).

- **With regard to weeds:**
  The regular observation of the plot remains the simplest method of evaluating weed populations.
  On the other hand, their identification is always problematic, especially when it comes to recognizing the young stages of weeds.

In order to intervene at the right time, particularly to rationalize the use of insecticides, **the notion of threshold of intervention, adapted to actual pest pressure, is recommended**. The methods of observation and the notions of the threshold of intervention have been discussed in the previous chapter.

6.2.4. Stage No. 4: Deciding on methods of intervention

Selecting the intervention, and in particular the most suitable treatment, is difficult, as the farmer is almost always confronted with a complex problem associated with crop protection; in fact, attacks by one single pest are very much an exception, taking the form of 'plagues' (mites, rodents, birds etc.) which require special intervention techniques (e.g.: eradication campaigns). In other cases, the grower makes the choice himself or with the assistance of advisers (managers, extension workers, etc.), in order to make the best possible choice of '**technical package**' (otherwise known as a 'plant health kit').

The difficulties the farmer faces concern:

- Correct identification of pests, diseases or weeds
- Estimation of observed and potential losses
- The strategy of intervention (timing and the combination of interventions)
- The actual choice of control method/s
- The absence of preventive measures and effective alternative products

6.2.5. Stage No. 5: Evaluating impact

The effect of the treatment(s) selected must then be evaluated from every angle, which must create a balance between the 'costs' and the 'benefits' of the intervention(s):

- efficacy and profitability for the grower,
- selectivity for the crop and non-targeted organisms,
- **respect for Maximum Residue Levels or MRL (safety for the consumer)**,
- side effects for the operator, domestic and wild animals,
- effects on the environment (soil, water, plants, air),
- effects on growing techniques (e.g.: direct sowing, mechanized harvesting, etc.),
- or even, social consequences induced (e.g.: more free time as a result of using herbicides).

The most important problems associated with using pesticides are:

- Lack of training
- Inappropriate choice of pesticide
- Poor quality formulations or products which are unsuitable for the use required (packaging too bulky; training inadequate for the application technique available)
- Lack of skill of operators, which results in non-compliant applications (failure to comply with doses, failure to comply with volumes of mixture/ha, spray drift, poor maintenance of equipment, etc.)
- Failure to comply with regulatory intervals (PHI) and lack of traceability
- Absence of, or refusal to wear, personal protection equipment (PPE)
- Dangerous storage

The advantage and the methods for each intervention may feature in a **Validated Crop Protocol** (for example by analyzing residue on harvested products and measuring the biological efficacy of the treatment) which guarantees compliance with the '**Good Agricultural Practices**' (**GAP**) to obtain optimum protection, while complying with the MRL values (maximum limits applicable to residues).

6.3. Principal strategies

6.3.1. Conventional and rational chemical control

The success of plant health control has been crucial in obtaining a very high agricultural output over the last thirty years, in both industrialized countries in the North and developing countries in the South. **Chemical pesticides** have been its main tool. Without them, we probably would not have been seen the excess of wheat and maize in the North, or the 'Green Revolution' which has allowed several countries in the South to become self-sufficient in food.

Traditional chemical control against disease or crop pests basically requires the use of **plant protection products**. The latter, more generally known as **pesticides***,* are substances used to protect harvests against their enemies, clean up plots and exercise physiological action on plant growth.

These are often products which act on mites, insects, nematodes, fungi, weeds and bacteria. Growers have been so impressed by the spectacular initial reduction of damage on crops and the gain in production per hectare, that they have tried to use increasing amounts of product, thus wasting their resources while contaminating the underground water and the soil. Other problems have confounded the situation: spraying apparatus which is often badly maintained, presence of chemical substances damaging to health, safety advice which is incomprehensible to farmers or ignored.

Farmers involved in subsistence agriculture in ACP (African, Caribbean and Pacific) countries in fact hardly ever have recourse to pesticides (as can be seen from the figures below), but even if they only make limited use of them for certain crops like cotton, coffee, pineapple, or banana, **they suffer the consequences:**

- consequences on their health and the environment because of incorrect use;
- economic consequences arising from the use of these products by their neighbors and competitors who are able to flood the market with large quantities of food at very competitive prices.

❑ **Developments in the use of pesticides**

Tobacco juice (nicotine) was one of the first insecticides of the modern era, while the use of arsenic and sulphur can be traced back to Antiquity. However, chemical control only developed in the 19th century, with the use of products of vegetable origin (rotenone and pyrethrum) or mineral origin (copper and arsenic). In 1939, P. Muller discovered the properties of DDT (**d**ichloro**d**iphenyl**t**richloroethane), which was marketed in 1943. Organophosphorous compounds appeared in 1950 (malathion) and progressively replaced the organochlorine compounds, which were blamed for accumulating in the food chain and the environment, although their acute toxicity was often higher. In 1973, pyrethrinoids appeared (permethrine) followed by numerous other molecules with an even higher biological activity (e.g.: sulfonylurea herbicides, neonicotinoid insecticides, etc.) which allow **the dose applied per hectare to be progressively reduced** (to only a few grams of active substances/ha).

The world market (approximately 40 billion dollars) has been stable overall for several years (2000). It is important to bear in mind that certain recent climatic events (heat and drought in Europe, rain in Oceania) have a strong influence on these figures. In Europe and in North America, herbicides represent 70 to 80% of the products used (in particular because of the strong increase in maize crops) whereas in the tropics, 50% of products applied are insecticides. Crop diversification, bringing about improved standards of living in some countries, also changes this balance, and China has also converted the equivalent of the surface of England from paddy fields to market garden crops, resulting in the diversification of products used.[1]

World pesticide market (source: ORP, 2010)
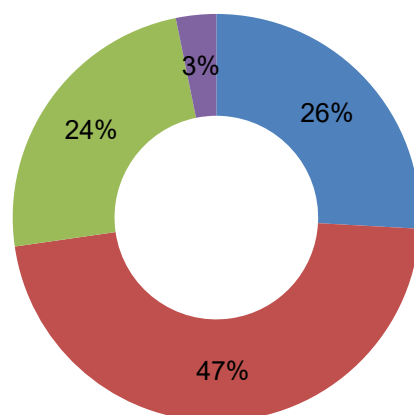

■ Europe ■ North America ■ Asia ■ Africa ■ South America

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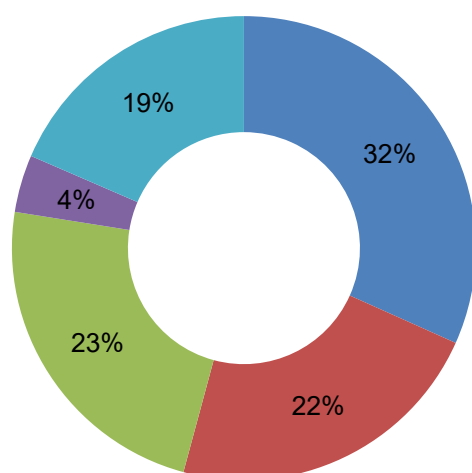
[1] According to the ORP, Observatoire des Résidus de Pesticides (Organisation Supervising Pesticide Residues). Consult: http://www.observatoire-pesticides.gouv.fr/

Distribution per type of product (source: ORP, 2010)

Although this results in a better food supply for the consumer, the inappropriate and/or excessive use of pesticides does however lead to **various undesirable side effects,** particularly **on the environment and human health**.

The contamination of the environment and the absorption of residues of pesticides contained in the food and drinking water clearly have harmful repercussions on health. These undesirable effects have led several international organizations, such as the FAO (International Code of Conduct FAO, Rome 1985), the OECD, the UNEP or the EU to take action with governments to ensure that they review their regulations on production, purchasing, marketing and the use of pesticides.

At European level, it is the European Commission which regulates[2] the marketing and use of pesticides via a series of Regulations and Directives. The aim is to harmonize the procedure for evaluating plant health products in the Member States of the European Union.

The emergence on the market of new substances which are more active, the improvement of treatment techniques, the need to reduce production costs, the development of threshold treatments, the pressure from society for better respect of the environment and for better health security, national and European politics for voluntary reduction of the use of pesticides have together led to a stagnation, or even a reduction, in volumes whereas the average value of products has increased because of the spectacular growth of costs necessary for their development.

❑ *Development of the principles of chemical control*

Taking into account the extent and frequency of the damage caused by a complex of pests or diseases led agronomists, in the initial phase of development of chemical

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[2]   We can quote: Regulation (EC) 1107/2009 concerning the placing of plant protection products on the market; Directive 2009/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides; Regulation (EC) 1185/2009 concerning statistics on pesticides; Regulation (EC) 1272/2008 on classification, labelling and packaging of substances and mixtures (regulation CLP); Directive 2009/127/EC with regard to machinery for pesticide application.

control, to recommend programmes of **systematic interventions** justified by analyzing the '**risk of infestation**' and **generally based on the life cycle of the plant** ('treatment calendar'). Calendar programmes were based on the likelihood of encountering a pest at a given point in the cultural cycle. This determined the choice of active materials. The dose of active material to be applied depended not only on the enemy targeted, but was also dependent on the behavior of the product after application (persistence). The basis of traditional chemical control merely consisted of using tests to determine: the *frequency* of interventions, the *choice of products* and the *dose to be used*.

However, systematic treatments **are expensive for the grower** (and some are not even necessary) **and have the opposite effect**: destruction of the beneficial insects which naturally limited populations of pests ("boomerang effect") and the development of populations of insects, acarids or diseases resistant to the product.

> Little by little, chemical control essentially based on calendar treatments were **replaced by better thought-out treatments**, **based on observations** made in situ or estimates of infestations (e.g. 'warnings'), and the use of more specific and more selective products.

The aim of rational chemical control is to **reduce the number of treatments** and **reduce the pressure of selection** affecting pests. To *reduce the number of treatments*, the notion of 'thresholds of intervention' must be respected. In order to **reduce the pressure of selection**, a pesticide must only be applied when its use has become essential, then different mechanisms of toxicity must be combined, before limiting repeated applications of the same chemical family.

> **Reminder of the 'thresholds of intervention'**
>
> Three states of a pest population can be distinguished:
> * one in which it is developing freely, with or without superposition of generations, but at a medium level which can be defined as the 'natural threshold of equilibrium';
> * if the plant cannot compensate for the damage caused by the pest, there is a loss compared with the production potential. The pest density considered bearable for the crop results in the notion of 'threshold of harmfulness'. If the threshold of equilibrium is higher than the threshold of harmfulness, the grower envisages intervening: this is the 'threshold of intervention';
> * the population which is maintained on this side of the threshold can then survive without arousing any particular worry for the growers. This is an important point, as many growers feel that all the individuals of a population of predators must be eliminated, which is neither realistic, nor profitable.

6.3.2. Biological control

Biological control is a method which consists of fighting a
pest by **using** or **encouraging its natural enemies**, or a
disease, by favoring its **antagonists**. Biological control
targets pests above all (insects, mites and nematodes).

The following are considered to be natural enemies of crop
pests: predator organisms, parasitoids or infectious
organisms (entomophagous fungi, viruses) which limit the
frequency and severity of pullulations.

➢ **Predators** immediately consume the prey they capture or use them to nourish their
progeny. This category includes: Neuroptera Chrysopids and Hemerobida, as well as
numerous species of Coleoptera, Diptera (flies), Thysanoptera (thrips), Hymenoptera
Vespida (paper wasps) and Sphecida (sphecoid wasps), spiders and carnivorous
acarids. The predators are usually restricted to a very particular type of habitat where
they "devour" all the prey they manage to trap. In species whose larvae are also
predators, the female lays her eggs in places likely to house a large number of
suitable prey. Most predators are classified as generalists because they attack
numerous types of prey without distinction. Their regulating action therefore affects all
the pests present in the environment, although the attacks are usually directed at the
most abundant prey.

➢ **Parasitoids** are insects which lay their eggs on or in the body of an insect from
another species. Their larvae consume the host's tissues and eventually kill it. Some
families of Diptera (or flies) and Hymenoptera belong to this group. The parasitoids
are usually very specific in terms of their choice of host and can only survive if this
host is present in the environment. On account of this specificity, they do not
represent any danger to other organisms. The parasitoids demonstrate great skill in
locating their prey even when the density of the host population is low.

➢ The term **pathogenic agent** is used to refer to any microorganism which infects the
cells and tissues of a host and multiplies there. Fungi, viruses, bacteria and protozoa
all have entomopathogenic species among their members. Infection occurs by
ingesting food or by penetration through the teguments of insects. In some cases, the
infection is transmitted by the female to its progeny. Under certain conditions, the
epidemic spreads over huge surface areas (epizootia) and can lead to virtually total
elimination of the pest. The pathogenic agents are more numerous when the pest
populations reach high thresholds and they can often put an end to infestations.

The importation of natural enemies to combat these new pests is gradually coming to
occupy an important place in biological control. Initially the origin of the pest must be
established and its main natural enemies within its original environment identified. The
next step is to establish which of these natural enemies presents the highest potential
and, therefore, is worth being imported before it is introduced in the regions where the
pest has become a problem. Because of their specificity, parasitoids are often selected,
but various species of predator have also been successfully introduced.

Even if, in practice, the success of biological control, used alone, is limited, this method
has been the subject of numerous research experiments and trials throughout the world.
Moreover, it has sometimes long since been used intuitively by farmers on the strength of

their own observations. It is at its best and reveals its potential when combined with other control methods within the more global scenario of integrated control.

6.3.3. Integrated control

Favoring Integrated Plant Health Control (IPHC) probably constitutes one of the methods capable of reducing the use of chemical pesticides, particularly in ACP countries. Currently, twenty years or more after the introduction of this concept in the United States, there is no universally accepted definition of IPHC. For some people, IPHC is part of a broad approach, leading to agriculture 'without chemical products'. For other people, it is a system leading to the more effective use of chemical pesticides. However, everyone agrees that IPHC requires a wider adoption of non-chemical procedures relating to plant health control.

> According to the FAO definition, **Integrated** Pest Management (IPM) is:
>
> "a control system which, by taking into account the environment in which the pest species lives and its demographic dynamics, calls upon all the appropriate techniques and methods, bringing them together as much as possible, in order to maintain the populations of pests at fairly low levels in order to avoid causing economic damage".

In other words, integrated control (IPM = Integrated Pest Management) is a **procedure** which aims to **contain the damage caused by pests at economically acceptable levels in terms of local production using methods of control which are as natural as possible.**

It gives priority to the **prevention of infestations** through recourse to **adapted growing techniques** and **recourse to biological control** instead of using pesticides which are only used judiciously and selectively, when no other solution is available or economically viable.

It also makes use of **phytogenetic resources** with the use of plants adapted to ecological conditions, resistant or tolerant to certain diseases and insects.

❑ Cultural practices and crop protection

In order to establish crops under optimum conditions of growth, it is important to **choose growing sites appropriate** to the variety to be established: exposure, type and structure of soil, slope.

By avoiding the coincidence ('**staggering plant growth**') often necessary between one given stage of development of the host plant (e.g.: seedling stage) and the contaminating or infesting stage of the disease or pest, it is possible to reduce the damage caused to crops. In order to determine the most favorable date of sowing, growth cycle and crop development must be compared with **the dynamics of the populations** of pests.

Crop rotation, **crop association**, selection of preceding crops, interspersed crops, present various advantages from a plant health point of view:

- **Using the soil resources to the best of its possibilities**: growing the same species continuously or bringing it back frequently to the same area of ground leads to imbalanced farming of the various layers of soil. After several monocultures, the layer of soil from which the plant takes it mineral elements begins to be depleted. In addition, the root system of some plants produces exudates which accumulate in this layer of soil and may bring about autointoxication of the crop (onions*)*.

- **Avoiding the development of diseases and pests**: diseases and pests specific to the species or family grown can survive from one year to another in the ground (e.g.: Sclerota of fungi, cysts of nematodes, etc.) or on crop remains (pupa of insects in stems etc.). The frequent replanting of the same crop or similar crops can thus **lead to the proliferation of these organisms** and the development of epidemics. Crop rotation can hence reduce some plant health risks. As some diseases and pests are common to various crops, crop rotation which is sufficiently long and varied is recommended. Introduction within the rotation of plants which can trap pests or periods of fallow can also reduce the incidence of some plant health problems.

- **Avoiding the development of specific weed flora***:* the repeated use of the same selective herbicides (or those which have the same method of selection) usually leads to the selection of a specific kind of weed flora which may be difficult to control after a few years. Because of the absence of soil cover, some crops also favor the development of weeds. Others, providing rapid cover, are, on the other hand, stifling for weeds. Crop rotation makes it possible to benefit from the cleaning effect (either natural, or using mechanical methods) of certain crops and to alternate weeding strategies. This makes it possible to **control weeds over the whole rotation.**

- It seems that **some crops associated** with other ones have an effect on the dynamics of pests (favoring insects or keeping them away from the main crop) or on the reinforcement of the density of the useful insect fauna.

The **destruction of the residues from the harvest** is a long-standing practice and it is effective if carried out correctly. Deprived of their host plant, pests adapt by entering the diapause or they migrate towards other hosts or other locations. Reducing the number of host plants during the dry season or the cold season makes the survival of species which have a low migratory power less likely. In monophagous or oligophagous insects, which survive in the diapause state, careful destruction of harvesting residues can limit the populations. This operation involves mechanical action using a rotary shredder or by grazing of the green parts of the plant by domestic animals. For species in the diapause in the surface layers of the soil, ploughing is effective. The chrysalids, which have risen to the surface of the ground, are destroyed by heat or by predators. It is also common practice, in Africa, to cut off crop remains, particularly on cotton plants, and then to burn them. This practice is not very effective if only the stems are destroyed as regrowth must also be halted. In fact, it is possible to see on regrowth multiplication of certain pests (Homoptera), or a concentration of infectious agents (viruses and mycoplasms). Burning does not allow weeds to be controlled in the most critical periods for crops.

If it is a practical option, **ploughing** both kills off the species present on the surface of the soil by burying them, and brings to the surface those found in the soil, such as 'white worms', where they die or are eaten by predators.

There is **interaction between fertilization and plant health protection**. The profitability of inputs of fertilizer depends on setting up a plant health protection programme adapted

to the potential of the crop (selection of varieties that make effective use of chemical inputs). Whether applied to the soil or via a nutritional solution, fertilization must be balanced. **The excessive use of nitrogen must be avoided**: excessively vegetative and luxuriant growth favors the development of numerous diseases, insect pests and weeds. Rationalizing fertilization is a concept that is gaining ground today as the farmer, under the pressure of economic constraints, tries to limit production costs and give preference to immediate profitability. At the same time, **conserving and improving the fertility of the soil** (including conserving humus) remains an essential aim of integrated agricultural production. Leguminous plants, grown as the main crop or undersown, retain a quantity of nitrogen into the soil which is advantageous for the next crop.

❑ **Use of phytogenetic resources**

To be able to have **resistant plant material**, or material which is at least **tolerant** to disease and to the different pests, naturally represents the ideal solution for farmers, even though it is not definitive insofar as pathogens and pests may circumvent this resistance or this tolerance.

The selection of varieties which are of economic value, productive and resistant to disease, has been practiced instinctively by farmers since the very birth of agriculture.

➤ **Resistance** can be defined as the ability of a variety to produce a more abundant, high-quality harvest than ordinary varieties for the same density of pests. Resistance to a disease or a pest may be total or partial.

➤ **Tolerance** indicates the ability of a variety to develop and reproduce in spite of the existence of a population of pests identical to that which damages a sensitive variety. The use of resistant and tolerant varieties also encourages the survival of useful species; so this method naturally falls within the framework of integrated control.

❑ **Use of pesticides as part of integrated control**

In integrated control, crop protection products must not be used:
- unless they are essential and no other method of control has proved sufficiently effective or represents an economic burden which cannot be measured against the value of the marketable product;
- unless they do not present any risk to the environment, and especially if they are fairly selective towards beneficial insects or natural predators.

Nowadays, a large part of market garden production is produced under contract for food-processing companies which require compliance with **specifications** that expect producers to make **reasonable use of crop protection products or even apply integrated control**.

As an example, the chapter about Plant Protection in the Global-GAP reference framework, requires producers only to use "*selective products that are specific to the target pest, weed or disease and which have a minimal effect on populations of beneficial organisms*".

Although the approval procedures in force in the EU require the manufacturer to **check the selectivity of the pesticide towards beneficial organisms**, hardly any information is available from manufacturers! As there is no accurate and justified indication with regard to the selectivity of the plant health products towards the insect fauna useful for each crop and each region of the world, during regular audits, producers risk finding themselves in a situation of non-conformity which is economically extremely damaging (closure of market; loss of market share to European competitors; competition of the 'organic' sector with the conventional sector).

6.4. Strategy for protecting crops: Case study

Basis of case study[3]

Market garden crops in La Réunion frequently undergo attack from various insects and acarid pests such as aleyrodes, caterpillars or vegetable flies. As traditional chemical control has reached its limit, it is becoming essential to use other methods such as integrated control. Monitoring various experimental plots showed that beneficials can restrict the development of some pests in combination with rational chemical control.

❑ **Stage 1 – Identifying the pest organisms present**:

Aleyrodes or whiteflies

An inventory of the pests and beneficials on market garden crops is carried out. The main pests are identified, and are: the aleyrodes (*Bemisia tabaci, Trialeyrodes vaporariorum* on various plants), vegetable flies (*Neoceratitis cyanescens* on tomatoes, *Bactrocera cucurbitae, Dacus ciliatus and Dacus demmerezi* on cucurbitaceae), caterpillars (*Plutella xylostella* on cabbages, *Helicoverpa (Heliothis) armigera* on tomatoes) and thrips (*Frankliniella occidentalis* on tomatoes, *Thrips tabaci* on alliaceae).

Some of these pests can transmit serious viruses to crops, such as *B. tabaci, F. occidentalis* or greenfly. We will focus on aleyrodes (or 'white flies') in this example as these insects are highly important pests, particularly because of the viruses they are able to transmit.

❑ **Stage 2 – Screening and evaluating the beneficial organisms**:

The predators identified are basically bugs (Miridae, Anthocoridae), ladybirds and hoverflies. Insect pathogens are present but are still largely unstudied.

Parasitoid hymenoptera are widespread among aleyrodes, greenfly, miner flies and caterpillars. The inventory of parasitoids of aleyrodes has revealed the presence of about twelve species belonging to the genera Encarsia and Eretmocerus.

In order to follow the dynamics of the populations of the two main species of aleyrodes and their parasitoids, plots of tomato have been planted. In an initial test, a plot of 700 m² planted at the beginning of February was split into two halves, one undergoing a weekly

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[3] The case study presented is based on the article by Philippe Ryckewaert and Frédéric Fabre (CIRAD-3P, La Réunion) about integrated control in market garden crops in La Réunion. AMAS 2001. Food and Agricultural Research Council, Mauritius.

treatment with broad spectrum insecticides and the other remaining untreated. The aleyrodes were counted every week on sticky yellow signs while the samples from leaves with nymphs allowed the level of parasitism to be estimated. The observations show an increase in the populations of aleyrodes and miner flies on the treated part whereas they have reduced on the other part one and a half months after planting.

The rates of parasitism exceed 80% on the part which received no treatment whereas they barely reached 40% on the treated half. These observations show the benefit of favoring **natural biological control** against aleyrodes and the need to limit chemical treatments as much as possible and only with selective insecticides.

❑ **Stage 3 – The methods of intervention available**:

Crop control will consist of manipulating the habitat (e.g.: density in crops) in order to reduce the populations of pests. The environment is rendered hostile and unfavorable to the development of phytophagous by using resistant cultivars for example, or by manipulating the habitat by planting plants which are attractive for natural enemies.

Physical control will consist of using protective nets and sticky yellow traps in order to intercept aleyrodes. In the greenhouse, the quality and maintenance of filters are the main measures taken to limit the introduction of aleyrodes. One month before planting, the seal on the nets and filters is checked very carefully. All the tears are sewn up, small openings are closed up with silicon or a mixture of paint and chalk.

Chemical control will consist of selecting active substances and effective formulations (several populations of aleyrodes are already resistant) that are selective for parasitoids. From two weeks before planting up to 8 days before introducing auxiliaries, chemical treatments can be carried out using authorized products.

Some other alternative methods are still at the experimental stage.

❑ **Stage 4 – Determining the thresholds of intervention**

Predicting developments in the populations of these pests is difficult, and the thresholds of intervention are sometimes not very representative in a growing system like market garden crops where the conditions are highly diversified and complex.

Six to ten sticky yellow plates/ha are put in place 8 to 10 days before planting and maintained throughout the cycle, to monitor populations of aleyrodes. Treatments can be triggered as soon as there is more than 1 to 2 individuals per plate.

❑ **Stage 5 - Combining the different methods of control available**

Releases of *Encarsia formosa* are carried out every week for 3 months. They are rationed according to the emergence of populations.

Predator bugs such as Macrolophus and Cyrtopeltis are generally associated with the introduction of *Eretmocerus mondus* or *eremicus*, or Encarsia.

During a harvesting period, the method of rational control consists of maintaining a very good seal on the nets and of spraying insecticides as soon as the threshold of 5 to 10 individuals / plate is reached.
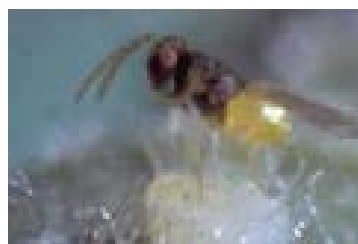
❑ **Stage 6 – Evaluating their impact**

The first experiments conducted in La Réunion have shown the advantage of natural biological control combined with rational chemical control to limit populations of pests on market garden crops.

Chapter 7

Chemical treatments of crops and harvested products

7.1. General information about plant protection products

7.1.1. Definition and general information about plant protection products

A **pesticide** can be defined as "a substance or combination of substances":

- which is intended to repel, destroy or combat:
  - **pests**, including the **vectors** of human or animal diseases (endo- and ectoparasites);
  - undesirable species of plants or animals causing damage or being harmful in some other way during production, transformation, storage, transport or marketing of foodstuffs, agricultural products, wood and ligneous products, or animal feed;
- which is used to:
  - restrict losses from crop returns;
  - protect stored food;
  - reinforce the farmer's position;
  - limit the development of human and animal pathogens;
  - destroy undesirable plants (herbicides, algicides, anti-moss agents);
  - destroy parts of plants, slow down or prevent undesirable plant growth (desiccants [haulm killers], anti-germination products etc.).

The term "pesticides" includes substances intended to be used as plant growth regulators, such as defoliants, desiccation agents, fruit thinning agents or to prevent the premature fall of fruits, as well as substances applied to crops, either before or after harvest, to protect the products against deterioration during storage and transport. The terms 'pesticides', 'agro- or phyto-pharmaceutical products' or simply 'phytos' are commonly considered as synonyms of **plant protection products**.

The term '**active substance**' (or 'active material' or 'molecules') is used to designate the **biologically active compound** (e.g.: deltamethrine) and 'formulation' to designate the ready-to-use commercial product or one which needs to be diluted in water (e.g.: DECIS 25 EC).

The active material, which is usually a chemical substance resulting from synthesis, has a common name (e.g.: chlorpyrifos-ethyl, endosulfan etc.) which corresponds to a particular chemical formula (developed formula).

Example of chemical pesticide (molecule of DDT)
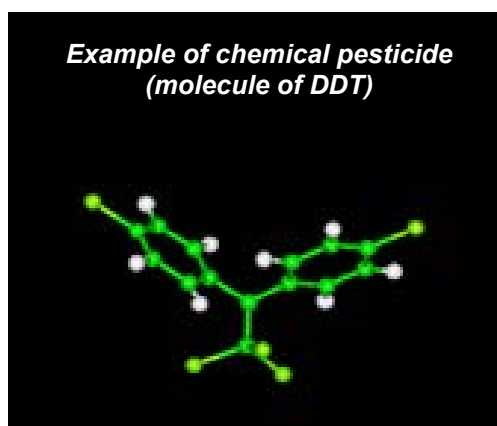
The **formulation** (commercial product) therefore contains **one or several active materials** (binary products, tertiary products, etc.) at well-defined concentrations expressed in g/liter or as a % depending on whether the formulations are liquids (SL, UL, EC, SC) or solids (DP, WP, WG).

It contains the active substance(s) and added substances or co-formulations (solvents, powders, emulsifiers, wetting agents, biocides, colorants, masks, and so on).

A product therefore consists of:
- one (or several) active molecule(s)
- formulation adjuvants
- packaging
- a label

Amongst the products used we find:
- **mineral** products (H_2SO_4, S, As, Cu… sulfo-calcium mixture,[1] Bordeaux mixture[2])
- **biological** products (Bt, fungi, viruses)
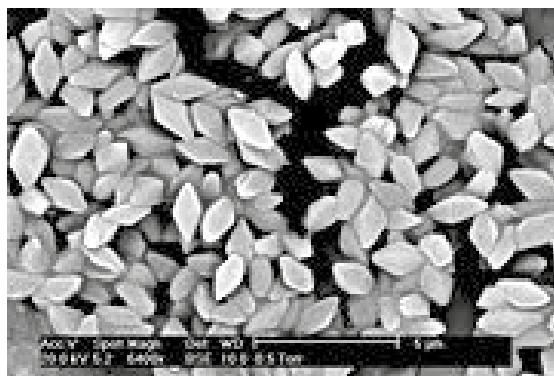
Bacillus thuringiensis or *Bt*   *Margosa*

- **plant** products or extracts (e.g.: Margosa, pyrethroids, rotenone)
- **products of synthesis** (most of them)

The products of synthesis are developed using:
- research in the form of 'screening test' (random selection)
- research by analogy (e.g.: pyrethroids)

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[1] Obtained by heating a mixture of milk of lime and sulphur (against scab, peach leaf curl and powdery mildew).
[2] Obtained by heating a mixture of slaked lime and copper sulphate (versatile fungicide, against mildew).

- research by 'designing' molecules (knowledge of type of action, enzyme processes targeted, specific reactions or study of relationships between structure/activity etc.).

In order to understand a product, its user must be aware of:

- its biological activity (= **use**), which may vary according to the intended target;
- its agronomic activity (= **use**, **intervention methods**);
- its physical-chemical properties (which will determine the type of formulation);
- its toxicity (acute, chronic, long term, etc. and its reference toxicological values: LD_{50}, DJA, ARfD, AOEL);
- its ecotoxicological properties (environmental behavior);
- its economic properties **(particularly the target market).**

7.1.2. Classification of products according to their biological activity

Different types of pesticide products are available to combat crop pests, diseases, adventitious plants (or 'weeds') etc.

In this way we can classify products into various categories according to their activity:

- insecticides and acaricides, which combat insects and acarid pests respectively;
- fungicides, which are able to combat pathogenic fungi;
- herbicides, which eliminate weeds;
- nematicides, which control phytoparasitic nematodes;
- rodonticides, used against rodents;
- helicides (or molluscicides), which combat mollusks (snails in particular);
- the growth regulators or substances which act on the physiology (growth, moulting etc.) of either plants (e.g.: shorteners or brighteners), or insects (e.g.: analogues of juvenile hormones, chitinase inhibitors etc.);
- repellents;
- elicitors, which trigger natural defense mechanisms in plants (especially against fungal disease).

For certain products with a specific activity, the activity referred to will be restricted. For example, for a specific anti-aphid insecticide (e.g. pirimicarb) the term aphicide will be used. Other examples: ovicide products (e.g.: certain mineral oils), crow repellents and corvicides, taupicides etc.

The actual activity will be completed by accurate information regarding:

- either its **method of penetration** (and/or 'contact' with the target) and/or displacement within the plant ('systemic' and 'non-systemic' products) (contact insecticides, systemic fungicides, contact herbicides, ingestion insecticides etc.);
- or its '**positioning**' (pre-emergence herbicides, pre-seeding herbicides, post-emergence herbicides, curative fungicide etc.);
- or its **selectivity** (as with herbicides) (total herbicide, anti-dicotyledonous herbicide).

A distinction must be made between the 'activity' of the product, its type of 'use' or methods of use, such as:

- its toxicity and the risks of exposure during use
- the recommended safety equipment (PPE) and emergency treatment
- the product's spectrum of action (any resistance)
- the dose /ha or the concentration/liter of the mixture (as a %) (if necessary adapted to suit the targets or to local circumstances, such as the type of soil)
- the (maximum) number of treatments authorized/season
- the recommended interval between treatments
- the point(s) of application (and of the first application)
- compatibility with other products
- selectivity compared with crop auxiliaries
- selectivity in relation to crop
- preparing the mixture
- the volume of mixture (per ha);
- the type of application equipment (recommended)
- the influence of environmental conditions on efficacy
- precautions for use relating to the drift (untreated zone, antidrift nozzles)
- the pre-harvest interval which must be respected (PHI)
- advice about satisfactory rinsing of packaging and its risk-free elimination
- the risks for the environment and the precautions to take (storage, transport, implementation, elimination)

Most of this information should feature on the label or on the instructions for using the product.

7.2. Properties and methods of action of insecticides

Nowadays, most insecticides on the market have **neurotoxic effects**.
Products which are active on the nervous system have effects:

- on transmission;
- on conduction.

The transmission of information, whether this involves perception or actions, takes place via the nerve tissue. Messages circulate via neurons. The process which accompanies the transport of information comprises: firstly, the **membrane** potential and the **ionic flows** which are its cause, and secondly the synaptic transport which involves different **chemical mediators**.

Representation of a neuron:
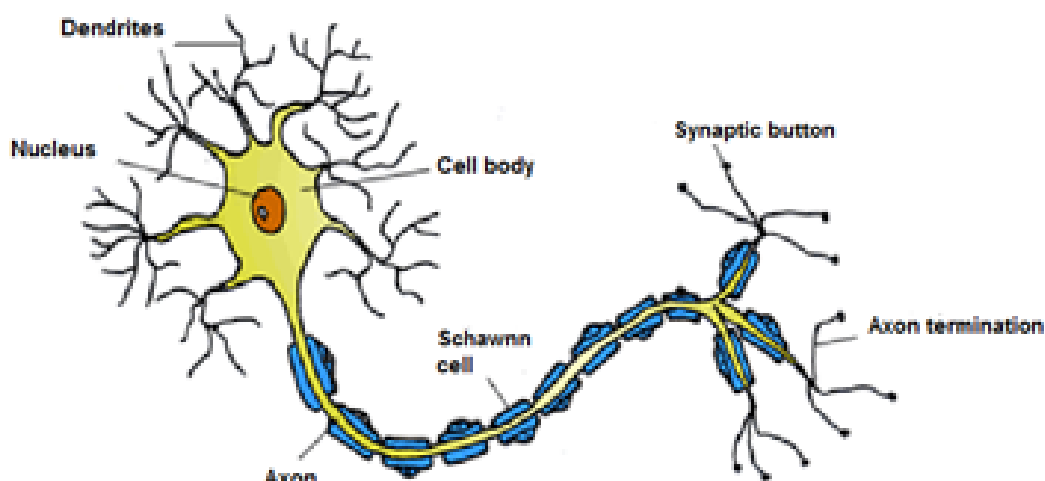
It is at the level of these two mechanisms that most of the molecules of the insecticides position themselves: thus, the organochlorines and the pyrethroids act on the conduction of the influx; the organophosphates and the carbamates act on the chemical synapse. The inhibition of acetylcholinesterase takes place at the end of the axon, **at the synaptic button** (linking place between two nerve cells). Acetylcholinesterase, an enzyme, is found in the blood and in the neuron synapses. It 'releases' acetylcholine. It may bind with the carbamates and OP (organophosphate) and become inactive!

Acetylcholine: chemical substance released by certain neurons in the synapses (=neurotransmitter). It ensures the transmission of the nervous influx to various places in the body.
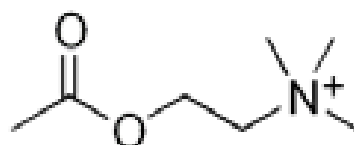
Diagrammatic representation of a synaptic button:

Direction of nerve impulse

Presynaptic membrane

Synaptic vesicle (neurotransmitter, acetylcholine)

Synaptic cleft

Postsynaptic membrane
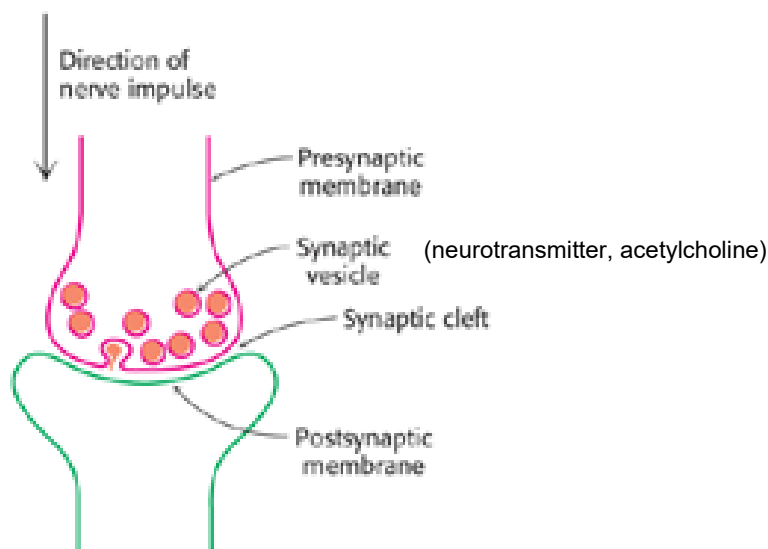
A nerve cell (neuron) consists mainly of a nucleus and a dendrite (or axon) which ends in a **synaptic button and a synaptic slit (or cleft)**, the location where information is transmitted from cell to cell.

In order to understand how the nerve message is transported to the brain, it is essential to understand how it is transmitted from one nerve cell to another. So we should explain how a synapse contacting both cells functions. The end of the pre-synaptic prolongation is formed by a swelling, the synaptic button, full of neurotransmitters (e.g.: glutamate, acetylcholine), contained in small blisters. A space known as the synaptic slit separates the pre-synaptic neuritis from the post-synaptic neuritis.

The post-synaptic membrane (designed to receive the influx) carries receptors specific to these neurotransmitters; and when the nerve influx reaches the synaptic button, it causes **the neuromediator to be expelled** (e.g.: acetylcholine) into the slit through the blisters bursting. The latter reaches the **receptor sites** of the post-synaptic membrane and triggers a nerve influx.

For the neurotransmitter to be released, *i.e.* for the blisters to burst, the receptor potential near the synapse must be located at a certain threshold of depolarization; the quantity released will then increase according to the level of depolarization.

The organochlorines and the pyrethroids act **on the** voltage-dependent **sodium channels** located on the axon. The sodium channel, or sodic channel of the potential for action, is an ionic channel specific to the sodium ions and responsible for the **depolarization of the neuron** and **propagation of the nerve signal**.
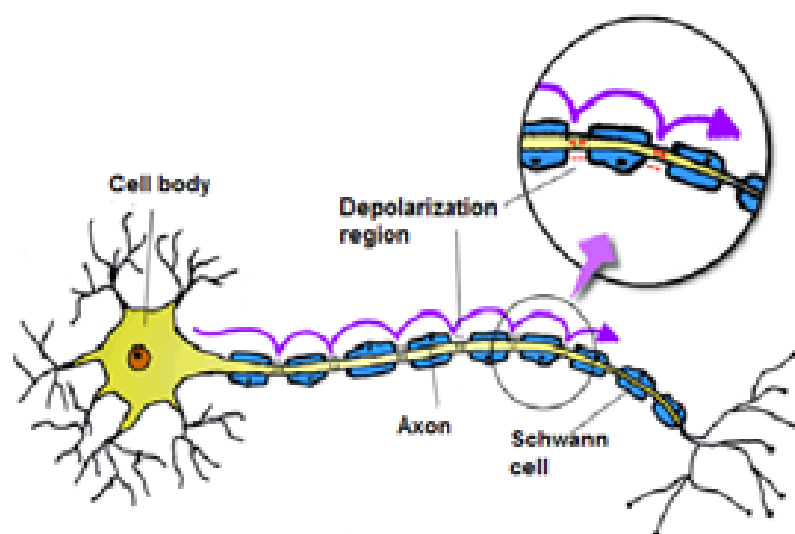
The sodium channel opens when the neurotransmitter fixes on the receptor, which allows the polarity of these nerve cells to be reversed. They are excitable in order to propagate an influx all along the neuron in the form of an action potential (AP). When the insecticide takes the place of the neurotransmitter, it disturbs the transmission of the signal (inhibition of conduction).
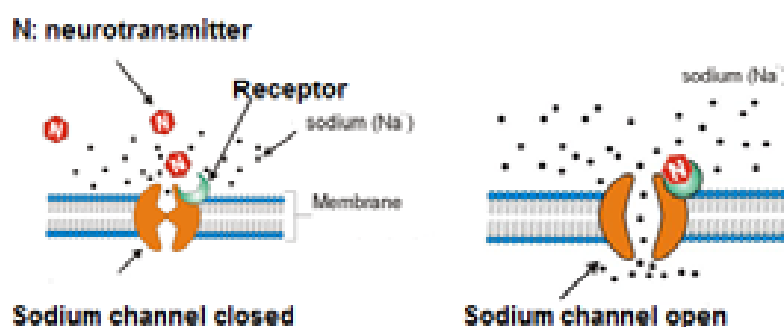
Outside the nervous system, several targets can be envisaged (change in behavior, disruption of endocrine functions, disturbance of synthesis by the endoskeleton).

The insecticide may penetrate via **three approaches**, which are often clearly distinct, and sometimes simultaneous:

- **Contact** action characterizes products which penetrate through the cuticle, usually when the insect moves over the treated surface. This is the way most popular insecticides, both old and current, act, whether they are organochlorides, organophosphates, pyrethroids, larvicides or ovicides.

- Action by **ingestion** needs the insect to consume a significant fraction of the treated plant. This is the case for growth regulators, but also for biological insecticides of the toxin type such as *B. thuringiensis* or NPV (Nuclear Polyedric Virus).

- Action by **inhalation**, characteristic of gaseous fumigants, but also certain products transported by the plant (systemic)

The cultivated plant is the medium for the action of insecticides, whatever their method of action. At this level it is possible to distinguish several types of insecticides according to their behavior on the plant:

- the first type is **neutral**. After the solvents have evaporated, the active substance remains on the surface of the tissue and the insect can only come in contact with it by moving about on the plant;

- the second type is **translaminar**. Due to its liposoluble properties, the product penetrates the first cell layers, and if it is slightly hydrosoluble it can diffuse into the few cell stages of the parenchyma, sometimes reaching the inner part of the tissue;

- the third type is **systemic**. This is a hydrosoluble product which is transported in vessels conducting sap. In this case, protection is not restricted to the treated organs alone, as long as sap circulation is active when applied at the level of the treated organ. This type of insecticide is particularly well suited to biting insects which do not move about very much and take their nourishment from the sap produced. However, on the other hand, the movements of the active substance depend on the physiology of the plant. Although these are very important in the plant growth phase, they slow down subsequently and disappear at the end of the cycle (which may partly explain the disappointing results of combating the producers of honeydew with chemicals). Finally, placed in an environment which is very active chemically, these insecticides are often rapidly metabolized, hence the low persistence.

As soon as it is applied, the insecticide is exposed to abiotic and biotic agents which will conduct the process of breakdown and metabolization. Degradation can be caused by temperature, photodecomposition through UV action, or hydrolysis. It may also be the result of metabolic processes involving enzymes. It is the degree of resistance of the active substance to this breakdown which characterizes the **persistence of a product, but it is most often plant growth which leads to the need for renewed application**.

We must bear in mind that the lifetime of a pesticide is always a threat to the environment, and that an excessive half-life value implies prolonged exposure of pests to sub-lethal doses (which increases the risk of resistant individuals appearing). This breakdown process is sometimes used to design insecticides which are less toxic to humans, but whose breakdown process or metabolization leads to the appearance of more effective active substances: these are referred to as 'pro-pesticides' (production of methamidophos via breakdown of acephate; production of carbofuran through breakdown of carbosulfan or benfuracarb).

There are various methods of applying insecticides: in the soil (buried granules), as applications to leaves (dusting, spraying), or on seeds (dusting, coating).

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7.3. Properties and methods of action of fungicides

Chemical treatments are widely used to combat fungal and bacterial disease. The world turnover of plant protection products is close to 23 billion euros with fungicides accounting for 18% and antibacterials for less than 1%. The around 120 antiparasitic active substances available are mainly **synthetic organic molecule**, although there are **a few mineral substances including elementary sulphur** and **copper products**, as well as **antibiotics**.

Most antibacterial and/or antifungal molecules which can be used in agriculture act directly on the pathogenic agents. Depending on the action exercised at the basic parasite cycle, a fungicide has a preventive or antipenetrating, curative or antisporulant activity. Depending on its behavior, the fungicide may be a surface (or contact), penetrating, translaminar or systemic one.

- **Preventive fungicides:** prophylactic treatment, prior to infection. Repeated applications are required to protect the new shoots and the new leaves, and to renew the deposit of fungicide (which dilutes and breaks down over time). This is the most frequent case, and the safest treatment as fungi reproduce quickly from a few infected cells. Preventive treatment is possible until the haustorium forms. Without the development of the haustorium, the fungus cannot develop and dies.
- **Curative fungicides:** treatment during the incubation phase (so after the initial development of the fungus in the plant).
- **Eradicating fungicides:** treatment after incubation, as soon as the symptoms of infestation appear.
- **Antisporulant fungicides:** treatment after infection, to prevent the dissemination of spores and propagation of the disease.

Fungicides have types of action that are much more diversified that the herbicides or insecticides. A distinction can be made between:

- the **direct action fungicides** which act directly on parasites (*in vitro*). The direct action fungicides have one or several sites of biochemical action;
- the **fungicides that are inactive in vitro** which act through the intermediary of host plants: the latter are converted in the plant into phytotoxic compounds. The activity can be due to a metabolite, or they inactivate the metabolites issued by the parasites and toxic for the plant without inhibiting the growth of the fungus, or again, they stimulate the defense reactions of the plant (such as fosetyl-Al, responsible for the production of terpenes and antifungal phenols, phytoalexins, for example in the infested tomato).

There are **multisite** and **single-site fungicides**. A distinction can be made between:

❑ **Contact fungicides**

- They have a **uniquely preventive action**, as they prevent above all the germination of fungal spores. Inhibition of the germination of spores is due to blocked cell respiration.
- They are **multisite**, i.e. their action is located at several levels of the cell metabolism (e.g.: sulphur-based fungicides, dithiocarbamates).
- **Their spectrum of activity is often very broad**.
- The **phenomena of resistance are almost never observed** with these products, precisely because they act on several mechanisms at once.

❑ **Systemic and penetrating fungicides**

- They possess **a degree of curative action**, with part of the fungicide penetrating *via a translaminar approach*, and then diffusing into all the other parts of the plant. They are more effective when applied preventively. The portion of the fungicide not absorbed by the leaves remains on the surface and exercises **preventive action**.
- They act in particular on the growth of the mycelium of the fungus. **These are single-site fungicides**: they act on a given process (primary site); this action is followed by a multitude of secondary consequences masking the primary effect.

There are various methods of applying fungicides:
- **Foliar** fungicides: applied to the foliage.
- **Soil** fungicides: treatment of the soil against fungi transmitted by the soil and systemic action against airborne fungi.
- Fungicides for the **treatment of seeds**: disinfecting seeds, against: pathogens at the surface or in the seed and the soil pathogens (damping off). They have a systemic action against airborne fungi.
- Fungicides applied during the **post-harvesting period**: in order to disinfect and protect the foodstuffs harvested in the course of their storage and transport (e.g.: treatment of bananas with imazalil and/or thiabendazole).

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7.4. Properties and methods of action of herbicides

Cereal crop invaded by poppies
(Photo B. Schiffers)

7.4.1. Efficacy

We expect an herbicide to be **effective**: for it to stop weed roots from developing (by inhibiting their development right from germination) and/or for it to destroy the competitor weed plants which have already developed.

Consequently, the efficacy of an herbicide depends partly on its **method of action**, **penetration** and possibly **transport in plants**, and partly on the dose used and the quality of the application. When a long-term effect is sought (e.g. desire to keep the soil clean), its **persistence** also determines efficacy. Efficacy determines profitability.

How do herbicides act?

Herbicides can have numerous effects on physiology, especially on: photosynthesis, permeability of membranes, growth (cell division, elongation (e.g.: 2,4-D, 2,4-MCPA, 2,4-DP, MCPP), inhibition of lipid synthesis, carotenoid pigments or amino acids, etc.

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Examples of the method of action of herbicides in plants

Sites of action	Mechanisms affected	Examples of herbicides
Photosynthesis	Transfer of electrons Trapping of electrons Oxygenated water in tissues	Triazines, ureas, carbamates, pyridate Paraquat, diquat
Membranes	Permeabilisation (H+ ions)	Phenols, ioxynil, bromoxynil
Areas of growth	Cell division Cell elongation	Dinitroanilines, carbamates
Lipid synthesis	Synthesis of fatty acids	Phytohormones
Pigment synthesis	Synthesis of carotenoids	Aminotriazole
Amino acids	Inhibition of synthesis	Glyphosate

Herbicides can act by destroying some of the biochemical factory, and necrosing the tissues needed for photosynthesis. They can also inhibit the development of rootlets or young shoots in the soil during germination.
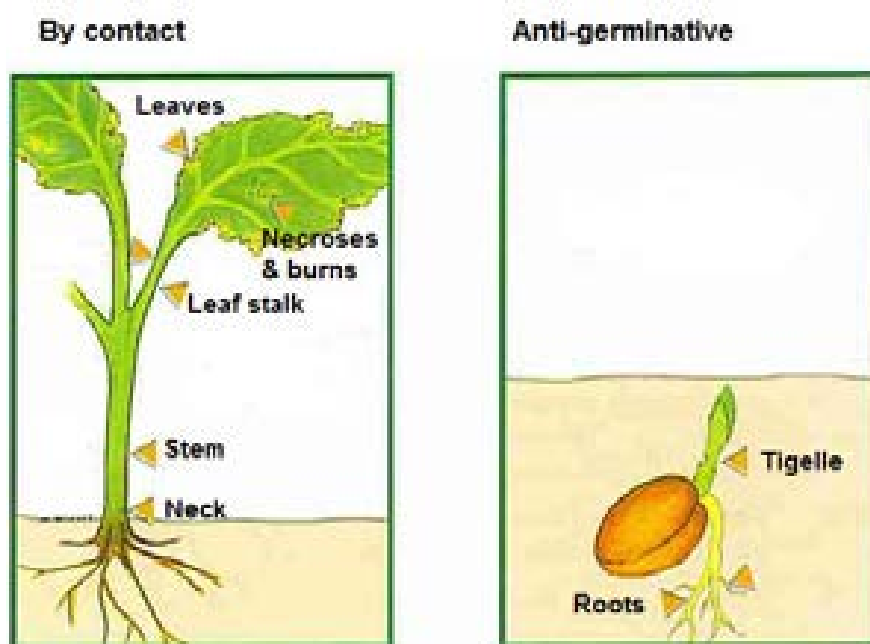
Herbicides can act by disturbing one or several of the plant's vital functions.

Blockage of photosynthesis

Yellowing and then necrosis of the leaf

Blockage of growth

Normal plant   Plant slowed down & blocked

Before   After
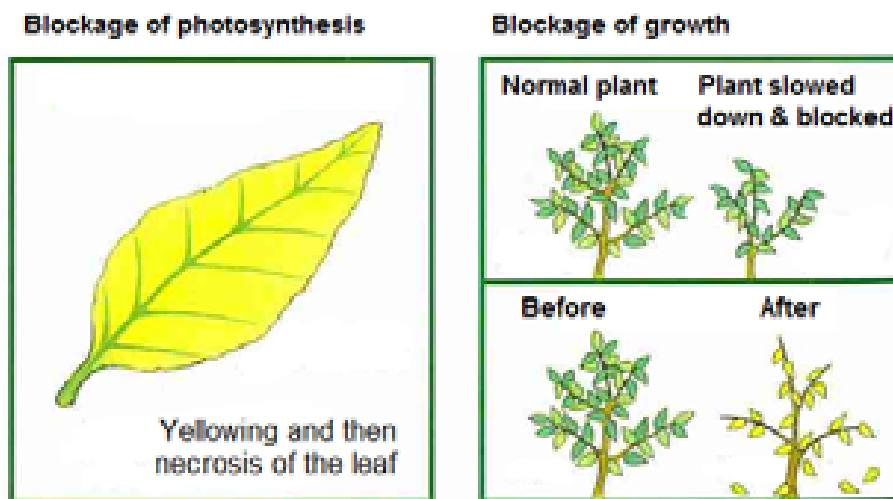
❑ **How do herbicides act?**

In order to be able to combat weeds effectively, we must be aware of their selectivity and understand how and by what method herbicides can **penetrate. To reach the critical internal concentration in the plants we wish to destroy,** we need to allow each plant to be penetrated at a given stage with a defined quantity of herbicide. Three options are possible:

1) **treatment at the stage of the germinating seed** or **seedling**: surface protection is present, especially on the aerial parts, but absorption poses no problem which is fundamentally different from penetration in the cell symplasm;

2) **treatment of developed plants**: foliar treatment requires transfer across the cuticle and the fairly thick walls;

3) **treatment through the roots**: from the soil, the essential region of penetration is located in the young, constantly renewed parts, corresponding to absorbent hairs or possibly mycorrhiza.

Absorption of the herbicide through the roots   *Absorption of the herbicide through the leaves*
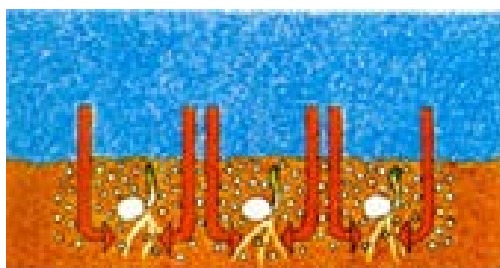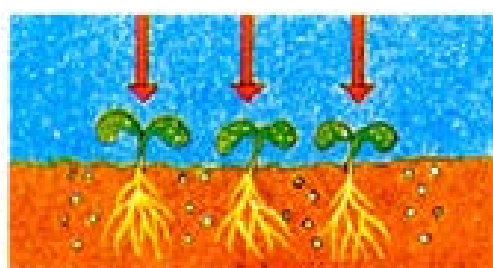
Different factors may influence the penetration of herbicides:

Factor considered	Root products	Foliar products
Absorption	Through the roots	Through the leaves
Type of soil	Significant	Not significant
Organic material	Significant effect	Negligible effect
Rainfall	Significant effect (solution)	Significant effect (leaching)
Temperature	Negligible effect	Very significant effect
Persistence	Generally persistent	Often not very persistent
Particular problems	If too soluble in water, danger of pollution of aquifers	Spreading out and adherence to foliage necessary for penetration
Type of application	Drops measuring 150 to 500 µm	Effect of adjuvants! Droplets 150-200 µm

Factors which affect root penetration:

- Dependent on the bioavailability of the herbicide (relationship with adsorption)!
- Influenced by 'hydric stress' (root volume).

Factors which affect foliar penetration:

- Hydrophilic/lipophilic properties of the molecule?
- Composition in terms of thickness of the cuticle (hairs?)
- Species considered?
- Stage of growth?
- Organs, bearing of plants?
- Weather conditions (hydric stress, dew, temperature, relative humidity)?
- Nature of the formulation (e.g. dissolved or not dissolved)?

❑ **How do herbicides travel in plants?**
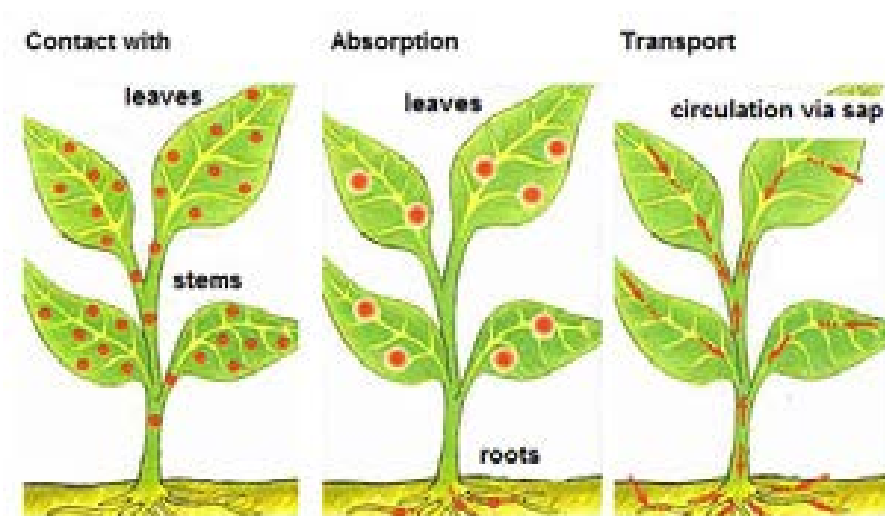
Two types of almost opposite behavior will allow two classes to be distinguished among the herbicides:

Contact herbicides *Herbicides which act from the exterior not transported by rapid means or only to a limited extent.* *These substances penetrate the plant, but most are immobilized in the first cell layers affected.*	**Systemic herbicides:** *Herbicides transported by rapid methods such as the xylem and the phloem (apoplastic and symplastic approaches).* *Distribution of the herbicide throughout the plant.*
Herbicides which 'burn' the surface affected (a drop = a burn) with a (generally) fast effect: necrosis. They only destroy the affected parts. (Very) short-lasting action. They require large quantities of water during application (water the plant well) and/or a wetting agent.	Herbicides which penetrate through seeds, shoots, rootlets, roots. Root penetration (radicular) *(e.g.: atrazine (and triazines), diuron (and substitute ureas), propachlore, hexazinone, sodium chlorate, bromacil)* Foliar penetration *(e.g.: 2.4-D (and phytohormones), aminotriazole, triclopyr) penetration through the roots and through the leaves (e.g.: glyphosate, glufosinate etc.)* For herbicides acting at the seed stage during germination and on plantlets, distance transfers in the plant are virtually useless. This is not the case for more developed plants which have sometimes simply reached the stage of 3 or 4 leaves and consequently have established a fairly significant root system.

7.4.2. Selectivity

Sometimes an herbicide is expected to be **selective.** Selectivity is the property which allows an herbicide, used under normal operating conditions (particularly by using the recommended dose/ha), to **respect crops** and to combat the weeds that are damaging to these crops. In order to keep the output potential intact, it is imperative for weeding to be selective. A plant which has been weakened or damaged by herbicides will tend to be more vulnerable to the various parasites. Selectivity depends not only on the choice of herbicides, but also on the doses, the stages of application, the climatic conditions and the varieties. As the industry is offering more and more new varieties, it is important to be particularly mindful of the various different sensitivities of these new varieties. An herbicide uses selectivity to kill weeds and leave cultivated plants intact (e.g.: destruction

of weeds such as the dandelion, the thistle, nettles, etc. on lawns). Selectivity **can be explained in various ways** (physiological, morphological, agronomic etc.).

Total herbicides:

- Act on all plants or parts of plants

Selective herbicides:

- Act on a "category of plants" (graminicides, anti-dicotyledons);
- Only act on a few very precise species
- Are selective in several ways: sometimes their selectivity is merely due to the « position » of the herbicide (without the latter being effectively and physiologically selective with regard to the cultivated plant)

❑ **Anatomical selectivity**

As a result of its bearing, depending on whether it is spread out or upright, the plant intercepts a varying quantity of the mixture. In the case of cereals for example, most drain off into the soil and the herbicide does not have time to penetrate into the plant.
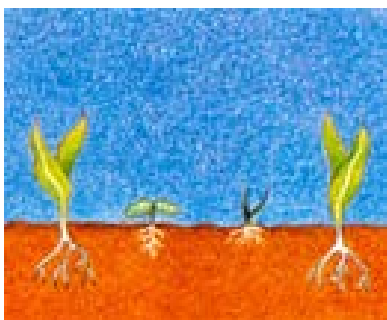
Physiological selectivity

The cultivated plant (e.g.: maize) possesses enzymes capable of 'detoxifying' the herbicide (e.g.: atrazine). Consequently, it is not affected by this herbicide, whatever the dose. This property is put to use in genetically modified plants to make them tolerant to herbicides (though not actually resistant).

❑ **Selectivity according to position**

The herbicide, applied to the bare soil, establishes itself (adsorption) in the first cm. Weeds germinate in this surface area. They are destroyed whereas the seeds of the crop, which are pushed in to a deeper point are not affected.

N.B.: In the case of leaching, on more permeable soil or if the seed is not deep enough, an effect can be observed on the crop as the product is not really 'selective'.

❑ **Selectivity of application**

'Selectivity' is obtained artificially, by directing the spray jet between the rows. Placing a protective hood at the end of the hose is generally necessary to avoid burning the plants in the crop. There are different devices to carry out this kind of application (e.g.: rollers impregnated with glyphosate).

It is obligatory for all the *efficacy trials* to be accompanied by *selectivity trials*, carried out at different doses. Consequently it is **very dangerous**:

- to use a herbicide recommended for one crop in another crop without carrying out a trial beforehand;
- to increase the dosage;
- to change the **formulation**: the form in which the product is presented (e.g.: EC, SC or WP) may partly influence its selectivity (e.g.: case of phenmedipham). In some of them, it can even be dangerous to reduce the **volume of mixture**, as this has the effect of concentrating the « wetting » agents which can increase the penetration of the herbicide into the cultivated plant, causing unexpected phytotoxicity.

It is very advantageous in weed control to combine « selectivity » with « crop rotation » : In fact, the weeds not destroyed by a herbicide in a rotation crop can be eliminated at a later date because of crop rotation and the use of other herbicides, which are selective in another crop (e.g.: Graminicides in beetroot, then anti-dicotyledons in cereals). Thus the phenomenon of '**flora inversion**' is avoided. This is the result of the repeated use of the same selective herbicides. It can even avoid the development of **resistant weeds** (or simply those which are tolerant).

7.4.3. Specificity

The first specificity of the herbicides concerns products known as '**graminicides**' and '**anti-dicotyledons**'.

Graminicides (Monocotyledons) *Elongated leaves* *Parallel veins* *1 cotyledon (invisible)*	*Dicotyledons* *Rounded, serrated leaves* *Network of veins* *2 cotyledons*

Herbicides have different **spectra of activity**, and can be effective against weeds from the same family, of the same genus or against one single species. Consequently there are "tables" indicating whether or not the weeds are sensitive to the herbicides recommended for weeding a crop.

7.4.4. Persistence

This is the period during which the effects of the herbicide are perceptible. Persistence **must be sufficient** to avoid competition from weeds during the growth phase (often critical) of the cultivated plant. However, persistence must also be limited to **avoid any post-effect** on the next crop (problems of 'persistence').

Time from application

Adequate persistence

Time from application

Inadequate persistence
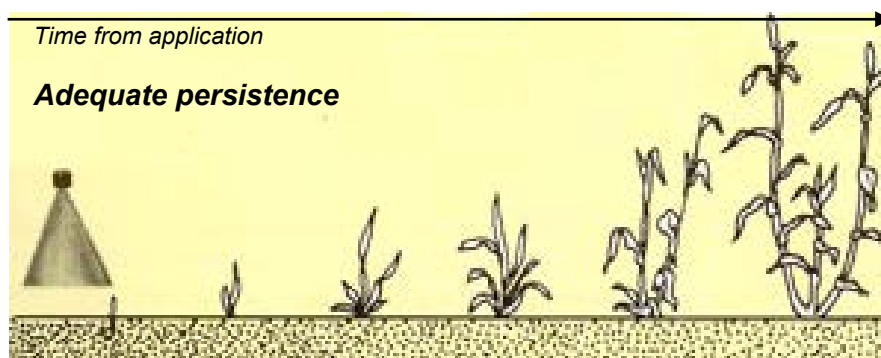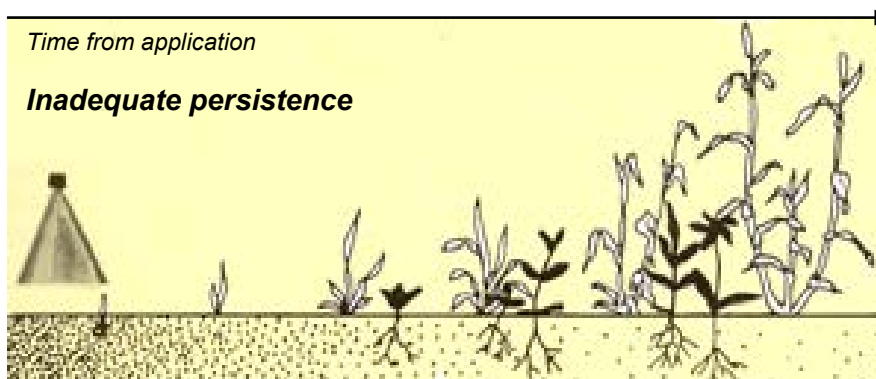
The concentration of herbicide in the soil becomes insufficient to prevent weeds from developing

7.4.5. What types of herbicide treatment are there?

An herbicide treatment is defined according to its **period of application** in relation to the **crop and the weeds**.

❑ **Pre-seeding treatments"**	The weeding product is applied to the soil **before the seeds**. It is only after it has destroyed the weed flora that seeding takes place or the hope is that it will inhibit the germination and development of the weeds for several days or weeks without interfering with the germination and normal development of the crop. In the event of planting out (e.g. potato, market garden crops), the term used is pre-planting treatments.
❑ **Pre-emergence treatments**	The herbicide is applied on the day of sowing or a few days later **but before emergence** of the cultivated plant. It is possible to make a distinction between: • *Contact pre-emergence treatment*: application on the weed seedlings which have emerged but before the cultivated plants have crossed the protective layer which forms the superficial area of the soil. • *Treatment of residual pre-emergence*: application to bare soil, before the appearance of weed seedlings, with the products then acting on the rootlets of the seeds of the weed plants.

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❑ **Post-emergence treatments**

Selectivity is morphological or physiological.

- *Treatment with contact herbicides*: act by killing the plant tissues directly affected. The action is generally rapid.

- *Treatment with herbicides with systemic action*: they act much more slowly as in order to be active the products must reach the meristems and create cell disorganization.

Herbicide treatment and stage of development of the vegetation

Treatment	Pre-emergence (or pre-emergence)	Post-emergence (or pre-emergence)
Target	Soil	Aerial parts
Expected persistence	Several weeks or several months	A few hours
Growth stages required for efficacy	Germinating seeds and seedlings of the first stages	Seedlings and developed plants
Results (effects)	Destruction of seedlings as they germinate and grow	Destruction of existing plants

7.5. Special uses of pesticides (bait, seed treatment)

7.5.1. Use of bait

There are various uses for bait. They can be used against snails, or usually **against rodents**.

The active substance is incorporated in a "block" which contains an attractive and edible substance, or even a product which masks the odor of the toxic product.

The bait contains very toxic products. They must not come into contact with the foodstuffs. That is why it is preferable to keep them inside a "bait box" specially designed to keep bait out of the reach of children and pets (also described as "baiting station").

The poisons used in bait must not kill rodents in situ otherwise the efficacy of the bait may rapidly decline, with the animal making a link between going into the "station" and the death of its peers.

1: the rodent enters the station

2: it eats the bait

3: it will not die near the station

7.5.2. Seed treatments

During germination, the young seedlings are fragile and sensitive to diseases or attacks by rodents. **Consequently seeds are often treated**, by **dusting**, by **film-coating** (film deposited on the seed) or by **coating** (thicker layer, which can even modify the shape of the seed). The most common case is dusting or film-coating with a broad spectrum fungicide (e.g.: thiram) to prevent 'damping off'.
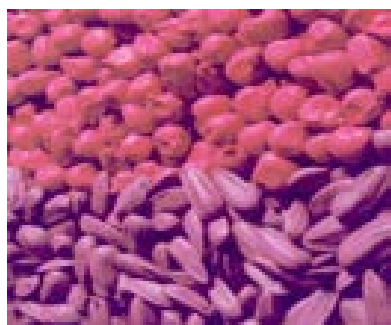
If the seeds have been treated, the deposit can be reduced, and under 1% of the cultivated surface is then treated.

The location of the product on the seed and its incorporation in the soil lead to a higher useful output than that from spraying or spreading a seed, to minimum contamination of the environment and reduced, or even zero, exposure, of beneficial insects.

In addition, the industrial treatment of seeds is carried out in closed, controlled buildings, and is restricted to trained operators, which allows more toxic products to be applied.

Treatment by dusting, or even by film-coating, can be carried out in fairly basic apparatus (drums). Formulations for seeds (WS, FS) are available and well adapted (good distribution, rapid drying of deposit, relatively correct adhesion). Coating seeds (e.g.: beetroot), on the other hand, requires motorized spheres and a drying device.

For the application of insecticides, and in particular the systemic molecules, coating is an economic factor (often 50% or under the recommended dose/ha for spreading is enough) and gives good results (staggered protection of the crop). The active substances can be incorporated into matrices (polymers), ground and calibrated, which will be closely mixed with the coating materials to obtain a slow-release effect for the active substance.

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7.6. Managing resistance to pesticides

7.6.1. General information on the phenomenon of resistance

By making use of the weak points of the organisms attacking them, the host plants and the animals have developed defense mechanisms, including, among other things, the **synthesis of toxins** and **repellents**. On the other hand, pests have selected **detoxication or adaptation mechanisms** allowing them to circumvent their host's chemical defenses.

Currently it seems that, the genetic pool of most living organisms already contains genes allowing them to break down enzymatically or modify the fixation sites of numerous products such as modern chemical insecticides. In fact, most modern synthetic insecticides come from natural molecules (pyrethroids from the synthesis of pyrethrin for example). The selection process was therefore able to begin a long time ago.

It was in the 1910s that Melander pointed out the first case of resistance of mealybugs *Quadraspidiotus perniciosus* or « Pou de San José » to the polysulphids in the orchards of Illinois (USA), so more than 92 years ago. Cases of resistance then increased slightly up until the appearance of organochlorine insecticides (DDT and cyclodienes) in the 1950s, an appearance which would mark a considerable increase in the number of resistant species.

In the 1980s, only 90 new cases of resistance were notified, falling from the 190 cases in the 1970s. This drop could be simply explained by the fact that today most species of any agronomic importance have developed one or several resistance mechanisms. Since then, new cases have become more rare, and only concern acquisitions of resistance towards other groups of pesticides. The number of cases of resistance to insecticides (approximately 500) is higher than those of resistance to fungicides (200), which, in turn, is higher than that of herbicides.

Distribution of resistant species in the various orders of Arthropods (1991)

Orders	Number of resistant species
Diptera	*177*
Lepidoptera	74
Coleoptera	72
Acarids	71
Homoptera	51
Other	59
Total	**504**

In spite of the high number of resistant species (over 500), no more than **forty insects, diseases and weeds are responsible for most problems of resistance currently encountered, usually in cases of intensive use of pesticides.**

The table below shows the number of resistant species and the different classes of insecticide in existence.

Distribution of resistant species according to the different families of insecticides (1991)

Families of insecticides	Number of species	% total
Cyclodienes	291	57.7
DDT	263	52.2
Organophosphorines	260	51.6
Carbamates	85	16.9
Pyrethroids	48	9.5
Others	52	10.3

Most resistant species are of agronomic importance (56.1%), but insects of medical importance represent a substantial proportion (39.3%), mostly mosquitoes and flies. Only 4.6% are auxiliaries (predators, parasites or pollinators).

All over the world, **every major crop** (cotton, rice, maize, cereals, fruit and citrus fruit, market garden plants) **presents at least one problem of resistance**, whether with insect pests, disease or weeds.

The **consequences** of this phenomenon are disastrous for users who often find themselves with nothing to combat the development of these populations which have become resistant. In addition to the major disadvantage of no longer being able to combat the targeted pests, this phenomenon has repercussions **at industrial level** (as the pesticide responsible may disappear from the market) and **at an environmental level** (as the increase in the doses applied and the uncontrolled diversification of the insecticides are responsible for significant contamination of soils and aquifers).

7.6.2. Definition of resistance to pesticides

If the same insecticide compound is frequently used (**selection pressure**), the number of insects resistant to it becomes dominant in the population and **a lack of efficacy** of the insecticide – or even the *chemical family from which the insecticide came or another insecticide with the same method of action* – is noted in practice (greater damage, losses in yield).

Initial treatment:

Prior to application   *After application*

Following treatments:

Prior to application   *After application*
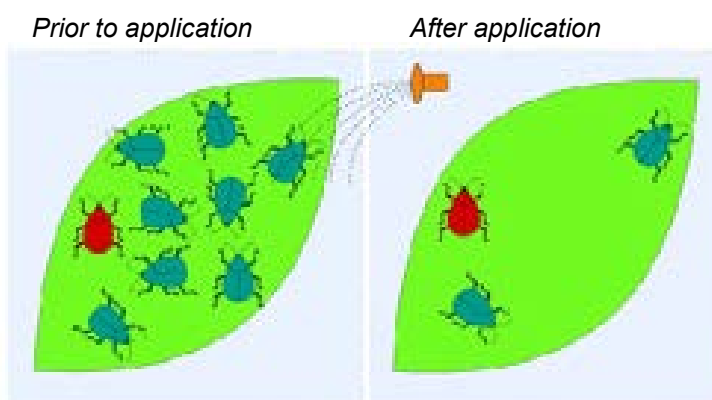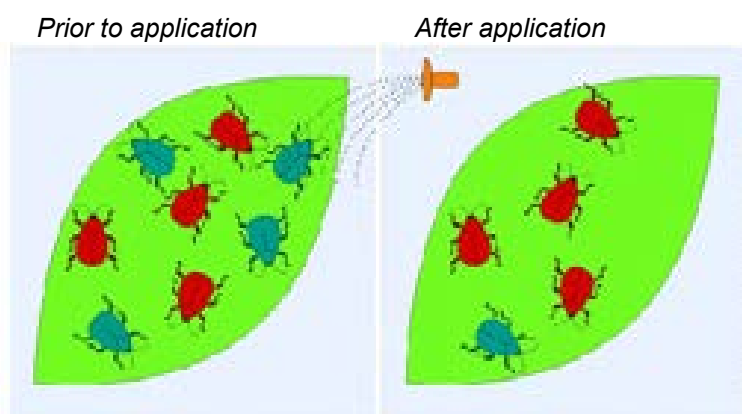
Resistance is defined by the EPPO (*European & Mediterranean Plant Protection Organization)* (EPPO *Guidelines, April 2000*) as "the *naturally occurring, inheritable adjustment in the ability of individuals in a population to survive a plant protection product treatment that would normally give effective control"*. It therefore has the result of reducing the sensitivity of populations of diseases and pests.

All animal species naturally display a certain **genetic diversity** mainly because of the mutations which take place in their populations.

When insecticides are used, for example, **natural selection** favors individuals less sensitive to the insecticide to which they are subjected. These insects may survive the treatments (insects known as «resistant», as they possess **genes** of resistance), and reproduce **passing on this characteristic of resistance** to their progeny.

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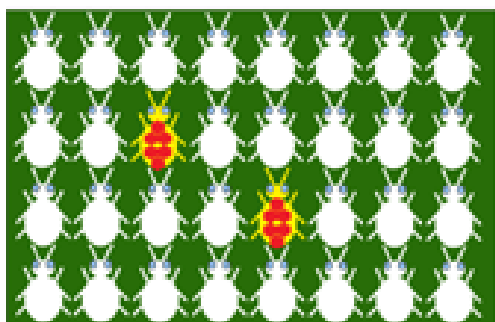
Presence of a characteristic of resistance in the population of insects present in the area treated
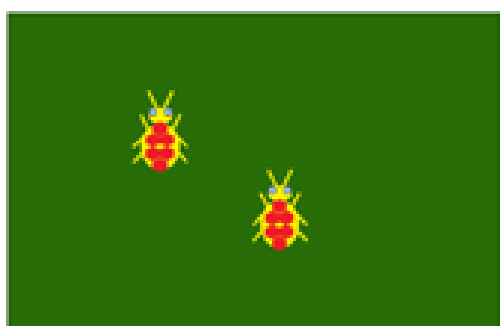
Only the individuals resistant to the pesticide are capable of surviving… and of reproducing

If the pressure of selection is maintained (repeated use of the pesticide), the characteristic of resistance spreads throughout the population. The species becomes resistant!

The same phenomenon can be shown by the fungicides (strains of resistant fungi and the herbicides (populations of weeds which have become resistant).

In the laboratory, by working on a certain number of successive generations with constant selection pressure, it is possible to select, more or less rapidly, populations of resistant insects. This acquired resistance is passed on in different ways and is maintained over a number of generations, which varies according to the insect and the product in question.

However, in **agricultural practice**, **things are much more complex**, and the ability of insects to develop and maintain their resistance to a product, is not therefore necessarily detected, as:

- **the selection pressure does not have to be constant**: alternating productive seasons with unfavorable periods (e.g.: dry season); alternating the insecticides

used and differences in the way they are used (active substances, doses/ha, formulations, type of application); periods of application; presence or absence of predators and/or parasitoids;

- **mixing up populations** is possible: migration of insects out of the treated plots and entrance of insects from sensitive populations. Also by the insects moving from one host-plant to another host-plant (in which case they may come across either other types of insecticides, or the same active substances);
- **other factors within the milieu** also exercising selection pressure: this is not necessarily favorable to the individuals who are the most resistant to insecticides.

7.6.3. What are the mechanisms involved?

The pesticides act on the physiological targets whose function is essential to the life of the insect. In order to construct a valid resistance prevention and management strategy, it is therefore important to be aware of the biological and biochemical mechanisms involved (methods of action of the products concerned).
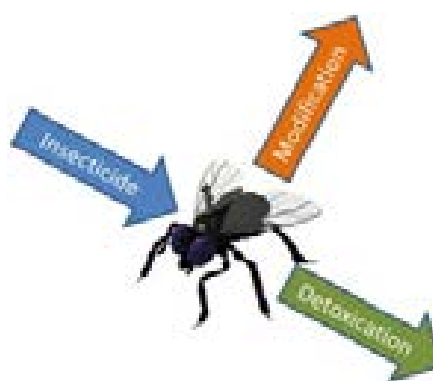
However, the **changes in behavior** and the **reduction in penetration** of the insecticides are mechanisms of resistance which are relatively rare or not very effective if they are not associated with other mechanisms, in particular effective detoxification.

On the other hand, **detoxification by metabolization** (bio-transformation into easily excretable molecules) and changes in the insecticide's targets (e.g.: change of receptor site on an enzyme) are generally behind very high levels of resistance, which is why particular attention must be paid to them.

7.6.4. Prevention and management of resistance

The prevention and management of resistance to insecticides can only be obtained by understanding the intrinsic factors which produce it, which explain its development and its extension (progression of resistance in terms of degree and in space).

❑ **Risk of resistance in practice**

The real risk of observing resistance to an insecticide in local agricultural practice ('**resistance in practice**') is the result of a combination of factors characteristic of the product/s and the target in question (which we will refer to as **inherent risks**) and factors associated with the conditions for using this/these product/s (which we will refer to as **agronomic risks**).

❑ **Unlimited risk and limited risk**

When, on the basis of its properties and those of the targeted pest, a plant health product is used in practice without any restriction on its conditions of use ('**unrestricted use**',

e.g.: calendar and systematic treatment every 14 days), the risk of the consequent appearance of resistance can be qualified as '**unlimited risk**'. If this risk can be estimated as low, the product can continue to be used without any need to adapt the conditions of use.

However, in numerous cases, the non-restriction of use of a product would lead to rapid development of resistance. In this case, experience shows that setting up an appropriate resistance management strategy may bring the initial potential risk to an acceptable level of probability.

When the risk of resistance management strategy usually involves restrictions or modifications in the use of the product in question ('**limited usage**'), for this product we talk of '**limited risk**', these restrictions or modifications of use being referred to as '**moderators**' (moderating factors).

Risks in practice	=	Inherent risks	x	Agronomic risks
Unlimited risks	=	Risks in practice	x	**Unlimited use**
Limited risks	=	Risks in practice	x	**Limited use**
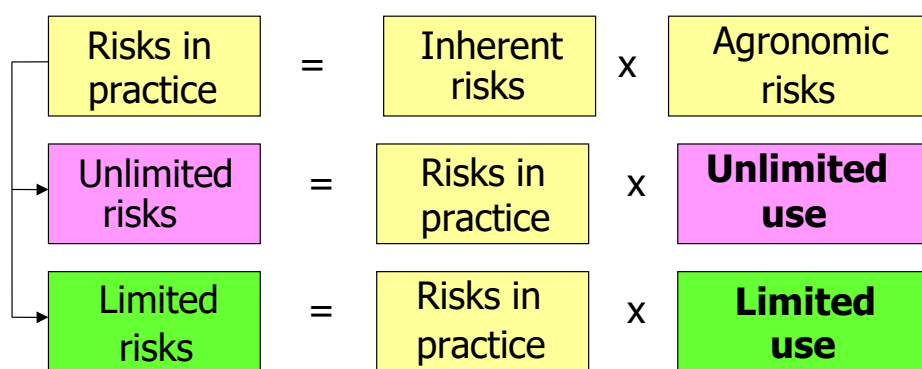
> The probability of actually developing resistance, in local practice, depends on the combination of inherent and agronomic risks, which can be limited by setting up a well-thought out agricultural practice and a supervision and resistance management strategy.

Risks inherent to the product

- high persistence and/or persistence of action
- method of action: single-site product
- monogenic resistance to the method of action (one single gene to be modified by mutation)
- metabolization: molecule easily broken down in the insect

Risks inherent to the target

- a short cycle (numerous generations/culture)
- high genetic variability (high probability of mutations in the population) and easy genetic dispersion in the population
- existence or possibility of cross resistance
- great biological vigor of resistant insects.

Agronomic risks

> - *crop spread over a wide area with short rotations, monoculture or perennial culture*
> - *application techniques used*
> - *other associated cultural practices (phytotechnics, inputs)*
> - *need for a high number of applications or persistent product(s) to guarantee effective control of the target because of the characteristics of the crop and its environment*
> - *use of sensitive varieties (sensitive to the target in question)*
> - *geographical isolation of the target populations preventing reintroduction of sensitive individuals into the treated area*
> - *environmental conditions favoring plagues of insects*
> - *recourse to a single protection product*
> - *absence of alternative methods of protection (AMP)*

On the basis of an examination of these properties (product and target), **the potential risk** of the development of resistance to the product as part of an unlimited use (*i.e.* without any modification to the schedule of application of the treatment) can be estimated validly.

❑ **Designing a strategy**

In order to design a strategy for the prevention and management of the risk of resistance in practice, the **following four basic recommendations** ('modifying factors') can be selected:

➢ *Recourse to Good Plant Protection Practices (GPPP) and the methods of integrated management (or IPM)*

Specific guidelines (to one crop) may act as a guide (e.g.: EPPO Guidelines, FAO recommendations). It is recommended to check:

- the possibility of using resistant cultivars;
- whether non-chemical control methods are available (prophylaxis);
- the methods of application and the competence of those applying the product;
- the quality / adjustment of the application equipment;
- the quality of the product/s proposed;
- whether an application on the threshold or a warning can be carried out;
- whether the alternative host plants are destroyed;
- what is the influence of other inputs (e.g.: fertilizer).

➢ *Combinations or mixtures of insecticides*

Using a combination of pesticides (in the spray tank or in an existing formulation) is an effective method of preventing the development of resistance as far as one or some

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product/s are used whose properties are complementary but **whose method of action is inevitably different**.

Combinations with a ready-to-use formulation are preferable (more stable and more effective as they often bring about an effect of synergy between the active substances). The combination, especially when there is an effect of synergy (or 'potentialization'), also allows the doses of each compound to be reduced in comparison with the effective dose when used alone, but each component in the mixture must make a significant contribution to efficacy.

The disadvantage of this technique is that it maintains a selection pressure within the crop from all the constituents in the combination.

> **Alternating insecticides**

Suggesting alternating products is only effective if the « partner » products are known to **belong to different groups**, **without any cross-resistance between them**. Take care as products from very different chemical families may demonstrate cross-resistance between each other: thus, insects resistant to D.D.T. (family of organo-chlorines) may rapidly become resistant to pyrethoids as the biochemical site affected is the same.

The advantage of alternating products is to reduce the period of selection pressure and allow the « alternative » product to eliminate the resistant biotypes selected. In general, the risk of resistance reduces in proportion to the frequency of applying the product. In fact, in the absence of any insecticide, the carriers of genes of resistance generally have fewer descendants than the others. Alternating products allows the genes of resistance to be maintained at a low frequency (the frequency of an *allele of resistance* which increased during the period the insecticide was used will decrease and, in the best of cases, regain its initial value during treatment with the other insecticide).

The disadvantage is the risk of seeing resistance to the « alternative » product also develop.

> **Frequency/schedule of applications**

Suggesting **reducing the number of applications** over the season is normally effective in reducing the selection pressure. This method is based on the hypothesis that when the product is no longer used the resistant biotypes tend to regress or disappear in the target population. To be really effective, this method must be associated with combining or alternating products.

The product's persistence of action must be taken into consideration, as the residual activity of a single application can be high!

Reducing the number of applications often means '**treating on the threshold**' (e.g.: TSC, or 'targeted stepped control'). The decision to intervene with an insecticide should normally be taken with due consideration for several factors:

- determining the number of **insect pests** in the plot observed through counting (trapping, netting, pheromone traps, etc.): a '**threshold of infestation**'; is defined as the number of insects (larvae and/or adults) that must be present for damage to take place in the crop;

- evaluating the size of the populations of **beneficial insects** (e.g.: larvae of mealybugs or syrphs which are predators of aphids) or insect parasitoids (e.g.: number of *Aphidius*, a micro-hymenoptera which is a parasite on aphids);

- being aware of the dynamics of their respective populations, and the influence of the environmental conditions (particularly atmospheric ones) on their proliferation;

- being aware of the '**economic threshold of damage**': connected to the threshold of infestation. This is reached when the number of insect pests present is enough to cause damage whose foreseeable economic cost (such as a significant fall in yield) will be higher than the cost of treatment;

However, added to the decision must be the factor of the **selectivity of the insecticide** towards auxiliaries and/or parasitoid insects (the product is described as 'IPM compatible'). In fact, if the product is not selective, it may give rise to a risk of '**boomerang effect**' (the effect that once the product has disappeared, the infestation takes over with added strength).

It is often very difficult to correctly control these different factors, which in practice limits the advantage of treatments on the threshold (e.g.: It requires intensive training).

Chapter 8

Good practice for pesticide application

8.1. Treatment and traceability of operations

8.1.1. Plant health treatment, GPP and GAP

Crops or harvested products are 'treated' with pesticide products to protect them against the harmful action of predators, parasites, diseases or competitor plants. This treatment is usually **applied by spraying the** crop. It may or may not be combined with other supplementary forms of intervention, whether cultural, physical and/or biological (integrated control).

> Complying with methods of application, instructions for the safe use, storage and disposal of unused products or those past their expiry date, empty packaging and remains of mixture, is the basis of '**Good Plant Protection Practice or GPPP**'.
>
> Respecting GPPP, applying the correct dose, at the recommended volume and observing the pre-harvest interval (PHI) in line with '**Good Agricultural Practices or GAP**' guarantee the consumer compliance with the regulations relating to health quality of foodstuffs, particularly by respecting the MRL (*Maximum Residue Level*).

A rational application of pesticides requires:

- training farmers to monitor crops (**threshold interventions**) and training applicators in the correct application techniques; teaching them how to prevent risks to themselves, as well as to animals and the environment;
- **defining the** most effective **methods of treatment** (by combining: choice of pesticide, type of formulation, and application techniques) which are the safest for themselves and for the environment, and that make it possible to optimally manage the risk of pest species acquiring resistance to pesticides.

> *The components of the efficacy of a treatment*
>
> **Efficacy** (from both an agronomic and economic point of view):
> **= timeliness** accurate evaluation of the situation and need to intervene,
> **+ selectivity** choice of active material, formulation and dose,
> **+ accuracy** identification of targets, choice of apparatus and user training
>
> **Dose:** kg(g) or l(ml) of product applied per hectare (per 100 m²).
> **Mixture:** any form of liquid used for spraying: product used in original condition or product diluted in a carrier (water or oil by-product). In most cases, the dose must be regulated by maintaining a constant concentration of mixture in the active substance or in the product.

8.1.2. Selecting products in accordance with regulations

Pesticides, which will be included in the crop protocol recommended for the crop, must be selected taking into account:

- the marketing **authorizations** (current national legislation), strictly complying with the authorized usage and the approved doses;
- the obligatory **precautions** for use (period of application, **pre-harvest interval (PHI)**, **maximum authorized dose**, maximum number of treatments authorized, requirement for untreated areas, protective equipment recommended on the label) and any restrictions on use (e.g.: application only in sowing period);
- the existence, on the foodstuff relating to this compound, of a **Maximum Residue Level** (MRL). If the foodstuff is exported, the MRL in the market where it will be distributed must be taken into account (national MRL, MRL harmonized at European level or MRL fixed by the *Codex Alimentarius*).

8.1.3. Organizing complete traceability

As with other operations carried out on crops, it is very important to **organize complete traceability of** pesticide applications **interventions**, by recording for each treatment at least:

- the application date (compared with the date of sowing);
- the product used (full name, supplier, formulation, batch n° etc.);
- the dosage actually used (the **measure actually used**, and not the dose indicated);
- the volume of mixture (per ha);
- the type of application (apparatus and possibly the number of the apparatus if it has been calibrated, nozzle, volume/ha, working width, speed) and the conditions of application (rain, wind etc.);
- the name of the applicator and of the person in charge of the treatment.

> This traceability is all the more important since we are attempting to guarantee the distributor and the processor that the product harvested meets the standards of plant health quality, and **in particular respect the authorised MRL** for the product/s in relation to this foodstuff.

8.2. Organization of the site, verification of the apparatus and prevention of contamination

The major aim of spraying is to apply a very accurate volume/hectare of mixture whose distribution is as even as possible and with the height, number and uniformity of spray droplets appropriate to the crop and type of treatment.

8.2.1. Marking out plots

In large crops, only accurate marking out is able to maintain the satisfactory spray boot spacing, established according to the width of the booms. If the spacing is less than the working width of the booms, the dose is doubled in the overlap areas. If the spacing is greater than the optimum working width, the part located between the boots is not at all or not correctly treated.

Incorrect marking-out has serious consequences for the crop and for the environment. Approximate marking-out must be prohibited: **marking-out using paces is inaccurate and is a source of numerous errors and approximations**!

*Using a decameter to correctly measure the plots
(Photo B. Schiffers)*

As with fertilizer spreading, the most common marking-out methods can be resumed as follows:

- on unworked land or grassland, the marking-out method involves measuring the plot with a **decameter** (50 m) and three or more lines of stakes, depending on the relief of the land;
- when sowing in lines using a spreader, marking-out can be carried out pre-emergence or post-emergence.

(Photo B. Schiffers)

For treatments on trees and vines, marking-out is, naturally, indicated by inter-row spacing. In this case, the working width (W) to be taken into account for calculations corresponds to the number (n) of widths between rows (l) treated in the course of each passage: W = l x w.

8.2.2. Personal protective equipment

Whenever there is a risk of splashing or contact with a plant health product, even diluted, wear waterproof overalls (gloves, waterproof apron, boots etc.): the skin is easily and rapidly penetrated by certain dangerous products. Do not forget to rinse this equipment after use. In some cases, it may be advantageous to use disposable overalls. Some products may require the use of respiratory protection when preparing the mixture and during treatment.

In the case of equipment without a hand-washing tank, **permanently** provide **a container of** easily accessible **fresh water** in the premises used to prepare and handle the equipment, allowing hands to be washed after any contact with the product.

Fresh water tank
This tank can be useful for rinsing the apparatus when the treatments are complete, but also in the case of contact with the product, to rinse the skin or the eyes if they have been contaminated.
(Photo B. Schiffers)

8.2.3. Protection of water sources

Every precaution must be taken to **avoid tanks spilling over** and **products running off** outside the area to be treated.

The production of foam while preparing the mixture carries a significant risk of spillage and flowing away to gutters and drains.

In all cases, in accordance with legislation, the residues in the booms and at the bottom of the tank must be emptied in the growing area or onto an authorized crop, avoiding runoff, and away from homes, streams, pools, lakes, wells and water catchment areas.

Keep water taps very clean and remember to wash hands before touching them. **Do not fill tanks by plunging a water pipe into the water and never use a direct connection to mains water** when preparing treatments unless the connection has a non-return valve; in the event of an abnormality or if the network is cut off while a tank is being filled, an anti-return valve avoids the risk of siphoning the product from the tank and pollution of the network.

Rinse the containers corresponding to the treatment under way **when preparing the mixture and incorporate the rinsing dilution in the tank** of the spraying equipment before applying the treatment. After they have been rinsed, **pierce the packaging** to avoid any re-use.

8.2.4. Instructions for using the products

The **instructions for using** all commercial pesticide formulations must be shown on all package labelling: specificity and type of action, stage of application, dose/hectare, volume/hectare, precautions for use and specific risks.

The manufacturers or distributors of pesticide products must also produce safety data sheets for their products (**SDS**): do not hesitate to request them from suppliers.

For each type of crop, it is strongly recommended that farmers follow the advice issued by local authorities, local technical organizations, advisory groups (groups of growers, research centers, local projects, agricultural warnings etc.)… not forgetting the "**Crop Protocols**" and the "**Good Phytosanitary Practices Guides**", written by the COLEACP (PIP Program and others) which have been the subject of local tests in collaboration with local authorities for their validation and are regularly updated.[1]

It is important to **check the quality and reliability of information** and not to rely on commercial information.

Consulting authorized sources and complying with rules laid down in the instructions for use, in safety data sheets and in technical documents are the basic pillars of responsible behavior.

8.2.5. Protection of biodiversity

Be aware and **comply with the instructions for use** for the products in relation to their possible harmfulness for insects and wild fauna, especially with regard to pollinating insects.

If possible, carry out an initial passage in the middle of the plot and treat the edges at the end of the treatment to give animals enough time to flee the plot. When treating with herbicides, take all the precautions needed to avoid attacking plants which constitute their natural refuges (hedges, enclosures, copses, etc.).

8.2.6. The instructions for use issued by the manufacturer of the spraying equipment

The **instructions for use** is the reference document for those who use spraying equipment. In addition to supplying it, in accordance with the safety regulations (employment law), these instructions provide the user with the information needed to:
- make the most relevant adjustments according to the treatments to be carried out;
- maintain the apparatus in good condition;
- maintain the equipment in perfect working order;
- prevent application abnormalities and overdosing.

If the user does not have the instructions for use, he should ask the dealer or manufacturer for them.

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[1]   See COLEACP/PIP Website: www.coleacp.org/pip.

8.3. Calculations and measurements of volume applied/ha and doses

> In general, determining the quantity of product to prepare (dose/ha) is carried out **by calculation**. However, there are less accurate but simpler methods which use, for example, the abacus (discs or rulers).

8.3.1. Definition of the dose

The term '**dose**' indicates the **quantity** of formulated product to be measured out and applied.

The labelling on each product indicates the **authorized dose per unit of surface area** and, depending on the volume of mixture/ha, the concentration to be carried out depending on the treatment aims.

As the case may be, the dose is expressed in grams (or kg) per hectare (g/ha) or in milliliters (or liters) per hectare (L/ha).

The various techniques used for applying pesticides pursue one and the same aim, to distribute the substance, often referred to as dose or quantity, **as uniformly as possible** over a unit area. In general, the hectare has been adopted as the standard unit area

For each pesticide and each problem (pest, crop types, etc.), there is a corresponding dose of pesticide per hectare. This data is (most frequently) validated when the product is approved using tests of efficacy, selectivity and compliance with MRL.

This means that the data is neither empirical nor approximate: compliance with the maximum dose[2] is the basic element of compliance with GAP!

The **approved dose** of product to be applied per unit area is usually expressed in kg/ha (solid formulations such as DP, WP, WG, GR, etc.) or in l/ha (liquid formulations such as SC, EC, EW, SL, etc.).[3]

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[2] The recommended dose can be reduced, although it should be noted that this can restrict the efficacy or persistence of action and encourage the development of resistance. In some cases, the dose can be 'split' (e.g.: treatment with herbicides, targeted stepped control in cotton). However, there must be continued respect for the PPH, even at a reduced dose.

[3] International codes designating the types of formulations using two letters:
DP = dusting powder; WP = wettable powder; WG = water dispersible granules;
GR = granules ; SC = suspension concentrate; EC = emulsifying concentrate;
EW = emulsion in water; SL = soluble liquid.

8.3.2. Volume of mixture and quantity of product to be measured

The concentration of product in the mixture depends on two elements:
- the approved **dose/hectare** which is indicated on the container label;
- the **volume/hectare** used for the treatment.

> Water is not necessary for the biological action of a pesticide. It is only useful for transporting the product. It is not economical to transport large quantities of water to the fields. Consequently, in modern application techniques, **the volume of mixture/ha is gradually reducing**.

In the past, 1000 liters of mixture per hectare were considered by be an appropriate volume. Nowadays, sprayers mounted on tractors can successfully apply quantities of as little as 50 liters per hectare.

The current volumes/hectare are in the order **of 200 to 400 liters/hectare (sprayers pulled by tractor) and in the order of 750 to 900 liters/hectare (sprayers carried on the back).**

The **type of sprayer** available will determine the range of volume/hectare to which the sprayings will be applied. The bigger the capacity of the apparatus, the more the volume/hectare can be raised; however, for practical purposes, the choice of a reasonable volume/hectare is essential.

Numerous other factors will influence the choice of a particular volume/ha: the type and development of the crop, technical recommendations, type of product and mode of action, availability of water.

Definition of the term 'volume/hectare'

This is the volume of mixture to be spread over the surface of one hectare. The various products and treatment techniques used result in the application of different levels of volume/hectare:

- ultra-low volume/hectare or ULV (below 5 L/ha) ;
- very low volume/hectare or VLV (from 5 to 50 L/ha);
- low volume/hectare (from 50 to 100 L/ha);
- medium volume/hectare (from 100 to 250 L/ha);
- high volume/hectare (over 500 L/ha).

The volume/hectare is indicated on the instructions for use for the products. It is a good idea to avoid the term 'output-hectare', which is commonly used for the same purpose. Likewise, any confusion with the term 'dose', which relates to the quantity of formulated product to be applied per hectare, should be avoided.

To optimize the behavior of the mixture (in particular in terms of surface tension[4] which governs the size of the droplets obtained by spraying) and its penetration into the plant, it is preferable to follow the recommendations of volume of mixture/ha issued by the manufacturer.

To effectively organize the 'spraying site', the farmer must be aware of or must calculate a number of parameters such as: the dose/ha, the surface to be treated, the volume/ha, the volume of mixture to be prepared, the volume of the spraying tank, the surface area treated with one tank etc.

Usable parameter for the site	Source:
Recommended dose (kg or L/ha)	Consult the label
Surface to be treated (m² or ha)	Accurately measure the surface to be treated with a decameter. Take into account the areas not to be treated.
Volume of mixture/ha (L/ha)	Consult the label If necessary, calibrate the volume distributed according to the conditions and the apparatus.
Capacity of the tank (in L)	Consult the manufacturer's instructions. Measure the volume for filling.

Usable parameter for the site	Calculation formula
Surface covered with one tank (m²)	$\dfrac{10{,}000 \text{ m}^2 \times \text{volume of tank (L)}}{\text{volume of mixture/ha (L/ha)}}$
Quantity of product (L or Kg) to be measured / tank	$\dfrac{\text{approved dose (L or Kg/ha)} \times \text{volume of tank (L)}}{\text{volume of mixture/ha (L/ha)}}$
Volume of mixture required (L)	$\dfrac{\text{surface to be treated (m}^2\text{)} \times \text{Volume of tank (L)}}{\text{surface covered with one tank (m}^2\text{)}}$

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4   The wetting quality of a liquid on a solid is the degree the liquid spreads out on this solid. We refer to total wetting when the liquid spreads out completely, and partial wetting when the liquid forms a drop on the solid. When the surface tension is high, the angle of contact between the drops of water and the leaf is almost zero: the drop does not spread out, and this does not allow any penetration. The presence of adjuvants in the formulation will reduce this surface tension and allow the drop of water to spread out. In the case of a drop of mixture dispersed in the air, the energy is minimal when the surface is minimal. So, the shape corresponding to the smallest surface is a sphere. This is why drops of water are spherical in shape. In reality, gravity is also involved in determining the shape of the drop.

Examples of the application of formulae

The total surface area of my plot is 5,000 m². The approved dose of the fungicide to be used is 1 kg/ha. After checking the adjustment, the volume sprayed is 200 l/ha. The sprayer available has a tank capacity of 15 liters.

What quantity of product must be measured/tank and how many mixtures must be carried out?

Recommended dose (kg or l/ha)	1 kg/ha or 1,000 g/ha
Surface to be treated (m² or ha)	5,000 m²
Volume of mixture/ha (l/ha)	200 l/ha
Capacity of the tank (in l)	15 l (apparatus carried on back)
Surface covered with one tank (m²)	$\frac{10{,}000 \text{ m}^2 \times 15}{200} = 750 \text{ m}^2$
Quantity of product to be measured out (g)	$\frac{1{,}000 \times 15}{200} = \textbf{75 g}$
Volume of mixture required (l)	$\frac{5\,000 \times 15}{750} = 100 \text{ liters}$ *i.e.* 7 tanks. So 7 x 75 g must be measured out.

8.4. Preparing and loading the mixture

As a reminder, the preparation of the spray mixture is a **critical stage** both for the health of the operator and for respect for the environment. The product formulated (commercial specialty) is actually handled in a **concentrated** state. The risks of contamination are the greatest during this phase of preparing the mixture.

Trained personnel, compliance with instructions supplied by the manufacturer and application of good plant health practices are the conditions needed for this operation to take place in a satisfactory way.

First of all, the product label must be read with care.

The label summarizes all the information needed for good and safe use of the product: the nature of the product (active substance and concentration), the authorized uses, the doses, the instructions for use, preparation and application, any compatibility with other products in the event of a mixture and especially indications of danger and recommendations for care to be respected for the safety of humans, animals and the environment.

The preparation stage requires adequate protection for the handler against splashing, dust or fumes. This requires gloves, as a minimum, overalls and boots. Wearing goggles and a mask will be included depending on the product's level of risk. There is no doubt that wearing the full range of protection against the products is not easy for reasons of comfort as well as image. However, it is a low price to pay for effective individual protection and, at the end of the day, for your health.

Anyone handling the product must refrain from drinking, eating or smoking throughout the working period and until they have changed and washed their hands. This condition

applies throughout the phases of spraying (preparation, spraying and rinsing) pesticide products.

8.4.1. Some elementary precautions

During preparation, those involved must make every effort to follow the minimum advice indicated below:

- avoid contamination with the skin by wearing the PPE according to instructions;
- prepare the mixture outside, away from homes, crops and buildings for animals within a stable area and never in a washing area or on bare soil, as the risks of runoff into drains and water points would be too high, as well as the risks of contaminating sources of water supply or ponds which may act as watering holes for animals;
- keep well away from children and animals;
- if the sprayer tank is at a high level, use a step ladder or a small ladder to easily access the tank opening;
- do not hesitate to use the product mixer if the apparatus is equipped with such a device (this also allows drums to be rinsed);
- if powders and wettable powders are being used, place the opening of the bag directly into the container or the tank to avoid any dispersion of dust;
- turn your back to the wind when emptying the bags of powder to avoid dust being absorbed;
- open packages with a knife or scissors without tearing them to avoid the product gushing out and be sure to have a clean pouring edge;
- use the appropriate equipment to measure out doses: measuring scoops supplied with the products (when applicable), if not use graduated test-tubes for liquids, a spoon for powders, buckets or drums, funnels, filters, etc.; this equipment will be set aside exclusively for this purpose and will be marked as such ;
- if a pipe is used for filling with water, do not plunge it into the tank to avoid any risk of discharge into the water mains (if possible use a pipe with an anti-return valve);
- if there are several products, make sure they are compatible;
- take your time, remain vigilant throughout the whole filling process and in particular do not leave the premises (do not leave equipment which is full and ready for use unsupervised);
- **special care will also be taken to rinse packages and dispose of them** (do not leave products or empty packages lying about and ensure they are well rinsed and rendered unusable);
- **close the packaging properly after use** in order to avoid any loss or contamination and store in a safe place. Always keep the pesticide product in its original packaging, never decant the products into containers which usually hold beverages or food;
- once preparation is complete, **wash hands carefully**, followed by the face.

8.4.2. Procedure to follow for loading

Unless special instructions are indicated on label:

- Fill the tank with one third of the volume of water.
- Measure the product carefully, without splashing, using measuring scoops of appropriate sizes.
- Add the product to the tank, with no splashes or dust (delicate movements).
- Shake to mix the mixture well (stirrer or rod kept for this purpose only.
- In particular never mix with your hands.
- Always leave the filter on the tank and fill through the filter.
- End filling the tank (total or partial if applicable) with the quantity of water needed, without frothing up the mixture!
- Rinse the utensils used for measuring the dose (measuring scoops, graduated container, bucket etc.).
- Rinse the tank at least three times if it is empty.
- Pour all the rinsing water into the tank.
- After each dosing procedure, note down: the date, the quantity measured, the plot, the crop, the name of the product, the conditions of application and the name of the applicator.
- Fill out the pesticide stock management sheet.
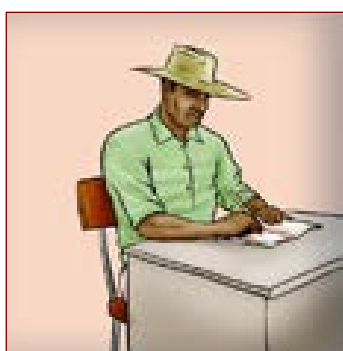
8.5. Principles for sprayer calibration

8.5.1. Basic rules for all types of apparatus
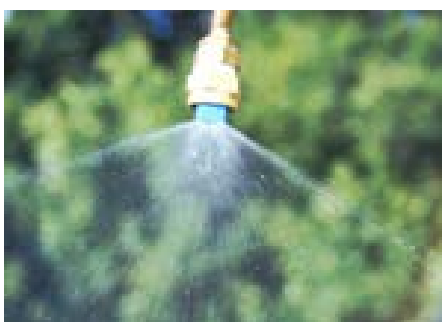
*Calibrating a sprayer, means **establishing a quantity of mixture to be spread per unit area,** so it means establishing a volume/hectare.*

Each piece of apparatus is adjusted according to the following general formula:

$$\text{Volume/hectare (L/ha)} = \frac{\text{Nozzle output (L/min)}}{\text{Speed (km/h)} \times \text{Width (m)}} \times 600$$

Each of the parameters will have an influence on the volume spread/ha:

	Change in parameter	Volume spread/ha
Output	↗	↗
Progress speed	↗	↘
Working width	↗	↘

Depending on the desired treatment conditions (according to the product activity and the crop), the characteristics of spraying must be adapted to be able to obtain a good covering of targets with minimum drift. In order to adjust the apparatus with regard to the expected performances, the following operations must be carried out:

1. Select a type of nozzle according to the volume/ha and the size of the droplets
2. Measure the speed of progress of the tractor or person walking
3. Determine the nozzle output needed to obtain the selected volume/hectare
4. Adjust the working pressure compatible with the type and diameter of nozzle used
5. Check the output actually obtained.

8.5.2. Adjusting the size of the droplets: selecting an appropriate nozzle

Before adjusting a sprayer, the characteristics of the spraying required must be known, *i.e*. **the volume/hectare** and **the ideal size of the droplets**.


The quantity of liquid to be spread per hectare depends on the type of product, the stage of development of the crop and climatic conditions. For treatments, in general, the volume/hectare can range from **100 to 1,000 liters/hectare**. With certain apparatus (centrifuged rods, ULVA (ultra-low volume application*)*), it is possible to go down to 10 liters/ha and even below.

Droplet size depends on the mode of action of the products sprayed as well as the strength of the wind. The **fineness of the droplets** determines their ability to run off the vegetation and fall onto the ground: **fine droplets have a greater covering rate but drift more easily, carried by the wind**.

The **nozzle** is the component which is able to split the mixture into droplets under the effect of **pressure from the** liquid through a calibrated opening. According to the principle of fragmentation used, they can be classified into hydraulic, centrifugal, pneumatic, electrostatic, electrodynamic nozzles, etc.

In spite of the advantages presented by some of these techniques (reduction of the volume/hectare, spectrum of uniform droplets, phenomenon of reduced drift), nozzles which work by liquid pressure (slit nozzles, turbulence nozzles, mirror nozzles and net nozzles) continue to be those most commonly used in agricultural spraying.
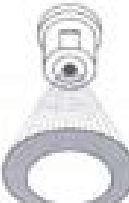
The slit nozzle is **the most commonly used**, as it is **versatile and can be used for all treatments** and provides uniform transversal distribution with single or double overlap. It is a nozzle with an opening of an **elliptical shape, producing a flat jet** (or fan jet). The two characteristics used to identify the nozzle are the angle of the jet on exiting the opening (**the most common is 110 °)** and the diameter, which corresponds to the output of the nozzle at a given pressure. The slit nozzle is recommended in order to obtain uniform spraying, without too much fog. It ensures good distribution from a pressure of approximately 2 bars and can be used up to 3 bars with most herbicides. For fungicides and insecticides, it may be possible to work at pressures which are slightly higher, between 3 and 5 bars
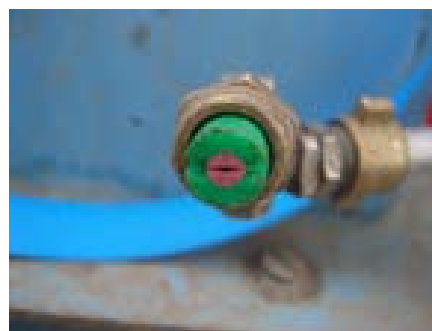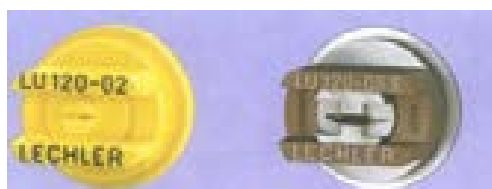
Turbulence or hollow cone nozzles consist of a coil, a turbulence chamber and a plug with a calibrated orifice. The liquid is rotated in the turbulence chamber before exiting via the circular opening in the form of a conical jet. Boom spraying with this type of nozzle is not as effective as spraying with the slit nozzle and the jet produced is more likely to drift. They **are reserved for fungicides and insecticides**, because distribution is not ideal, and there is greater drift of the mixture (fine droplets and a greater boom height)

The **flat spray nozzle** is a nozzle with a smooth deflector which produces a flat jet which fans out. The jet basically consists of large droplets (> 500 microns). It is intended for use with liquid fertilizers: working at low pressure, production of large drops. The **triple net nozzle** is intended for liquid fertilizers: low pressure, inaccurate, forms three rod-shaped jets consisting of large droplets.

Characteristics of the jet produced by the different nozzles:

	Nozzle with standard slit	Air induction anti drift nozzle	Triple-stream nozzle for liquid fertilizer	Nozzle with deflector plate	Hollow cone nozzle
Shape of the nozzle					
Shape of jet & Trace in ground					
Drift	Average	Low	Very weak	Low	High
Ideal pressure	2 - 4 bars	3 - 7 bars	1 - 3 bars	1 - 3 bars	3 - 20 bars

*Trace left on ground by a hollow cone nozzle. The jet clearly forms a hollow cone. The finest droplets are at the exterior of the jet and are carried by the wind (drift). This type of turbulence jet is well suited for fungicide treatments as the fine droplets can adhere to the inner face of leaves.
(Photo B. Schiffers)*

Choice of type of nozzle according to type of treatment to carry out:

Nature of application	Restrictions	Type of nozzle recommended	Pressure recommended (bar):
1. Plant health treatment			
Herbicide	Significant uniformity of quantity applied, average-sized droplets average	Slit	1.8 to 3
Insecticide Fungicide	Average droplets providing maximum cover, enveloping fog, fine droplets	Turbulence or slit	2.5 to 5
2. Fertilization			
Clear liquid	Avoid burning, average-sized to large droplets	Slit or mirror or triple-stream	1 to 2
Fertilizer in suspension	Large droplets	Mirror	1 to 2

To sum up, when selecting nozzles

- Bear in mind the crop to be treated
- Bear in mind the product to be applied
- Take into account the desired volume/hectare
- Bear in mind the wind conditions: very significant as a wind which is too strong will cause droplets to drift outside the plot.

8.5.3. Adjusting the speed of progress: timing

The speed of progress and the spacing of nozzles allow the **output needed** to **obtain the volume/hectare selected** to be determined. It is therefore essential to be aware of the speed of actual progress of the equipment under working conditions.

In the case of apparatus carried by a tractor or pulled by the latter, it is determined by calculation after measuring the time needed to cover a given distance of, for example, 100 metres, preferably in a field, with the spraying tank **filled to half its capacity**.

In the case of apparatus carried on the back, the user covers a distance of 100 metres, with the sprayer filled to half its capacity and a chronometer calculating the time taken.

*Timing an operator.
In this case, the human factor has an impact
on the result. Each operator works at a
different speed.
(Photo B. Schiffers)*

8.5.4. Adjusting the output: measuring the volume emitted

The output of a nozzle, i.e. the volume of liquid which flows per unit of time, depends on the pressure of use, the diameter of the nozzle (section of nozzle opening) and the density of the liquid sprayed. As the pressure of use as well as the nature of the mixture are imposed by the type of treatment, the choice of diameter depends on the volume to be sprayed and the speed of progress.

There are various **instruments** for **calibrating** the output.

- **Test-tube or graduated container**: collect the liquid which has been sprayed by the nozzle in the test-tube or the graduated container, over a given time (generally 1 minute) using a chronometer.
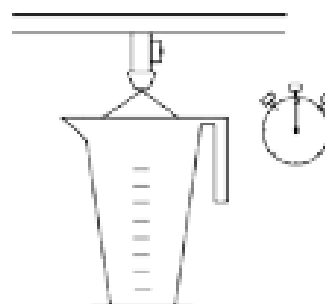
*Measuring the output of a nozzle into a
graduated container, measuring the time with a
chronometer
(Photo B. Schiffers)*

- **The bearing flowmeter**: indicates the immediate value of the nozzle output via a bearing positioned opposite a graduated scale. It is sufficient to apply, avoiding any leaks, one of the ends of the flowmeter under the nozzle.
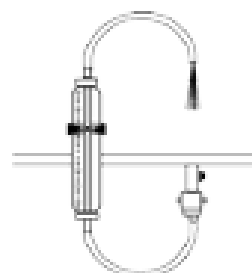
- **Plastic bags:** these are **flexible graduated test-tubes** which can be fixed to the nozzle screw using a metal staple on any type of nozzle-holder.
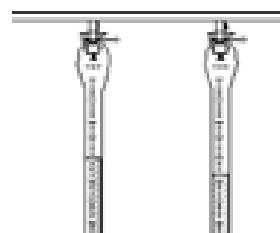
To check the **overall output of boom sprayer nozzle**, we can:

- activate the sprayer and make sure that all the nozzles are giving off a regular flow, make sure there are no leaks;
- adjust the pressure to the value given in the tables supplied by the manufacturers to obtain, with the selected nozzles, the desired volume/hectare;
- cut off the boom supply;
- fill the tank **to its maximum** (line on gauge);
- make the pump turn at working speed;
- activate all the booms for a **given period *t*** (assisted by a chronometer or a watch. Spray for **several minutes** in order to be as accurate as possible);
- **measure the volume of water *V*** needed to return to the tank's maximum level. When the apparatus is equipped with an accurate graduated gauge, the measurement of the flow volume is read directly.

Actual output of the sprayer (in l/min)

$$Q = \frac{l}{t}$$

with

Q	=	actual output of the sprayer (in l/min)
l	=	volume of water returned to the tank (l)
t	=	duration of spraying (min)

with

Q	=	actual output of the sprayer (in l/min)
l	=	volume of water returned to the tank (l)
t	=	duration of spraying (min)

However, this method only allows the **average output of the nozzles** of the sprayer to be calculated.

8.5.5. Adjusting the pressure

The **output** of a nozzle and the **pressure are directly linked** (the output of a nozzle is actually proportional to the square root of the pressure). After having selected the nozzle (and the diameter of the nozzle, generally indicated by a colour code), only the working pressure needs to be established/adjusted by taking action, depending on the type of adjustment, either on the bypass, or on the pump output. The pressure is adjusted by measuring its value on a manometer. In the case of apparatus carried on the back, work is always carried out at maximum pressure, obtained by regular pumping.

The pressure can be measured with a **manometer**.

Place one or several calibration manometers instead of one or several spraying nozzle/s.

If the **manometer** equipping the sprayer gives doubtful or unreliable information about pressure, dismantle and place it on a **pressure calibrator or comparator**.
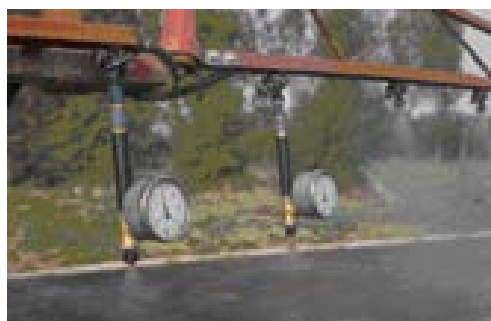
8.5.6. Adjusting the working height

The **height of the boom determines the uniformity of distribution** on the ground or on the plants for all types of nozzle. It must therefore be adjusted taking into account characteristics of distribution, type of nozzle and their spacing on the boom.

If using slit nozzles, the boom must be placed above the minimum height (**50 cm with nozzles at 110 °** and 90 cm with nozzles at 80 °) so that the **overlap of the jets is sufficient** not to affect distribution, following the inevitable variations in height which occur in the course of work.

Minimum height between the boom and the surface to be treated for slit nozzles of 110 °:
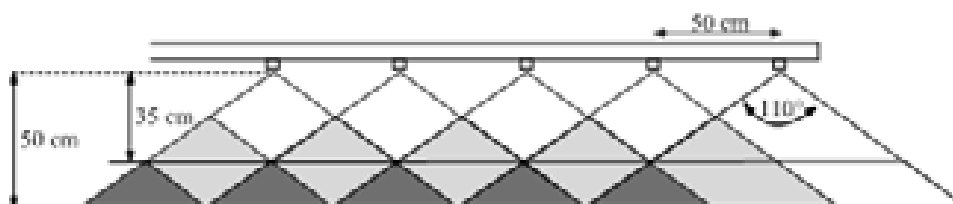
With hollow cone turbulence nozzles, we also select a boom height which produces an overlap of jets. For nozzles spaced 50 cm apart with nominal jet angle of 80 °, the

optimum height is located between 70 and 90 cm from the target, although it is difficult to obtain good distribution with this type of nozzle.

With new generation deflector plate nozzles, the height of the boom must allow slight overlap between jets. When these nozzles are placed every metre, the boom must be positioned at a minimum height of 90 cm.

With triple-stream nozzles, it is the inclination of the streams on exiting the nozzle which determines the height; 70 cm is a minimum for the streams to fall vertically and ensure regular spacing between the bands formed in the ground.

For volumes of water below 100 l/ha, the risks of clogging are greater and the recommendation is sometimes to use nozzles at 80 °. However, with the latter, it is always necessary to know that distribution is more sensitive to variations in the height of the boom.

The following figure illustrates a case where the extremity of the boom was located 35 cm above the ground. In this area, there is no longer sufficient overlap between the jets from the nozzles at 80 ° whereas double overlap still exists for the nozzles at 110 °.

Influence of the movements of the boom on the transversal distribution with nozzles at 110 ° and 80 °:
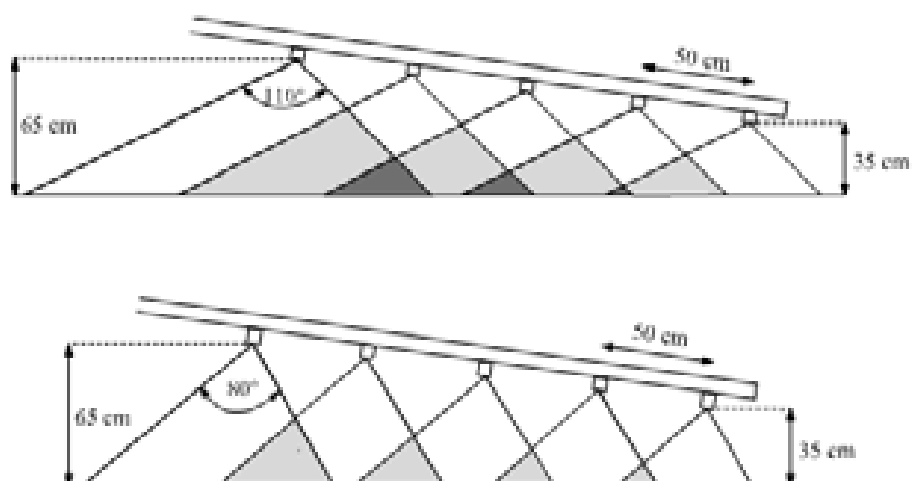
> **The operations** of adjustment and calibration **must be suitable for each type of apparatus**: apparatus to be carried on the back, nozzle boom on a tractor, pneumatic sprayer, rod with centrifugal disc, dusting equipment etc.

8.6. Origin of the drift phenomenon

Drift is considered to be the most significant side effect of spraying. It can be defined as the quantity of product sprayed which, displaced by air currents, falls back to the ground or evaporates after travelling a distance of varying lengths. It therefore occurs at the actual time of the application or a short time afterwards.

It gives rise to pollution of the ground, water and air and to contamination of the operators.

The factors influencing drift are numerous and depend on physical, chemical or climatic parameters and on the interaction between these parameters.

➤ ***The size of the droplets:*** the droplets from a spraying nozzle vary in size and speed. The size of the droplets, measured in micrometres, is often characterised by the mean volumetric diameter (MVD) also referred to as D_{50}. The MVD is a statistical value which defines a mean droplet diameter, i.e. the diameter of the drop for which 50% of its volume is made up of bigger droplets and 50% of the volume consists of finer droplets. The size of the drops is **an essential element of drift**.

The **large drops** subject to the laws of ballistics **fall by gravity**, whereas the **fine drops tend to remain in suspension in the air** and undergo the effect of the atmospheric conditions (transport and/or evaporation). Several authors have pointed to a significant reduction in drift for droplets of a diameter greater than 150 μm. According to studies, a drop measuring 100 μm released from a height of 3 m with a side wind of 5 km/h will be carried 15 m, whereas a drop of 20 μm under identical conditions **may drift 304 m before reaching the ground**.

➤ ***Pressure:*** for a given nozzle, **an increase in pressure results in** a change in output, generates **a reduction in the granulometry** of the drops and, as a consequence, **a greater sensitivity to drift**.

➤ ***Height of spraying***: this parameter **influences falling time**. The greater the height, the more the drop can undergo the effects of climatic conditions. If the height of spraying increases, the limited lifetime of the droplet is brought forward, the diameter of its base is reduced and it becomes more sensitive to drifting.

➤ ***Product formulation***: the physical-chemical properties of the mixture (especially viscosity and above all surface tension influenced by emulsifiers, wetters, dispersants) influence the size of the drops and therefore the drift. So, when applying fine drops, using a less volatile liquid is recommended in order to avoid reducing the size of the drops, or even the formation of a spray which presents significant potential for pollution. It must be noted that the concentration of product in the mixture or **the addition of an adjuvant** to the tank can considerably modify the properties of the mixture.

➤ ***Weather conditions***: atmospheric conditions have a **significant influence on drift**. Once the droplet has formed, it is subjected to atmospheric parameters, *i.e.* **wind, temperature and humidity** which tend to affect its trajectory and/or its lifetime. The wind acts on the direction and trajectory of the drops. If there is no wind, when a drop

is allowed to fall it tends, under the effects of gravity and aerodynamic pressure, to fall at a constant speed. **Droplets which are small in diameter are more exposed to air movements, which slow down their fall, carry them off** horizontally, and as a consequence, **expose them more to drift**.

From a certain wind speed (greater than 5 m/s), the recommendation is to completely stop treatment. Direction must be taken into account in order to avoid above all the contamination of sensitive areas and that of the operator. These parameters are very variable in the field, which makes knowing the direction of spray drift a delicate matter.

T**emperature** and atmospheric **humidity play a role** in the process of **evaporation** and consequently the persistence of the droplet. This depends on its initial diameter and the temperature of the environment. So that the droplet can reach its target, its lifetime must be longer than the time it takes to fall. It is important for the operator to take this data into consideration when selecting suitable conditions to spray the mixture.

➢ *The crop*: this is the target of the spraying. It also constitutes a biological obstacle to drifting. Moreover, the microclimate generated around the foliage could constitute a way of reducing the contamination of sensitive areas (streams, neighbourhood, etc.).

It is essential for the operator to act on these different factors to **reduce the risk of drifting** when spraying.

Using 'antidrift' nozzles which increase the average size of the drops is one of the effective measures that can be taken.

As the drift can never be reduced to zero, it is also recommended to leave a sufficiently wide **untreated area ('buffer' zone)** between the crop treated and the area to be protected (surface waters). The risk must be evaluated according to the ecotoxicological and physical-chemical properties of the product.

8.7. Cleaning and maintaining equipment

> Warehouse operatives and site managers must ensure the supply of **equipment in perfect condition** as well as all the **spare parts** needed before the spraying season begins.
>
> The brochures supplied by the manufacturers about use, repairs and spare parts must be available for consultation.

8.7.1. Role of the operator

The operator must:

- **Clean and check** equipment at the end of each day of application. Pay special attention to this cleaning, especially if the equipment is not to be used for some time, as **product residues** may cause **corrosion** or **clogging** of the distribution circuit (pipes, nozzles etc.) in subsequent treatments.
- Make provision in the field for the **spare parts** and **tools** most frequently used so that ongoing repairs can be made in situ (washers, nozzles, clips, screwdrivers, adjustable wrenches, pliers etc.).
- If possible, and especially if a certain number of machines are used simultaneously, make provision in the field for a spare machine to replace the one which may require repair and save on repair time.
- **Do not use leaking equipment:** leaks may lead to **skin irritation** and **poor application**, which can seriously damage crops.
- **Do not use poor quality equipment**, as this can be dangerous. Poor application or poorly applied dusting lead to **mediocre results**, can cause **damage to the crops** and consequently constitute a **waste of time and money**.

8.7.2. Actual maintenance

As is the case with all equipment, the **regular maintenance** of the sprayer is essential, as this ensures **accurate and reliable performance** and increases equipment **lifetime**.

When using and maintaining equipment, operating instructions and methods must be scrupulously followed as defined in the **instructions for use** supplied by the manufacturer. These instructions form an integral part of the equipment. If you do not have or no longer have these instructions, the following observations will not replace them but may constitute a summary of the main recommendations made at various stages.

❑ **Daily maintenance**

Prior to **making an application**, the sprayer must be **ready to function** and **be absolutely clean**.

Carry out a few checks:
- Check the state of the equipment: there must not be **any leak** (pump, anti-drip device, connections, pipework, etc.) and **none of the flexible pipes must be squashed** (necks, score lines, etc.)
- Check that the manometer is working properly (if there is one)
- Check the air pressure in the air chamber (if there is one): the pressure must be between 1/3 and ½ of working pressure
- Check the tension of the transmission belts
- Grease moving parts (transmissions, universal blocks)
- Check the oil level in the pump
- Check the **condition of the filters** and clean them if that is necessary (replace them if they are damaged)
- Check the functioning of the anti-drip device and the nozzles
- Calculate the exact quantity of mixture needed for the area to be treated in order to avoid surpluses
- Fill the rinsing tank and the tank for washing hands.

❑ **Rinsing the equipment**

Rinsing is essential after a day's treatment in order to **avoid product deposits** and **any clogging**. Whenever the product is changed, rinsing must also be carried out in order to avoid any accidents with the crop and also any precipitation of certain products. In order to eliminate all traces of chemical product that have not been removed, a detergent can be added to the washing water.

If the equipment does not have a rinsing tank (or the equipment is carried on the back), it must be emptied completely, rinsed in plenty of water; then filled to 1/3 of its capacity and turned on to allow the 'clean' water to circulate through all the circuits of the sprayer and exit via the spray nozzle or nozzles.

Whenever possible, these rinsing procedures must always be carried out at the edge of the plot which has just been treated, so that the rinsing water can be emptied directly onto the plot (spray while walking at a faster pace to distribute any product residue).

Never empty this rinsing liquid into the drainage system, a pool, a lake, or near a stream or river!

❑ **Maintaining the spraying nozzles**

The nozzles can be cleaned either using a **soft brush** (such as an used toothbrush) using water, or with compressed air (compressor, cylinder of inert gas), or using both methods (preferable if possible). These operations may be preceded by dipping in an appropriate solvent.

Under no circumstance use a piece of wire, a needle or any other metal object for cleaning or unblocking the nozzle, as this may damage the nozzle and therefore significantly modify its characteristics.

Never blow through the mouth, as you may experience irritation or poisoning.

Clean the nozzles in water or with a flexible rod.

Do not dismantle the nozzles of a piece of equipment while it is operating and always wear gloves to dismantle it.

(Photo B. Schiffers)

❑ **End-of season maintenance**

Once the **season has come to an end** checks must be carried out to identify, as quickly as possible, any problems, in order to rectify them so that the equipment is **returned to perfect condition** and is ready for the next season. To do so, make sure that you follow the few recommendations indicated below:

- **carry out intensive cleaning of the spraying circuits**, of the **interior of the tank**, of all the **external parts**;
- store the equipment under shelter and not outside;
- loosen the transmission belts;
- release the adjustment system (in order to take stress off the spring);
- empty the air from the air chamber;
- **grease the moving metal parts** (transmissions, universal blocks, pumping lever, boom etc.);
- replace the pump oil
- for pumps with membranes, inspect them every year and replace them if they are damaged;
- check the condition of the manometer, replacing it if in doubt (if possible, establish a comparison with the control manometer);

Chapter 9

Spraying equipment

9.1. Introduction to spraying equipment

The sprayer is a piece of apparatus designed to apply either a mixture (pesticide product mixed with a carrier liquid) in order to combat a pest, or a liquid nutrient formulation intended as a fertilizer. In the most commonly used equipment, the liquid under pressure is divided into droplets by its passage through a calibrated nozzle.

Spraying equipment can be broken down into these types in particular:
* the pressurized back-pack sprayer;
* the motorized mist blower back-pack sprayer;
* the tractor mounted hydraulic nozzle boom sprayer;
* the radial flow air assisted sprayer.

The back-pack sprayer and the tractor mounted boom sprayer are the types most commonly used worldwide. They are best adapted to the application of a wide range of volume/ha of mixture on most crops at all latitudes. Its principle is simple: the mixture is taken under pressure from the tank up to the spraying parts (the nozzles) via which it is projected into the ambient air. It breaks up there into droplets. There are countless models of this type of equipment.

In many agricultural regions, the reduced surface area and the dispersion of plots, the difficult access to them and the unevenness of the ground make individual portable equipment obligatory (back-pack equipment).

Back-pack and boom sprayers are well suited to the requirements of these situations. As their market is extremely widespread, they undergo constant adaptations and improvements. A distinction can be made between two categories:
* the pre-pressurized back-pack sprayer (the tank is pressurized);
* the back-pack sprayer whose pressure is maintained constant by a lever pump.

9.2. Back-pack sprayers

9.2.1. Pre-pressurized sprayers

The sealed tank is pressurized by a piston pump which may be an integral part of the pump or separate from it if it has to serve a range of equipment. Equipment of this type, whose usable capacity does not exceed 5 liters, is frequently used for domestic purposes and in the public hygiene sector. The largest models are reserved for applications which require team work under qualified supervision.

As the equipment is pressurized when it is stopped, the user's work throughout the spraying activity is limited to manipulating the spray arm.

The pressure and therefore the output progressively reduce as the tank empties. Keeping the tank at a certain air pressure before introducing the mixture and mounting a pressure adjustment valve at the discharge reduce these disadvantages.

Keeping a tank with a usable content of more than 10 liters under pressure at all times is not without danger unless basic precautions are taken:
- check manufacturing quality at the time of purchase (welds, rivets, etc.);
- monitor, throughout the season, the state of the tank (metal fatigue, as impacts and corrosion may impair its resistance);
- regularly check the satisfactory functioning of the manometer and the safety valve.

This equipment is not generally used in agriculture, except for very small jobs.

9.2.2. The constant pressure back-pack sprayer

Main characteristics and components of the equipment:

- a tank whose capacity is generally between 10 and 18 liters;
- two straps to keep the tank firmly attached to the back;
- a manually activated pump in order to keep liquid under pressure;
- two filters located at the filling spout and in the control handle (sometimes a third for the nozzle-holder screw);
- an air chamber to stabilize pressure (not always present);
- a spray arm with a control handle and spraying nozzle at the end.
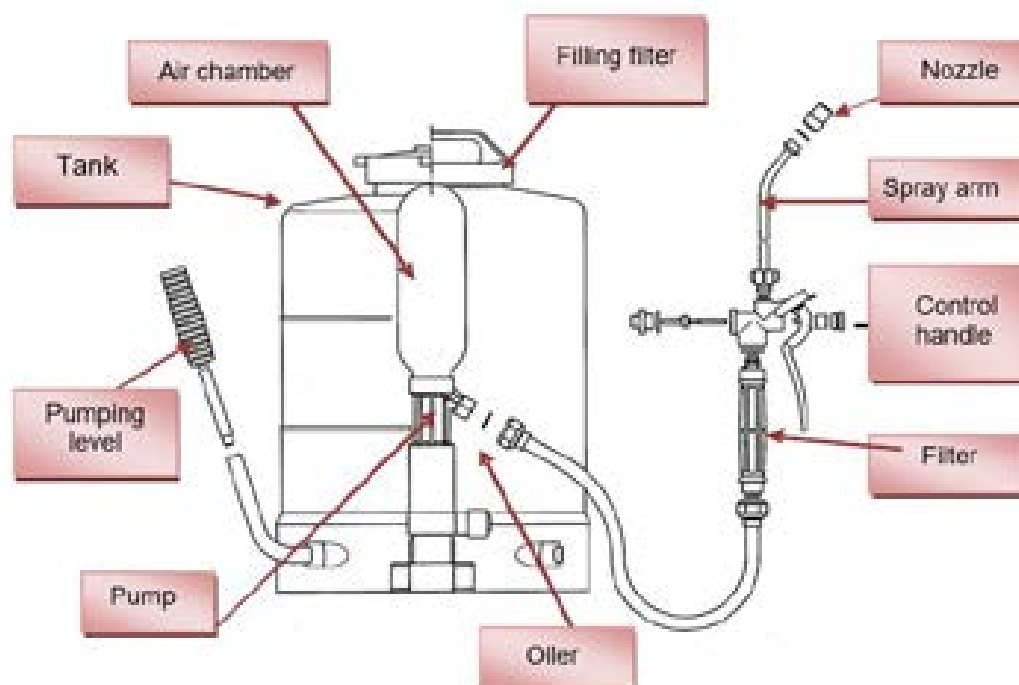
When the pump is activated, the piston sucks up the mixture and discharges it into the hose of the spray arm for spraying through the nozzle located at the end of the circuit.

With this type of sprayer, **the pressure must be continually maintained** during treatment by activating the pumping lever. The faster the movement, the higher the pressure as well as the output at the exit of the nozzle. An air chamber, which is not always present on this type of equipment, stabilizes the pressure during pumping. The tank is not pressurized and can therefore be filled completely with the mixture.

Some simple **basic ideas** must be understood and respected when a back-pack sprayer is used:

- before any use after a long period in storage, check that there are no leaks, **grease the sliding parts** of the pump and carry out calibration using water;
- when preparing the mixture and during spraying, use the recommended PPE;
- incorporate the pesticide product when the tank is half-filled and mix using an appropriate utensil; top up without foaming the mixture;
- screw on the cap so that it is hermetically sealed and prevents the mixture from flowing out when the sprayer is put onto the person's back and while they are working;
- avoid treatment when the air is too dry, before it rains or if the wind is too strong (in all cases, always spray with your back to the wind);
- when spraying (particularly for an herbicide treatment), hold the spray arm in front of you at all times, at a constant height throughout the treatment and without swaying. This can cause an overdose of 3 to 10 times the dose with the resulting wastage and pollution;
- the faster the pumping movement, the higher the spraying pressure, the higher the output from the nozzle, the greater the volume/hectare;
- the higher the pressure, the finer and therefore more sensitive to drifting the drops formed, and the poorer their penetration into dense vegetation
- to increase the volume/hectare without increasing the pressure, it is necessary to either advance less quickly, or select a bigger diameter nozzle;
- in order to limit drift, use a nozzle with a bigger diameter (drops of a larger size), pump at a lower frequency, reduce the distance between the nozzle and the target;
- after each use, rinse the sprayer in plenty of fresh water and clean the filters.

9.2.3. The motorized mist blower back-pack sprayer

Air assisted spraying is characterized by the use of a high-speed air current to reduce a liquid sheet (mixture) injected into its medium at very low pressure into fine droplets. The air current also facilitates the transport of the drops towards the targets to be protected. In this respect, it offers an advantage over traditional pressure spraying which only uses kinetic energy communicated to the drops during their formation to project them a short distance towards the plants.

Air assisted spraying allows **effective deposits** to be made on most of the leaf surface with **relatively small quantities of mixture**. This quality explains its success in market garden or ornamental crops, in viticulture, plant nurseries, arboriculture with small and medium stems in temperate regions where apparatus of varying capacity is used, equipped with distribution elements (hoses) adapted to the automatic treatment of the different types of crop. In tropical and subtropical crops, it offers the possibility of

improving the efficacy of treatments by reducing the quantity of water used and relieving the physical stress on operators.

The structure of agricultural undertakings and the technical staff available do, however, leave little room for developing a very efficient motorized mechanism. The cultivated plots generally have a small surface area and are often spread out and are difficult to access. Only fairly light-weight apparatus, carried on an operator's back, is suitable for this situation.

The air assisted back-pack sprayer with a fuel-powered engine (other names in general use: **nebulizer, atomizer**, mist blower etc.) are able to carry out insecticide and fungicide treatments using an oily and aqueous mixture on a wide diversity of crops including: rice, millet, sorghum, pineapple, cotton, cocoa, coffee, banana, young oil palm trees, young coconut trees and in tree nurseries.

The results have shown the advantage of the technique all over the world. They have confirmed that the level of training and learning of operators and the impossibility of having recourse to technical-commercial support services could restrict the development of the mechanization of techniques for applying pesticide products.

The total weight of the fully-loaded apparatus (fuel and mixture tanks filled) cannot exceed 25 kg. The composite construction materials, plastics, light metal alloys, etc. must be resistant to impacts, to the corrosive action of products, to deterioration under the effects of light or high air temperatures.

The apparatus consists of the following essential parts: a supporting framework, a motor fan unit, an air distribution circuit which finishes in a rigid tube with a handle and a spraying hose and a mixture circuit comprising tank, flexible hoses, stop tap, filters and devices for calibrating output.
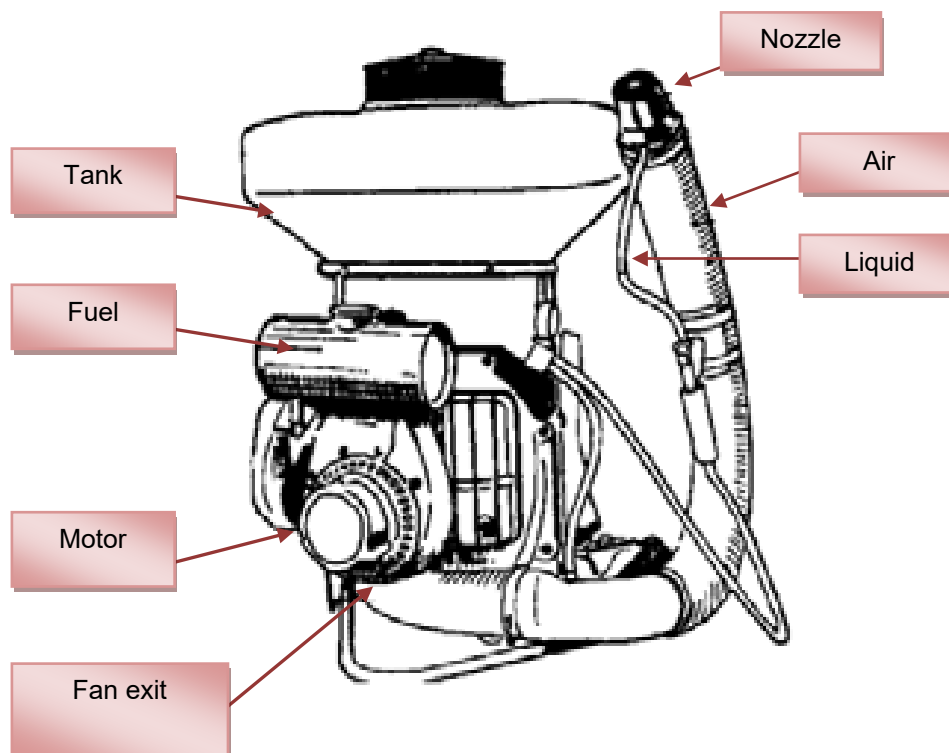
A small engine drives a **fan** which produces a **flow of air at low volume and high speed**. A Venturi device placed in the hose allows **the mixture to be sucked** out of the tank which is discharged at low pressure through a hose directly to the point where air exits and where it is 'atomized' and sent to the target.

The air flow is constant and the output of liquid (therefore the volume/hectare) is adjusted with a restriction (valve) positioned just before atomization. The advantage of this equipment over other types is that the **output is stable** (as the outflow of air is constant), **there is no need for pumping** and the treatment of plants and trees is facilitated thanks to a **much longer drop trajectory**. On the other hand, as for the previous equipment, it is more expensive and also heavier to carry (25 kg).

Several important parameters must be taken into consideration for the application of plant health products with back-pack pneumatic sprayers to be successful:

- volume/ha determined for application (ULV or VLV);
- controlled output from apparatus compared with desirable nominal output;
- optimum working width: bearing in mind the technical performances of the equipment (maximum range in a calm atmosphere), the influence of the wind (force and direction) and the temperature of the air;
- height of plants and density of vegetation;
- determination and control of speed of progress of operator;
- monitoring distribution of mixture.

9.3. The hydraulic nozzle sprayer either mounted on or pulled by a tractor

9.3.1. Operating principle

Sprayers for **low**-growing **crops** are treatment apparatus with horizontal booms. Their spraying method is generally of the liquid pressure type with hydraulic nozzle. Spraying is carried out by **fan nozzles assembled on a boom**, which means that nozzles of different diameters or types can be used (depending on the treatment to be carried out).

Main characteristics and components:

- a main tank (from 200 to 4,000 liters);
- a pump for spraying;
- a pump for filling and stirring (not always the case);
- a pressure regulator;
- a distribution unit (broken down into several electric or manual valves);
- multiple filters (at the tank filling spout, at the point of suction , at the pump discharge, on the sections of the boom, on the nozzles);
- a spraying boom (from 6 to 36m) with a manual or hydraulic open-close system, mechanical or hydraulic suspension, positioning system in order to compensate for any unevenness of the terrain;
- a product incorporator (not always present);
- a rinsing tank (not always present);
- a tank for washing hands (not always present);

9.3.2. Different boom sprayer models

❑ **The mounted sprayer**

This type of apparatus is the most commonly used, with a tank capacity of 200 to 1,200 liters and a boom width ranging from 6 to 24 m. This type of apparatus is easy to operate but the lifting stress if it is carried by a tractor is significant.

❑   **The trailed sprayer**

This type of apparatus offers greater autonomy (tank of 600 to 4,000 liters), and can offer a larger working width (6 to 36m), requires more motive power but there is no stress associated with being lifted up by the tractor. This equipment is not as easy to handle and may cause damage on curves or bends at the edge of the field.

❑   **The self-propelled or integral sprayer**

This apparatus has a very large capacity: up to 6,000 liters, with of boom up to 48 m.

9.3.3.   Description of the main components

❑   **The boom**

The structure of the frame of the boom must provide a compromise between robustness, rigidity and lightness, in order to obtain good stability both horizontally and vertically. Large widths amplify the movement of the extremities and result in added heaviness of the unit. The lightness of the materials is becoming a characteristic which is increasingly sought-after. In large booms, steel may be replaced by aluminum or fiberglass.

The structure can also be reinforced by an assembly in the form of a trellis, a triangle or a trapeze. Various suspension devices improve the stability of the boom. One section of the boom is a portion of hose with its own mixture supply. The choice of number of sections will basically depend on the width of the boom.

The diameter of the hoses must be sufficient to avoid excessive losses of pressure between the supply and the end of the section. In the case of sections whose length is in excess of 4 m, supply through the center of the section is preferable.

> **To sum up, when selecting the boom:**
>
> - Structure: beyond 12 m, trellis structure necessary in order to increase the rigidity of the unit.
> - Material: many booms made from steel, development of large widths suggesting the use of lighter materials (aluminum, fiberglass).
> - Width: depends on the apparatus model, conditions of use, width of the seeder and site performances sought.
> - Stability: beyond 12 m, suspension system needed in order to maintain the boom parallel to the ground.

❑ **The tank**

The sprayer tank is used for preparation, agitation, transport and, exceptionally, for storing mixture. The main parameters which characterize a tank are the capacity, the shape and the material with which it is made.

The agitation system present in the tank plays an essential role in maintaining the characteristics of the mixture. Variations in the mixture generate over or under-doses of the active substance in the course of spraying. Agitation must be adequate and preferably flexible, for example using a pump suction adjustment valve, especially when the tank is nearly empty. Most systems are hydraulic, either from the bypass, or with a specific agitation circuit.

The choice of tank capacity is extremely important. It depends in particular on the sprayer model. The size of the plots, their arrangement and the desired volumes/hectare must also be taken into consideration.

> **To sum up, when selecting the tank:**
>
> - Shape: sloping bottom to allow the tank to be emptied completely into a catch basin, no corners, presence of anti-roll devices for large capacity tanks.
> - Material: polyethylene or polyester tank (higher cost), and no rough parts on internal walls.
> - Capacity: depending on the apparatus model, the volume/hectare most commonly used, the site performances sought, the size and arrangement of plots.

❑ **The pump**

A pump must give out a certain quantity of liquid under pressure not only for spraying purposes but also to ensure the mixing of the product. Sometimes it is also used for filling the tank. The output needed will depend on the volume/hectare, maximum speed of progress, the length of the boom, the sprayer model and the adjustment system.

> **To sum up, when selecting the pump:**
>
> - A membrane type: quasi volumetric, vulnerable to certain aggressive liquids, inexpensive.
> - A piston-membrane: remarks identical to the membrane pump.
> - A piston: strictly volumetric, suitable for liquid fertilizers and apparatus equipped with a PAO mechanical adjustment, very expensive.
> - Centrifuge: non volumetric, allows high outputs, frequently used as filling pump or mixing pump for large capacity apparatus, inexpensive.

❑ **The adjustment system**

The aim of the adjustment system is to fix, control and maintain the volume/hectare decided by the user. The quantity applied depends on various parameters brought into relationship by the following formula:

$$Q = \frac{D}{V} \times k$$

with

Q = volume of mixture per unit area (in L/ha)
D= output to the boom (L/min)
V = speed of progress (km/h)
k = constant (equal to the value 600 divided by the width of the boom).

The quantity applied to the hectare and the characteristics of the spraying do or do not remain constant, according to the adjustment system.

There are three major types:
1. System with a **constant pressure (CP)**
2. System with an **output proportional to the motor speed (MSO)**
3. System with an **output proportional to progress (PAO)**

> **To sum up, for an adjustment system:**
>
> - CP: the characteristics of the jet, but not of the volume/hectare are maintained if the speed changes, difficult to control.
> - MSO: the volume/hectare is maintained, for small speed variations (due to variations in motor speed), but not the jet characteristics, easier to control.
> - PAO: the volume/hectare is maintained for all changes in speed, but not the jet characteristics. There are two variants of this system: mechanical (reliable and simple, requires two pumps) and electronic (reliable, accurate but very expensive.

The variation in the parameters of the table is illustrated by arrows with the following meaning: constant ($\rightarrow$), increase ($\uparrow$), reduction ($\downarrow$):

Working Conditions	Parameters spraying	Adjustment systems		
		CP	MSO	PAO
Sliding Speed [(1)] $\downarrow$ Engine speed [(2)] $\rightarrow$	• output and pressure to boom, fineness of spray • volume/hectare	$\rightarrow$ $\uparrow$	$\rightarrow$ $\uparrow$	$\downarrow$ $\rightarrow$
Climbing Speed $\downarrow$ Engine speed $\downarrow$	• output and pressure to boom, fineness of spray • volume/hectare	$\rightarrow$ $\uparrow$	$\downarrow$ $\rightarrow$	$\downarrow$ $\rightarrow$
Descending Speed $\uparrow$ Engine speed $\uparrow$	• output and pressure to boom, fineness of spray • volume/hectare	$\rightarrow$ $\downarrow$	$\uparrow$ $\rightarrow$	$\uparrow$ $\rightarrow$

(1)   *Speed of progress*
(2)   *Engine speed*

9.4. The mounted air assisted radial sprayer (atomizer)
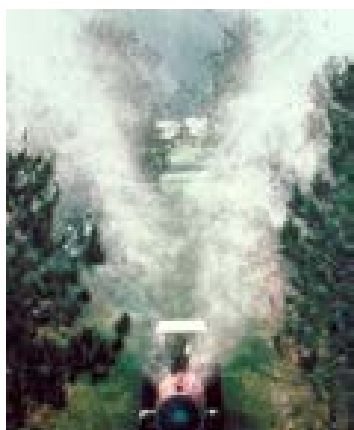
Fragmentation of the mixture is obtained by pressure of the liquid in the nozzles and transport of drops is ensured by an air current.

These sprayers can be mounted, trailed or very rarely are automated. They are frequently used for arboriculture. Their design is generally compact and low so that it can move around easily in plantations and in orchards while catching onto branches as little as possible.

The mounted apparatus are equipped with tanks of 200 to 800 liters, whereas trailed models have tank capacities varying between 600 and 2,000 liters.

The mixture circuit has a volumetric pump, distributors, a pressure adjuster, several filters and booms placed in the arc of a circle (or otherwise called a crown) round the discharge periphery of a powerful axial fan, also known as a turbine, and absorbing 15 to 40 kW depending on the equipment. The booms have a total of 12 to 16 nozzle-carriers which can be used in their entirety or in part depending on the pursued aim and the height of the zone of plants to be reached.
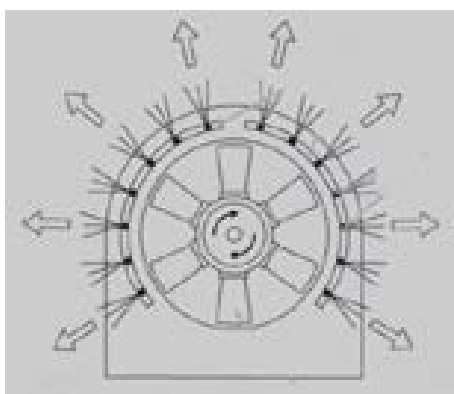
The fan is made of light alloy or, at times, in synthetic material and its diameter varies between 0.6 and 1 meter. It is housed inside a circular shape in the form of a hose which transforms the axial trajectory of the aspirated air from the rear into one or two adjustable lateral angular flows, which can cover a total angle of 240 °. Drive is provided by the power take-off of the tractor via an angled gearbox transmission, comprising a neutral point and, in some cases, a centrifugal clutch. The output of air from the fan can be adjusted by acting on its speed (from 1,500 to 2,500 rev/min, using a gear box), by varying the number of blades or by modifying the pitch of the blades.
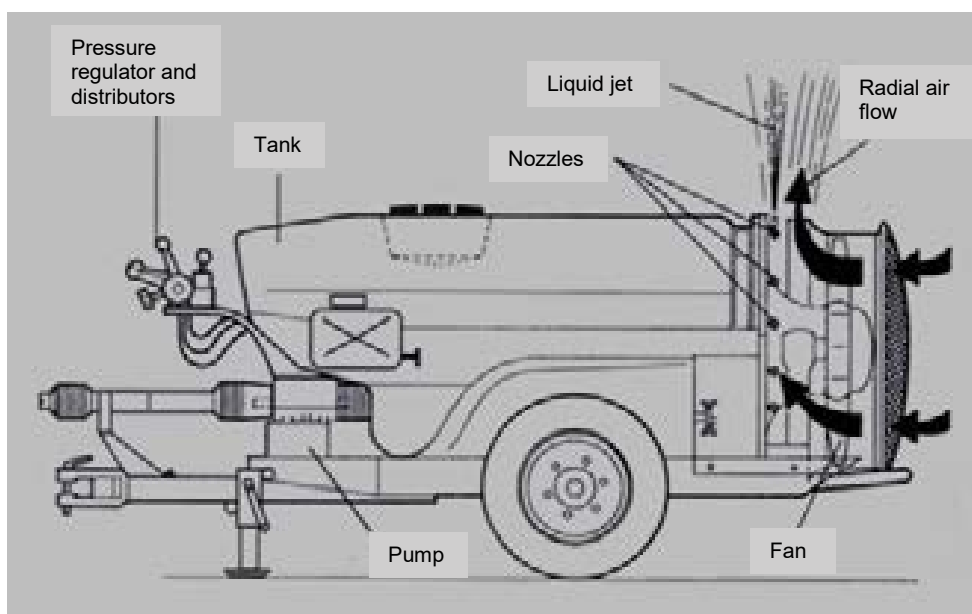
The mixture is first fragmented into droplets by the pressure of liquid in the nozzles. As soon as they come out of the nozzles, the drops are controlled and driven by the air current from the fan, which conveys them to the foliage to be treated.
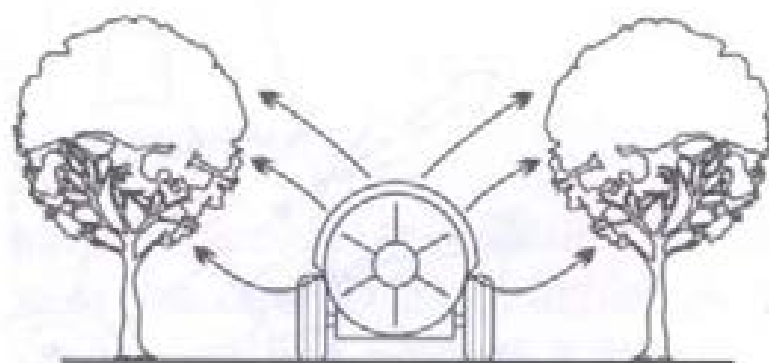
Depending on the materials, the output of air varies between 3 and 25 m³/s and its peripheral speed on exiting the fan may vary between 30 and 60 m/s (between 100 and 250 km/h) depending on the output and adjustment of the exiting section. This method of functioning is common to all mounted traditional sprayers with jets placed at the exit of the turbine.

9.5. Adjustment and calibration of apparatus

9.5.1. Calibration of the constant pressure back-pack sprayer

*Constant-pressure
back-pack sprayer.*

Most small growers use **apparatus under pressure maintained by manual pumping, carried on the back** to treat their crops. The way in which this functions and is adjusted is very simple and will be described in the next chapter.

Pesticide products sprayed using this apparatus are spread over the plants in the form of a spray in order to ensure as uniform a cover of the leaves as possible. The mixture must dampen the leaves of the plant entirely (upper and lower faces) and cover them sufficiently to be effective, but it must not run off the leaves. This is only possible with **fine drops**.

The 'calibration' of back-pack equipment **makes it possible to certify** that, under normal conditions of use, the apparatus will be able to apply the desired volume of mixture on a given area unit. This operation must be carried out regularly (**at least once/season**) for each piece of equipment and **be registered** (with the number of the apparatus). It guarantees that the apparatus is in good working order (e.g.: maintenance of the output at maximum pressure) and compliance with the 'rules' of application (e.g.: number of L/ha to be sprayed at time *t*).

Several elements must be taken into consideration when calibrating:

1) **Pressure (in bars)**

   A regular pumping rhythm must be maintained in order to keep up the pressure[1] and thus ensure the formation of fine drops that will cover the leaves of the plants. When the pressure drops, the diameter of the drops increases and the cover of the surface of the leaves will continue to fall. The finer the drops (high pressure, turbulence nozzle generating more fine drops), the higher the risk of contamination outside the plot.

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[1] In reality, the pressure obtained by pumping with the lever is not really constant. It increases to a maximum and reduces when the apparatus is spraying, following the rhythm of pumping. With this type of apparatus, the term "average pressure" must be used. However, this solution is preferable with a piece of "pre-pressurised" apparatus whose pressure drops progressively while work is carried out.

No adjustment is necessary as the maximum pressure depends on the construction of the apparatus; on the other hand, as the parts become worn, it may decrease. A manometer can be used to measure the pressure and check it regularly.

2) Output (l/min)

When the apparatus is properly adjusted, the pressure is able to produce fairly fine drops which will evenly cover the surface to be treated.

At maximum pressure, **fan nozzles** deliver **a clearly defined output**.

No adjustment is necessary. The output will be measured at the nozzle using a graduated container. **In order to change the output (and therefore the volume/ha), the nozzle is changed**. There are sets of fan nozzles in different colors according to the output. So we can see that changing the nozzle can change the output from the apparatus. When the nozzle is replaced, it is therefore important to re-calibrate the apparatus by measuring the output. On the other hand, the adjustable turbulence nozzles must be **used with care** as they may easily lose their adjustment, which changes the output of the apparatus.

3) The working width

The height of the nozzle in comparison with the target determines the working width. The height of the nozzle allows the jet to spread out and for the whole surface area to be well covered. Carrying out the treatment at a shallow height causes the depositing of an excess of mixture which risks flowing away from the leaves to the ground where it is lost. **The normal height of the nozzle must be maintained**.

In order to measure the working width, spray very dry ground with water from the planned working height. Measure the width of the trace on the ground.

4)   The speed of progress (in m/sec)

This is the most delicate parameter to 'calibrate'… and is therefore decisive for the result. In fact, each operator has his own style of walking and thus he must adjust his steps according to the volume of plant growth he has to treat (excessive wetting is unfortunately quite frequent!). Timing an operator who sprays bare earth or a crop is not the same. The speed of 1 m/sec (3.6 km/h) is often quoted as a "standard". However it must be noted that the actual speed is much lower… and so, if all the other parameters remain constant, the volume of mixture spread/ha is much more than the recommended value.

The only way of carrying out calibration consists of the operator being timed and being sure to respect a regular rhythm of progress, by the operator adjusting his steps in time to his pumping movements.

Once the speed of progress is known, the volume spread can be calculated/ha.

5)   The volume of mixture spread (L/ha):

As a general rule, the recommended volume/ha on the label is that for one ha on the bare earth. However, the foliage on plants develops considerably between sowing and harvesting: **the surface to be treated therefore varies according to the stage of the crop**. Too much mixture generates effluents which must be eliminated (residual spray left in the tank). Too little mixture may be harmful to efficacy: the producer wishes to cover his foliage and generally adapts his speed of progress over the surface occupied by plants and/or their height. For the same output, if he reduces his working speed, the volume applied increases automatically. If he wants to obtain complete and uniform cover of the leaves in the course of the season, the volume of mixture **must therefore be adjusted** permanently by trial and error (e.g.: 150 L/ha at the start of growth to 800 L/ha at the end of the season).

It is not advisable to adopt an increase in volume in advance depending on the stage (some technical documentation makes such recommendations).

It is preferable to **carry out a test in the field** to determine the volume of mixture spread per hectare **under the conditions at the point of application and for a**

given operator. This will give a more realistic idea of the volume of mixture used during treatment. This volume/ha will be mentioned in the register (traceability).

To measure the volume actually spread:

- Measure a given surface area (e.g.: 500 m² - or by using a number of lines; each line has a given width): using stakes at all 4 corners and string, make a plot to be treated and measure its surface.
- Pour a specific volume of water into the empty tank (using a graduated container).
- Measure part of the surface (100 to 500 m²) and spray it.
- Spray the whole surface marked out following normal practice.
- Empty and measure the water remaining in the tank, and calculate the volume spread using the figure for the difference.
- Calculate the volume spread/500 m² and make up to a hectare (for 500 m², volume spread x 20).

Use the abacus according to the volume of the tank as shown in Annex A2.

Example of calculating the measurement of the volume/hectare:

After spraying 500 m² with a sprayer with a tank of 15 l, a volume of 7 liters was added. The quantity of mixture applied is therefore 8 l.

The volume/hectare applied is calculated as follows:

$$\text{Volume (L/ha)} = \frac{8}{500} \times 10000 = 8 \times 20 = 160\,\text{L/ha}$$

This value can be taken directly from the abacus in Annex A2: 15 L tank, 7 l added, 500 m² = 160 l/ha.

Once the actual volume/ha and the total surface area to be treated are known, it is then possible to calculate the total volume of the mixture and the product needed, as well as the number of tanks to be prepared to treat the plot.

9.5.2. Adjustment of the sprayer with a nozzle boom

1) *Measuring the speed of work*
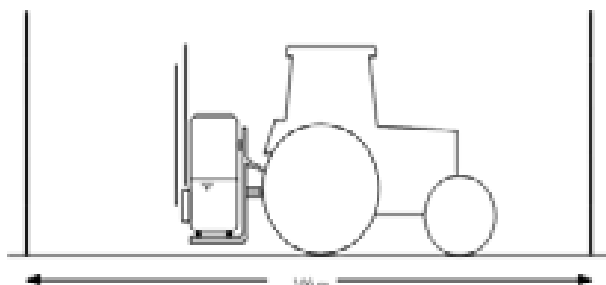
The **speed of progress** and the **spacing of nozzles** allow the **output needed** to **obtain the volume/hectare selected** to be determined.
It is therefore essential to be aware of the speed of actual progress of the equipment under working conditions. This is determined by calculation, after having measured the time needed to cover a **distance between 2 stakes, of a minimum of 100 m**, preferably in a field, with a tank half-filled.

Calculating speed of progress (in km/h):

$$\text{Speed of progress (v in km/h)} = \frac{e}{t} \ \times \ 3.6$$

where:

v	:	speed of progress (km/h)
e	:	distance between the two stakes (m)
t	:	time needed to cover the distance marked out with stakes (s)
3.6:		unit adjustment factor.

2) *Determining the necessary output of the nozzle*

The output of a nozzle, i.e. the volume of liquid which flows per unit of time, **depends on the pressure** of use, the **diameter of the nozzle** (section of nozzle opening) and the density of the liquid sprayed.

As the pressure of use as well as the nature of the mixture are imposed by the type of treatment, the choice of diameter depends on the volume to be sprayed and the speed of progress of the tractor.

The following formula supplies the output value of a nozzle according to these two parameters:

$$\text{Output of a nozzle (o in L/min)} = \frac{Q \ x \ s \ x \ E}{600}$$

where:

o:		output of a nozzle (L/min)
Q		volume per unit area (l/ha)
s		speed of progress (km/h)
E:		distance between nozzles (m)
600	:	unit adjustment factor

In addition, the same formula can be used to formulate, for a given type of nozzle, the **quantity to be applied per hectare (Q)** or the **required speed of progress (s)**.

The distance between nozzles on the boom is generally 0.50 m.[2]

3) *Determining the working pressure*

This will be determined using the output tables supplied by vendors and constructors (if they are available).

If the density of the sprayed liquid is **different to 1** (density of traditional mixture), the pressure of use indicated in the tables must be multiplied by density of liquid used. This correction is necessary in order to retain the desired volume/hectare. For example, in order to apply a **fertilizing solution** of density 1.28 to a volume/hectare of 125 L and a speed of 8.5 km/h, the pressure indicated in the output table must be multiplied by the density of the nitrogen solution. For the nozzle with a red diameter, the working pressure becomes: 1.6 x 1.28 = 2 bars.

Another method consists of using a **conversion factor** by means of which it is necessary to multiply either the output, or the volume/hectare or the speed before referring to the output tables, based at all times on liquids whose density is equal to 1 (water).

Density of the mixture	Conversion factor
0.84	0.92
0.96	0.98
1.00	1.00
1.08	1.04
1.20	1.10
1.28	1.13
1.32	1.15
1.44	1.20
1.68	1.30

4) *Using a 'slide rule'*

'Abacuses' or 'slide rules' are available.

They consist of several scales some of which can move in comparison with others which remain fixed. These scales show various values of volume/hectare, of speed of progress, of nozzle output, of working pressure as well as the different diameters available. By positioning the desired volume/hectare in

---

[2] When the space between nozzles is different to 0.50 m (formerly it was 0.33 m), the output must be corrected in the following way: multiply the initial output by 2 and divide by the number of nozzles per metre. The pressure associated with this new output can be obtained by looking for this new value in the tables or from the slide rule. It should be recorded that the corresponding values of speed and volume/hectare no longer apply.

accordance with the presumed speed, the output value can be read as well as that of pressure according to the diameter of nozzle chosen.

As for all output tables, we select the most favorable working conditions according to constraints (nature of treatment and climatic conditions) and according to the type of nozzle on the sprayer.

9.5.3. Adjustment of the motorized sprayer mist blower

As far as adjusting this equipment is concerned, two cases need to be pointed out:
- the treatment of **low-growing crops** and crops with bushy growth;
- treatment of trees, shrubs or other plants with a high carriage.

❑ **Adjustment for low-growing crops**

These are usually uniform plants planted in rows spaced out no more than 1 m apart whose height of development does not exceed 1 m to 1.20 m.

In these conditions, the operator keeps the spray hose almost horizontal and uses a minimum of movements.

Equipment suitable for carrying out this type of treatment is simpler in design as the presence of a pump is not required to bring the mixture from the tank to the hose. As the difference in height between the tank and the diffuser is small and relatively stable, the slight excess pressure created by the arrival of air is sufficient to stabilize the output.

1) ***Choice of volume of mixture Q to be sprayed per hectare*** *(in l/ha)*

This choice is solely down to the man in the field. He will only choose well if he has received the correct instruction. The following must be taken into consideration:
- the type of treatment and product;
- the nature of the parasite;
- the plant and its level of development;
- the climatic conditions at the time which have an effect on product distribution.

Calculation of volume of mixture applied (*Q* in L/ha):

$$Q\ (L/ha) = \frac{D\ (ml/min)}{W\ (m)\ x\ s\ (m/sec)\ x\ 6}$$

where:

D: *Output from the equipment (ml/min.)*

L: Working width (m)
s   Speed of progress (m/sec)
6 :   Unit adjustment factor

On the basis of this general formula, we can calculate Q, D, L, or v as required.

2) ***Adjustment of output D from equipment*** *(in ml/min)*

The output sought O is provided by the formula: O (ml/min) = Q x W x s x 6

For a given motor system (fan), the effects of taking in air from the fan and the convergent-divergent system of this hose maintain a constant pressure in the delivery pipe.

In order to modify the output **O** of the equipment, the **calibrated opening** located upstream of the diffuser must be **changed**. The change takes place through a tap with multiple openings or more accurately (for low outputs) by means of a set of plugs or interchangeable calibrated nozzles. The manufacturer supplies the nominal output value of the various diameters generally established for the maximum engine speed (fan) and for a standard liquid (usually water). Usually, a series of diameters is offered whose theoretical output is between 120 and 1600 ml/min for plugs or calibrated nozzles and between 500 and 2000 ml/min for taps with multiple openings.

Monitoring the output from a pneumatic sprayer

Output must be monitored when the motor-fan unit is functioning at working speed (generally the maximum speed). Under these conditions, the violence of the air current means that the sprayed liquid cannot be collected directly in a container to measure it as is the case for the pressurized back-pack sprayer and the centrifugal manual sprayer.

An indirect measurement must be taken:
- Pour into the tank a known quantity (3 to 4 liters) of water to which a thickening product and a surfactant may have been added to ensure it has the characteristics of a mixture.
- Place the equipment upright on the ground, with the hose facing forwards and slightly raised (+ 10 cm) compared with the frame base.
- Start up the engine and bring up to maximum speed.
- Open the diffuser supply tap for a period of 2 to 6 minutes depending on the size of the output (2 minutes for outputs close to 800 ml/min). Time is measured accurately using a chronometer or a watch with an analogue function.
- After turning off the tap, switch off the engine.
- Empty the remains of the liquid into a container through the tank's filling spout. Turn on the tap and empty the residual content of the hoses through the hose diffuser. Through the difference with the initial volume, we obtain the volume sprayed. When divided by the observation time, this value provides the output expressed using ml/min. The operation can be repeated to improve accuracy.
- Rigorous control of the output can only be carried out using the 'ready-

to-use' mixture as is the case for the pressurized back-pack sprayer and the manual centrifugal sprayer. This operation cannot be envisaged with a pneumatic sprayer: If diffused for several minutes when turned off a mist of fine toxic droplets constitutes a risk of acute one-off pollution of the environment and of poisoning for the people present. If necessary, the output may be controlled, during treatment, by measuring the volume of mixture used over a period of time with a chronometer (volume obtained by subtracting from the known initial volume of mixture placed in the tank the remaining volume measured into the equipment). By measuring the distance covered during the time measured with the chronometer, the actual mean speed of displacement can be obtained. Finally, by multiplying the distance covered by the working width W (interval between the axes of displacement), the surface treated in the course of the monitoring is obtained and the value of the corresponding volume Q (l/ha) is deducted from this.

3) *Working width* (in m)

With manual back-pack sprayers with directable hose, satisfactory results can only be obtained by adopting an overlapping spraying technique. Working width (interval between the axes of displacement) must be **calculated so that successive sprayings partly overlap**. The width *W* forms one of the parameters determining the volume applied to the ha and is obtained from a general formula.

It must be **as wide as possible** in order to increase the hourly output of the application and reduce the operator's overall effort. For crops sown in rows, the width *W* is a whole multiple of the value of the interline distance.

A prudent choice of its value depends on the operator's ability to correctly evaluate the situation. The theoretical horizontal range announced by the manufacturer **must be corrected by a series of factors**:

- the height and the density of the plant mass, a high speed of progress, a reduced angle of direction of the hose in comparison with the axis of displacement are **reducing factors**;
- the existence of a transversal wind whose speed is limited to 3 m/s (approximately 10 km/h) is a **favorable factor**.

N.B.! **The violence of the air current on exiting the hose may cause mechanical damage to the plant parts closest to it**. Extremely fine droplets come away with a great deal of difficulty from a very fast air flow at this point. The deposit which forms at this point is insufficient and usually blown immediately from the target.

So a distance of 1 to 2 meters must be maintained between the hose and the nearest plants targeted. The height of the hose and the angle of incidence of its direction with the axis of displacement must be adjusted accordingly.

4) *The speed of progress w* (in m/sec)

The speed of progress must be **as fast as possible** as it has a direct influence on the hourly output of the application. It is limited by the topography and the condition of the ground, the type of planting and the operator's ability to keep to a constant speed.

In most of the situations encountered in practice, it cannot exceed 1 m/s i.e. 3.6 km/h. The value of the speed of progress, calculated from that of the other spraying parameters, is given by the general formula.

The value of the speed *v* can be fixed in 2 ways:
- Each user calibrates his own usual walking speed as follows: on terrain sharing the same topography as the zone to be treated, he delimits a distance of either 50 or 100 m in a straight line. A timer is used to time (in seconds) how long it takes to cover the distance. (He starts walking around 100 meters before the first indicator to ensure that his walking pace is regular by the time he reaches this point). He repeats the operation several times in both directions in order to reduce the effect of the slope of the land. The average of the various measurements is taken and used in the formula which allows the speed to be calculated (or consult a reference table). In order to obtain the volume/ha *Q* chosen, each user must adapt the output *O* to his own speed *v*.
- *If the terrain allows this*, the speed of 3.6 km/h (i.e. 1 m/sec.) is made compulsory and users force themselves to learn the procedure described above, in order to comply. This method can be facilitated by learning to count paces (strides) to calculate the distance travelled. The user can, for example, get used to taking 2 paces/meter covered (= 2 paces/second)*.

❑ **Treatment of crops of trees**

If the operator is treating trees, bushes or other high-standing plants, more often than not he must keep the hose on the apparatus directed upwards. In this case, **a small auxiliary pump is necessary to stabilize the output** from the calibrated plug (nozzle) as the slight excess pressure in the tank is no longer sufficient. It is also advisable to select apparatus with a powerful engine (5 cv) and a 'long distance' type hose.

The choice of the volume/ha *Q* to be sprayed (in l/ha) **depends on a certain number of factors**: type of crop, number of trees per ha, degree of development, architecture of the crown, density of leaf mass, nature of treatment and the plant organs targeted. The skill and experience of the operator are essential in this choice.

For example, volumes from **50 to 400 L/ha** are found in plantations of coffee trees with aqueous mixtures. With oily formulations in ULV, the volumes applied are noticeably below the minimum quoted.

The volume *Q* (L/ha) is adjusted taking into account the specific characteristics of this type of application:
- the tree is considered to be the basic working unit;
- each tree is treated individually on all sides and at all stages of its spatial development, preferably going all the way round it and moving from one tree to another, row after row;

- if the crowns interpenetrate or are too close together, treatment is applied by working from one side of the row then the other while paying particular attention to the specific needs of each tree.

Various parameters are involved in determining the volume/ha to be applied:

- ***at average time needed for treating a tree***. It represents, in minutes (unit or decimal fraction), the time required to replace the volume of air occupied by the tree by air carrying droplets. Periodically, the operator can check the correction he has selected by examining the deposits on the foliage.
- **O Output from the equipment (ml/min.)** In relation to the engine's working speed (maximum speed), this is governed by interchangeable calibrated plugs. For example, a series of plugs (nozzles) may cover a number of outputs located between 120 and 1600 ml/min. Weak outputs generate the finest droplets whose ability to cover the targets is the highest. The quest for fineness comes up against its limits however when these are so fine as to cause drift and the rapid evaporation of drops.
- ***Nt number of trees per ha***. This can reach 1000 trees/ha.

The parameter relating to speed of progress ***S*** is not taken into consideration as in this type of application, it is variable and movements have a random trajectory.

Calculation of volume of mixture applied (*Q* in L/ha) :

$$Q\ (L/ha) = \frac{at\ \times\ D\ (ml/min)\ \times\ Nt}{1000}$$

where:

at: *average time to treat a tree (min unit or decimal fraction)*
D: *Output from the equipment (ml/min.)*
Nt: *Number of trees per ha*
1000: *Unit adjustment factor*

***N.B.*!**

A certain number of recommendations must be respected:

- Keep the hose at an adequate distance from the targets to avoid the formation of unsatisfactory deposits or their immediate elimination by too violent an air current.
- A transversal wind, even if it is of low intensity, is not necessarily favorable to the regular distribution of deposits. It is preferable to treat in calm weather conditions, characterizing the start and end of the day, and to avoid strong midday heat.
- When working, the operator often finds himself in the place where some of the sprayed mist that is not intercepted or held back by the plant mass falls back. This means there must be strict compliance with the safety rules and the recommended PPE (Personal Protection Equipment) must be worn!
- For the same reasons, after work, the apparatus must be carefully cleaned and reconditioned (mainly all the external surfaces).

Appendices

A.1. Calculation examples

❑ Quantity of product to be incorporated in the tank

The usable capacity of a sprayer tank is 15 liters; after verifying the adjustment, the volume applied is 100 liters/hectare. The approved dose of the product to be used is 2 liters/hectare. What quantity of product must be incorporated in the tank?

$$\text{Quantity of product (L ou kg)} = \frac{2\,(\text{L/ha})}{100\,(\text{L/ha})} \text{ x } 15\,(\text{L}) = 0{,}30\text{L}$$

The usable capacity of a sprayer tank is 12 liters; after verifying the adjustment, the volume applied is 120 liters/hectare. The approved dose of the product to be used is 1 kg/hectare. What quantity of product must be incorporated in the tank?

$$\text{Quantity of product (L ou kg)} = \frac{1\,(\text{kg/ha})}{120\,(\text{L/ha})} \text{ x } 12\,(\text{L}) = 0{,}10\text{ kg}$$

❑ Volume of mixture needed and quantity of product to be provided

The total surface area of my plot is 5000 m². The approved dose of the fungicide to be used is 1 kg/ha. After checking the adjustment, the volume sprayed is 200 liters/hectare. The sprayer available has a tank capacity of 15 liters. What quantity of product and mixture must be planned?

$$\text{Surface covered by 1 tank (m}^2) = \frac{10\,000}{200} \text{ x } 15 = 750\,\text{m}^2$$

$$\text{Volume of mixture needed (L)} = \frac{5\,000}{750} \text{ x } 15 = 100\,\text{L}$$

$$\text{Quantity of product needed (kg)} = \frac{1}{200} \text{ x } 100 = 0{,}50\,\text{kg}$$

The total surface area of my plot is 30,000 m². The approved dose of insecticide to be used is 0.5 l/ha. After checking the adjustment, the volume sprayed is 200 liters/hectare. The sprayer available has a tank capacity of 600 liters. What quantity of product and mixture must be planned?

$$\text{Surface covered by 1 tank (m}^2) = \frac{10\,000}{200} \text{ x } 600 = 30000\,\text{m}^2$$

$$\text{Quantity of product needed (L)} = \frac{0{,}5}{200} \text{ x } 600 = 1{,}5\,\text{L}$$

$$\text{Volume of mixture needed (L)} = \frac{30\,000}{30\,000} \text{ x } 600 = 600 \text{ L}$$

A.2. Calibration table to determine volume applied/ha

Calculation of volume of mixture applied per hectare using a practical method (volume in l/ha)						
15 l tank	**Surface treated**					
Volume remaining	**50 m²**	**100 m²**	**200 m²**	**300 m²**	**400 m²**	**500m²**
1.0	2,800	1,400	700	467	350	280
1.5	2,700	1,350	675	450	338	270
2.0	2,600	1,300	650	433	325	260
2.5	2,500	1,250	625	417	313	250
3.0	2,400	1,200	600	400	300	240
3.5	2,300	1,150	575	383	288	230
4.0	2,200	1,100	550	367	275	220
4.5	2,100	1,050	525	350	263	210
5.0	2,000	1,000	500	333	250	200
5.5	1,900	950	475	317	238	190
6.0	1,800	900	450	300	225	180
6.5	1,700	850	425	283	213	170
7.0	1,600	800	400	267	200	160
7.5	1,500	750	375	250	188	150
8.0	1,400	700	350	233	175	140
8.5	1,300	650	325	217	163	130
9.0	1,200	600	300	200	150	120
9.5	1,100	550	275	183	138	110
10.0	1,000	500	250	167	125	100
10.5	900	450	225	150	113	90
11.0	800	400	200	133	100	80
11.5	700	350	175	117	88	70
12.0	600	300	150	100	75	60
12.5	500	250	125	83	63	50
13.0	400	200	100	67	50	40
13.5	300	150	75	50	38	30
14.0	200	100	50	33	25	20
14.5	100	50	25	17	13	10

Calculation of volume of mixture applied per hectare using a practical method (volume in l/ha)

18 l tank	Surface treated					
Volume remaining	**50 m²**	**100 m²**	**200 m²**	**300 m²**	**400 m²**	**500m²**
1.0	3,400	1,700	850	567	425	340
1.5	3,300	1,650	825	550	413	330
2.0	3,200	1,600	800	533	400	320
2.5	3,100	1,550	775	517	388	310
3.0	3,000	1,500	750	500	375	300
3.5	2,900	1,450	725	483	363	290
4.0	2,800	1,400	700	467	350	280
4.5	2,700	1,350	675	450	338	270
5.0	2,600	1,300	650	433	325	260
5.5	2,500	1,250	625	417	313	250
6.0	2,400	1,200	600	400	300	240
6.5	2,300	1,150	575	383	288	230
7.0	2,200	1,100	550	367	275	220
7.5	2,100	1,050	525	350	263	210
8.0	2,000	1,000	500	333	250	200
8.5	1,900	950	475	317	238	190
9.0	1,800	900	450	300	225	180
9.5	1,700	850	425	283	213	170
10.0	1,600	800	400	267	200	160
10.5	1,500	750	375	250	188	150
11.0	1,400	700	350	233	175	140
11.5	1,300	650	325	217	163	130
12.0	1,200	600	300	200	150	120
12.5	1,100	550	275	183	138	110
13.0	1,000	500	250	167	125	100
13.5	900	450	225	150	113	90
14.0	800	400	200	133	100	80
14.5	700	350	175	117	88	70
15.0	600	300	150	100	75	60
15.5	500	250	125	83	63	50
16.0	400	200	100	67	50	40
16.5	300	150	75	50	38	30
17.0	200	100	50	33	25	20
17.5	100	50	25	17	13	10

A.3. Slide rule for determining volume applied/ha (example of system proposed by SYGENTA)

Using this device, and being aware of the recommended dose/ha, the volume of the tank and the volume of mixture/ha, we can determine with acceptable accuracy the quantity of product (in g or in ml) to be measured out/tank.
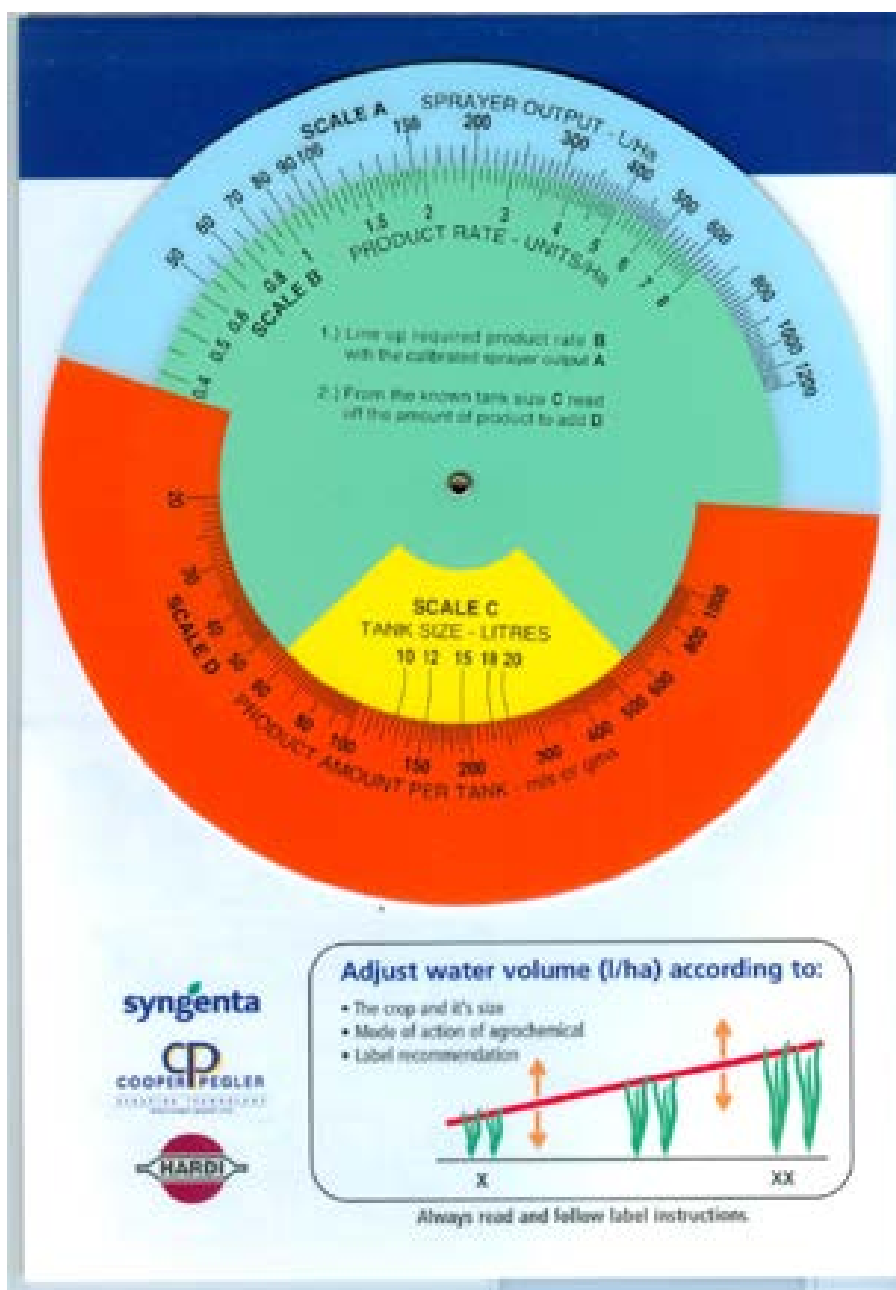
Chapter 10

The management and disposal of effluents and waste

10.1. Purifying spray wash effluents using biopurifiers (biofilters, Phytobac® and Biobed®)

'**Effluents**' is the name given to the dregs in tanks, unusable pesticide mixtures, cleaning water from spraying equipment (which must be rinsed inside and out), which have been in contact with plant protection products.

Poor management of the dregs of tanks and washing water often undertaken in unsuitable places is one of the major sources of pollution. Managing this effluent is of paramount importance for limiting pollution by pesticides, and acquiring benchmarks under tropical conditions has now become essential.

Today, generators of effluents from plant protection products (usually growers) have several effective devices for safely disposing of these effluents, in the field (by spreading over the plot under strict conditions) or on the farm (using a treatment whose purification efficacy has been measured and recognized as being sufficiently effective). These methods can legally replace treatment in an approved center, greatly reducing the cost for the grower.

So the grower should ideally have on his farm:

- An area for measuring, mixing and filling;
- An area for washing the equipment used to carry out the pesticide treatments, with recovery of dirty water;
- A system for collecting and treating effluents;
- An area for storing used PPE[1] and empty and rinsed packaging;
- Premises for storing NUPP,[2] separated from the stock of usable products.

10.1.1. Setting aside a filling zone

A **high risk of pollution** in the environment exists at the time of filling the sprayer, through accidents such as contamination of the source of water being used, tank spillage, leakage of plant protection products, and so on. The recommendation is to set aside a sprayer filling station to manage this risk. No standard has been drawn up to date governing the setting aside of such an area. Consequently, we have come up with a series of recommendations to allow you to meet this target.

For back-pack equipment, the current recommendation is to carry out operations for filling the tank in a **grassy area** as this can neutralize 'minor losses'.

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[1] PPE: Personal protection Equipment (e.g.: gloves, mask, goggles etc.).

[2] NUPP: Non-usable pesticide product (out of date or obsolete).

With regard to the large sprayers, a **waterproof area** (concrete) must be adapted. The area used for filling must be located away from dwellings and natural water take-off points. It must also be located outside perimeters protecting catchment areas (contact the town hall) but preferably near the premises where the plant health products are kept. It must be constructed in sealed concrete with slopes for recovering water, taking it subsequently to a storage tank. It cannot be connected to the drainage system or to a drainage well, or any means whereby pesticide products enter directly into the water system.

In order to avoid pollution of water resources, you are strongly advised not to empty the contents directly from a sprayer or plunge the equipment into a lake, a canal, a well or a river.

The figure shown below illustrates the recommendations for an ideal filling area, to be recommended for large facilities.

(1) Drum drainer
(2) Raised edge to confine liquids
(3) Storage of empty packaging
(4) High pressure cleaner
(5) Sprayer
(6) Intermediate water tank
(7) Premises for storage of plant protection products

Various arrangements are possible to **avoid flowback of mixture** into the supply network of fresh water: a bracket whose end must not come into contact with the mixture (see photos), an intermediate tank filling with a 'chain' system, or even a simple anti-return valve on the water supply circuit.
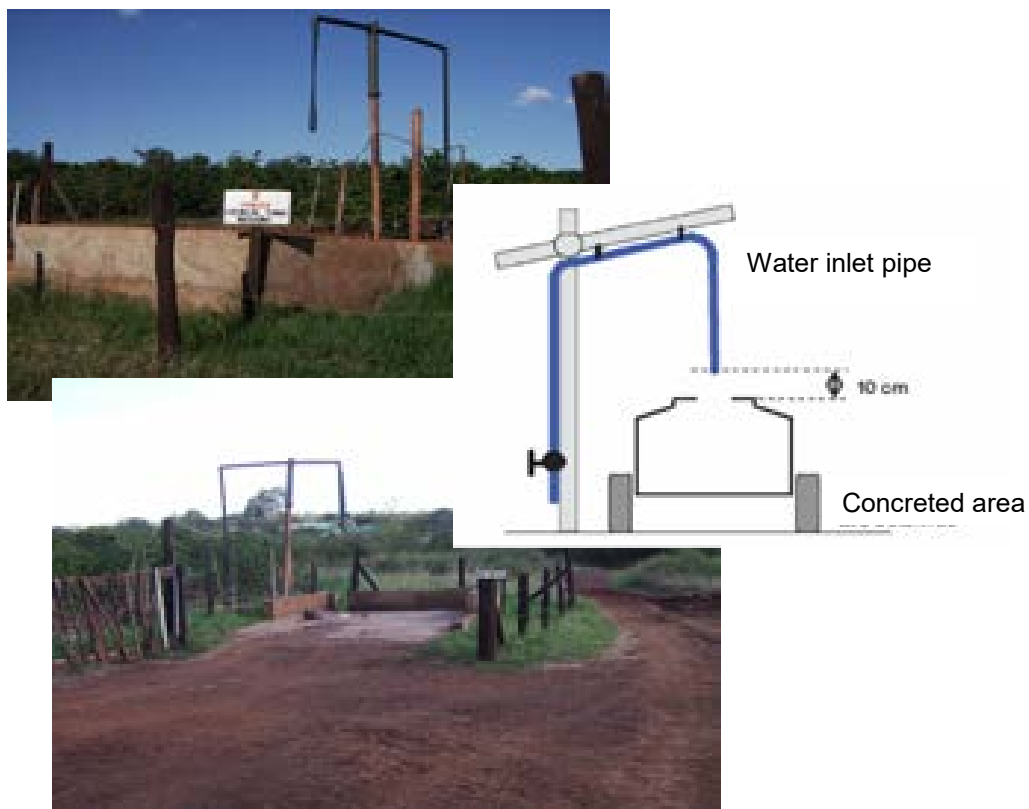
Area for filling and washing spraying equipment in Kenya
(Photos B. Schiffers)

The **safest** solution consists of using a raised intermediate water tank (which can be placed on a platform which is accessible and lockable):

- either solely to fill with water and then fill the sprayer tank
- or to prepare the mixture there if the farmer does not have a product incorporator. At this point, the mixture is transferred into the spraying tank then diluted with fresh water, which is used at the same time to rinse the intermediate tank.
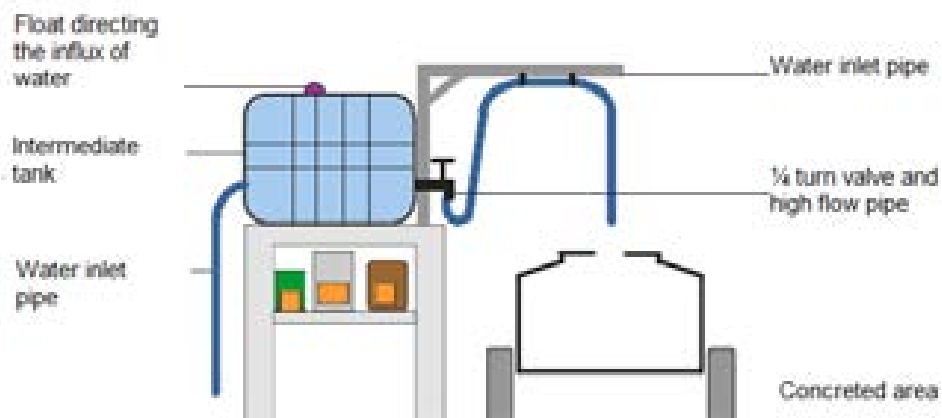
To avoid any **overflow** from the tank as it is filling, several precautions must be taken:

- always be present and watchful during filling;
- have a clearly visible gauge to check the water level;
- avoid any foam appearing in the tank (mixture too concentrated, mixture of products, addition of a wetting agent, etc., as this reinforces the mixture's ability to foam).

Overspill of the tank and leaks during filling (Photos Phytophar).

Please note that handling dangerous products requires full concentration on the operations being carried out. Operators are advised not to take any hurried action, not to be distracted, to have the right equipment to measure the required dose and to ensure adequate protection.

An **overflow** may come from an uncapped half-filled drum placed on the ground; to reduce this risk, using a working area close to the sprayer filling location is a good solution. **Leaks** are generally the consequence of equipment wear and tear. To avoid them, the sprayer must be maintained in good condition. In particular the seal on the different joints must be regularly checked.

Pesticide containers must also be rinsed **in the filling area** at the time of preparing the mixture. This ensures that the operator is using the whole of the product, properly eliminate the rinse water and disposing of the empty container.

A well-designed and well-managed filling area allows the operator to both check the different sources of occasional pollution and to work safely. It must be designed in order to be able to collect all the water containing plant protection products from this phase of the work. A **containment tank** must be constructed for the effluents, which will be stored there before being eliminated.

10.1.2. Disposal of tank washings

The **dregs at the bottom of the tank**, the volume of mixture remaining in the sprayer after spraying and priming of the pump, can be spread over the plot which has just been treated, provided that it is diluted in **at least 5 times its volume of fresh water** contained in an attached tank. This must contain at least 10% of the nominal volume of the spraying tank in fresh water or 10 times the residual volume to be diluted.

This operation can be repeated in order to obtain an even greater dilution. However, the operator must ensure that the total dose applied at the end of subsequent passages does not exceed the maximum authorized dose for the usage in question.

This solution has the disadvantage of requiring the operator to spend some time on the procedure. However, it means there is no wastage of the plant protection product (which may be applied to those areas most affected by diseases, weeds or pests), and above all that contamination of the environment is avoided. The second advantage lies in the fact that an initial rinsing of the sprayer is carried out in the field, directly after spraying. The subsequent risk of the nozzles becoming blocked is then considerably reduced.

After rinsing the tank, it is also possible to re-use the dregs for the next treatment, provided it has been sufficiently diluted (at least 100 times).

Instead of spraying out, it is possible to **empty the dregs** in the field subject to the following:
  a) the concentration of active substances in the dregs is divided by at least 100 compared with that of the first pesticide mixture used;
  b) that at least one rinsing and one spraying out procedure is carried out on the plot.

The rinsing water must be emptied over 50 m away from water take-off points, gutters, catchment basins; over 100 m from fish farms and water catchment areas; once only per year over the same surface; on ground not saturated with water and with only a slight slope. The tank must never be emptied in a farmyard, into the drainage system or into a ditch.

10.1.3. Elimination of effluents by the grower

If rinsing was not carried out on the plot or if the dregs were not emptied or re-used, the remaining water can be treated by an **installation approved** for this purpose and used in accordance with the manufacturer's technical specifications or the recommendations of the body responsible for the installation.

Purifying processes and principles	Setting aside of filling areas/ washing areas
Coagulation - Flocculation with: ▪ Filtration by reverse osmosis ▪ Filtration over activated charcoal	Separation of rainwater / plant health effluents
Photocatalysis: Breakdown by oxidation	Screen clearer / Grit chamber / Oil separator
Biological breakdown station in an aerobic liquid environment	Storage tank
Biological bed: biological breakdown in solid environment	Separation of rainwater / plant health effluents directed towards the 'biological bed' (if necessary buffer tank for regularizing inputs)

In France, in 2008, there were 12 approved processes for treating this effluent at the farm (MEDAD – *Ministry of Ecology, Development and sustainable Management* – site, 2008) (see attached description of some processes).

The most economical processes and the easiest to install which have currently been developed are based on **the purifying power of the soil and the bacteria** it contains (the terms 'biological bed' or 'biofiltration' are used). The analyses carried out show that biological beds have an excellent purifying capacity. Only a breakdown product of glyphosate (AMPA) sometimes remains in the form of traces in the substrate. The tests on the innocuousness of the substrate are conclusive since no toxicity is reported, either on earthworms, or on higher plants. The substrate can therefore be spread over soil around crops, but it is also important to wait for a minimum of 6 months after the last supply of effluent before spreading it over the plot.

A few restrictions on use are still essential, particularly with regard to **non-biodegradable heavy metals** (copper and sulphur) which may be found in mixtures and certain herbicides (MCCP (*mecoprop*) isoproturon, chloridazon etc.) which can still be detected at the biofilters' exit.

> ### *N.B.*!
>
> Biofiltration will only be effective if dregs have been diluted and applied to the plot. If this is not the case, the quantity of active substance found in the tank will be excessive and will rapidly saturate the biofilter, rendering it uselesstile.

Three systems are presented below, listed according to their efficacy and popularity: the Biobed®, the Phytobac® and the biofilters.

❑ **The Biobed® system**

The Biobed is a Swedish system invented in 1993. Biobeds are systems for breaking down active substances using the bacteria present in a substrate consisting of soil (25%), peat (25%) and straw (50%). The substrate is placed in a sealed vat to encourage the breakdown of active substances by aerobic bacteria. The content of vats can be emptied by spreading on fields.

After 10 years' practice, biobeds are considered effective but numerous parameters still have to be studied, such as full monitoring of the molecules and associated residues, the objective criteria for changing the substrate or the characterization of biological strains effective for breaking down pesticide molecules. The CIRAD (International Centre for Agricultural Research for Development) has been able to validate the process in Guadeloupe with local materials (by replacing the straw with sugar cane bagasse) (the mixture is known as the biomix: 25% soil, 25% compost and 50% bagasse).

Biobed vat (Photo F. Le Bellec, CIRAD)

❑ **The Phytobac® system**

Inspired by the biobeds already used for several years in Sweden, Phytobac® biological beds (developed by Bayer Crop Science) allow retention of pesticide effluents and the microbiological breakdown of active substances and their metabolites. The effluents that can be introduced into these devices are diluted dregs and water used for cleaning spraying equipment.
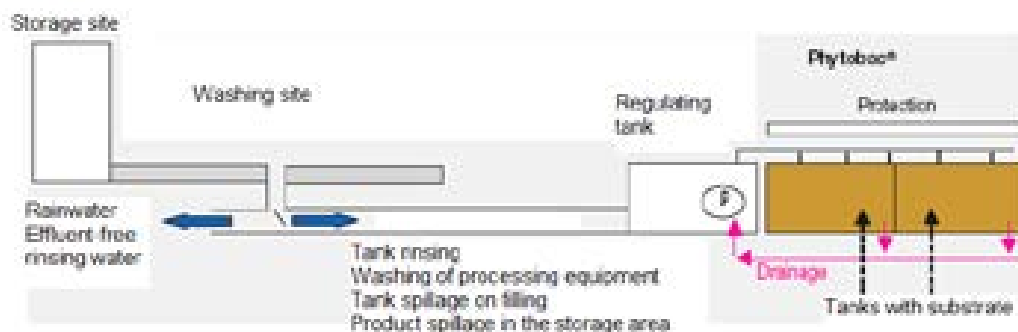
Effluents can be added directly above this device, or from the area used for washing the spraying equipment through specific pipes. In this case, it is advisable to provide a

system for collecting effluents in the area used for filling and washing spraying equipment. This area must be easy to access and a long way from permanent or temporary water draw-off points.

At the exit, a series of pre-treatment units (oil separator, grit chamber, screen cleaner) can be put in place to retain hydrocarbons, plant detritus and fractions of earth requiring management since they qualify as dangerous waste. However, the plant detritus and the fractions of soil which have been collected can be dispersed over the substrate of the Phytobac. It must be positioned well away from permanent or temporary water draw-off points. Access to children and animals must be secured or rendered impossible.

The Phytobac® system

This device must consist of a **sealed tank** whose walls can be a waterproof membrane or a concrete, metal or plastic wall. If this tank is buried in the ground, its upper part must be

above ground level in order to avoid the entry of rain water from runoffs. To avoid any splashing from the container or phenomenon of asphyxia during heavy rain, **the tank must not be open to rain water** and must have an easily-opened cover, placed a minimum of 30 centimeters above the tank to allow ventilation.

This tank contains, up to a height of approximately sixty centimeters, a substrate consisting of soil (humus from plots representative of the farm in order to facilitate the proliferation of adapted microbial strains) and straw. Straw is able, at least initially, to give the medium a degree of porosity and supplies a source of energy for microorganisms in the substrate. The substrate must be made by mixing a volume of 70% earth and 30% ground straw.

Determining the ideal size of the Phytobac depends, among other things, on the distribution of effluents during the year and weather conditions. The choice of the form of the Phytobac is important, as it must incorporate the tool which will be used for agitation. The Phytobac requires minimum maintenance: agitate once a year when adding earth and straw.

Very simple for the grower to install and use, the Phytobac allows complete management of farm effluents. In the case of small volumes of effluent, systems in sealed plastic vats can be installed.

Phytobac® "Petit Volume"

Phytobac® 'Petit volume'

With a maximum capacity of 2 m³, it allows a volume of effluents of between 600 and 800 liters per year to be treated.

❑ **Biofilters**

A variant of the Biobed (offered by the Agrochemical and Veterinary Research Centre or CERVA, from Tervuren, Belgium), the Biofilter can also deal with large quantities of effluents containing spraying products. It can also be used for residues from other forms of treatment: aqueous baths, seed treatment, hydroponic culture etc.
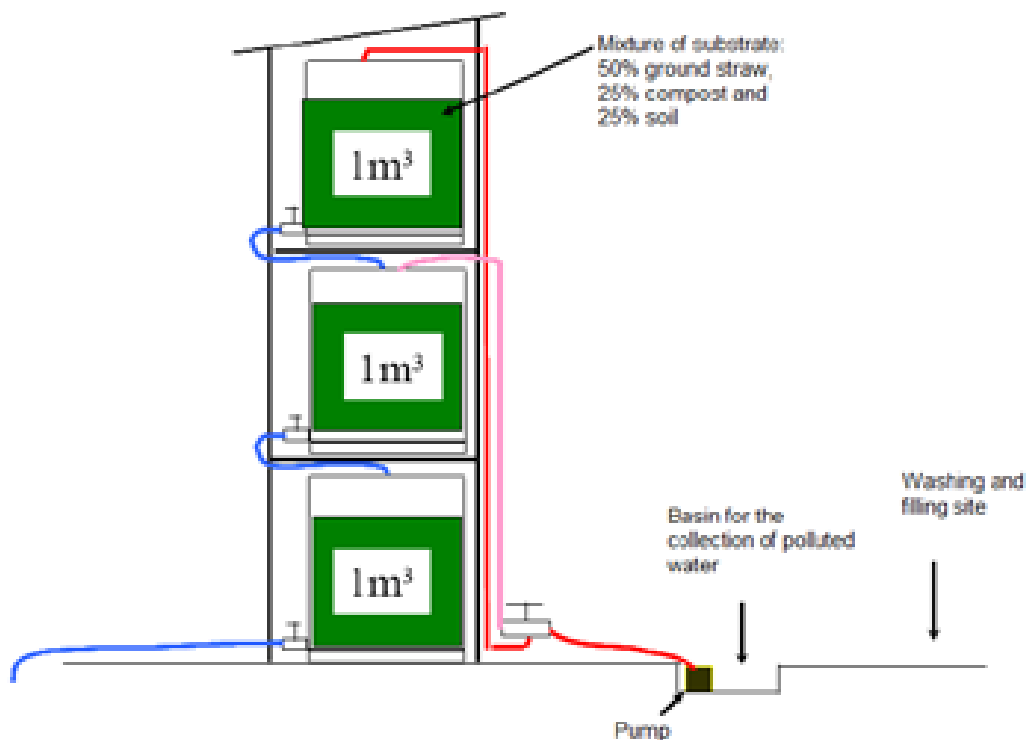
Diagram of the system for purifying effluents using Biofilter

As with the Biobed, a mixture of straw (50%), peat (25%) and soil (25%) takes care of the (biological) breakdown of products. However, the biological bed is placed in vats with, at their bottom, a drainage system that allows the effluent to be recovered after filtration. The system takes up little room, as the 3 tanks are stacked high, and it consumes very little energy as the water circulates by gravity. The loaded effluent is pumped into the upper vat. It stays there for a few hours, then the gate is opened and the effluent can move into the vat immediately beneath.

The operation is repeated up to the third and last vat (see diagram and photo). Finally, the purified water can be released into a drain or a drainage well as the purifying efficacy is sufficient.

Biofilter device (Photos B. Schiffers)

10.2. Cleaning the sprayer

After use, the inside and outside of the sprayer are dirty and may contaminate the operator. The sprayer must therefore be carefully cleaned by rinsing in fresh water. During cleaning, the pump and the pipes leading to nozzles (pipes, filters etc.) must also be rinsed.

In the case of **back-pack equipment**, the spraying equipment can be **rinsed in the field, in a grassy space**.

Start by **rinsing the tank**: the inside of the tank must in fact be rinsed **directly each time it is used** in order to prevent the residue present in the tank contaminating the next mixture, or deposits from forming and blocking the filters and the nozzles.

Fill the tank with fresh water to one third of its capacity, shake well and empty over a grassy area **away from the crop and water take-off points** (zone set aside for this purpose). Fill one third of the tank again with fresh water to rinse the spray arm and the nozzle.

Empty the tank on grassy ground, in a place well away from the crop and water take-off points (area set aside for this use). Avoid throwing away the surplus into a water course or into a water take-off point (or into a drain, a sink or a WC).

Rinsing sprays is one of the main causes of contamination of surface water!

Once the tank has been cleaned, rinse the apparatus by spraying fresh water for a few minutes over a grassy, uncultivated surface. Avoid rinsing the apparatus and/or emptying it by spraying the crop.

After carefully rinsing the apparatus and its spray arm, dismantle the nozzle to clean and rinse the filter. Put away the clean, empty sprayer in a dry place, and keep separate from the pesticides.
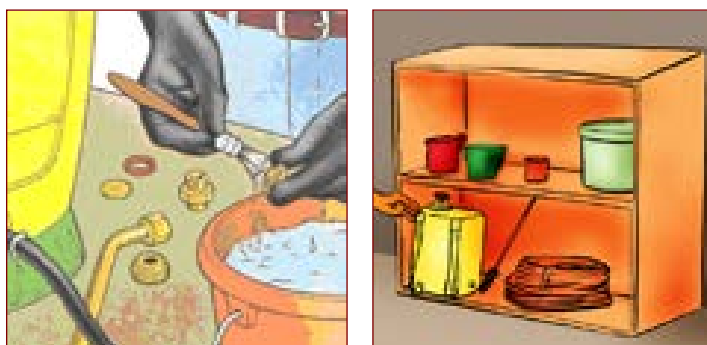
In **large apparatus**, the presence of revolving jets (mainly installed on sprayers equipped with rinsing tanks) allows efficient rinsing of tanks with a limited amount of water.

The sprayers **must be cleaned over a grassy area** or, preferably, over a filling area, fitted out for recovering and treating the water. By acting in this way, the operator will collect all the dirty water in the storage tank which will allow their later treatment by biofiltration.

10.3. Rinsing, collecting and disposing of containers

10.3.1. Rinsing and collecting

Correct cleaning of product containers, by adding rinsing water to the sprayer tank:
- guarantees savings in products,
- allows elimination of over 99.9% of the product,
- will allow it to be disposed of more safely.

You must always make sure that you have **emptied the container completely** when preparing the mixture:
- for liquids: leave the bottle to drip for at least 30 seconds in order to collect the last traces of the product.
- for powders and granules: make sure that the container has been completely emptied by shaking it. Be careful of the dust which may contaminate you!

As re-use is prohibited and recycling containers not advised, it is preferable to ensure they cannot be used again by piercing them prior to disposal. Empty plant protection product containers must not be mixed with household waste, even if they have been rinsed. It is preferable to organize collections in the yards of agricultural product distributors and on growers' premises, in order to avoid burning, burying or re-using drums that have contained plant protection products.

Growers will be required to rinse (**at least 3 times**) containers immediately after using the product and to store them on the farm ready for collection, in an area set aside for this purpose, preferable in closed, sealed, labelled bags ('Danger – Toxic waste').

How do you rinse containers properly?

Read the label very carefully and check the instructions.

Rinse the containers three times:
1. Fill the empty bottle to a quarter of its capacity with clean water.
2. Put the cap back and screw on carefully.
3. Depending on the size of the container, shake it using rotating motions (roll it on the ground) or shake it vigorously to rinse all the internal walls.
4. Remove the cap, pour the rinsing water into the sprayer tank.
5. Leave the last drops to run out for 30 seconds or more if necessary.
6. Repeat this operation two more times.
7. Put the cap back on and dispose of it.

(Copyrighted by Bayer CropSciences)

Rinsing containers (FAO Guidelines, May 2008).

The experience of '*Phytofar Recover'* in Belgium demonstrated that it was possible to recover and deal with over 90% of empty containers, by encouraging growers to work with distributors. In France, *ADIVALOR* collects drums which contain 25 l or less, barrels of 25 l to 300 l, boxes and bags of less than 25kg and 'big bags' of fertilizer and soil additives. Several other countries have set up facilities to recover packaging with a view to their destruction or recycling (Chile, Guatemala, Brazil, Germany, Hungary, USA etc.).

Logo of the Phytofar Recover operation (Belgium) "I rinse my phyto drums"

Collection and storage of Empty Plant Protection Packaging

- **If you have empty drums:** once rinsed and drained the completely empty drums which are also clean on the outside must be stored in a covered area, separate from the caps. When collection takes place, separate delivery of drums and caps will be requested.
- **If you have drums containing out-of-date or unused products:** they must be returned with caps on and in good condition when collection takes place. This involves products which are out of date, those prohibited following a change in legislation, or even products unused following a change of crop.

Area for collecting Empty Plant Protection Packaging on a small farm in Kenya (Photos B. Schiffers)

10.3.2. Disposal of containers

With regard to the destruction of containers and other waste contaminated by pesticides, the only method which can really be recommended is controlled incineration in an approved (accepted) center. It is generally prohibited and unadvisable to burn them on the farm.

Unfortunately, given their cost of installation and operation, few incinerators which have received approval for pesticides are available, especially in ACP countries.

If a perfect installation is not available, under certain conditions (e.g.: not for pesticides containing organic chlorine products, such as endosulfan, lindane, DDT etc., nor for compounds containing mercury), use cement furnaces as temperatures reach 1,400 to 2,000 °C for 6 to 10 seconds. However, you must be aware that these installations do not have any system for purifying fumes and can therefore generate pollution through the emission of toxic compounds (e.g.: dioxins). So they are not suitable for the destruction of large quantities of out-of-date pesticides!

More complete information about destruction procedures are provided in the "Guidelines on Management Options for Empty Pesticide Containers" (FAO, May 2008). The FAO makes this guide available on the Internet.

10.4. Disposal of waste plant protection product

10.4.1. Use of an approved incineration installation

Incineration is a process of high temperature thermal oxidation in the course of which the pesticide molecules are broken down into gas and non-combustible solids known as 'residues' (cinders and slag).
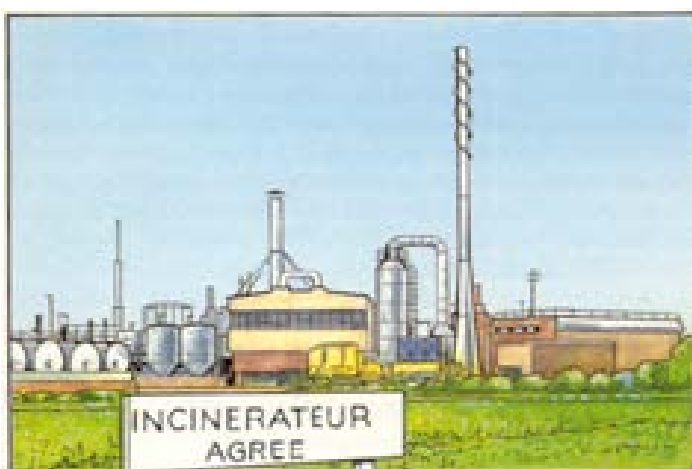
Approved incinerator

A high chimney leads the gaseous effluents into the air where they are dispersed by the wind. The chimney gases contain water vapor, carbon dioxide (CO_2), acid or toxic gases and toxic particles, including volatile cinders and metal oxides. In order to reduce pollution, the incinerator must therefore be equipped with a device for purifying gases and fumes (cooled to 200 °C) and/or electrostatic filters. The solid waste must be disposed of in an approved way.

With regard to the destruction of out-of-date pesticides, packaging and other waste contaminated by pesticides, the only method which can really be recommended is controlled **incineration in an approved (accepted) center**, as it is equipped with an installation allowing:
- storage of waste completely safely prior to destruction;
- incineration at a very high temperature in a furnace (minimum 1,100 °C for a few seconds to reduce most of the waste to non-toxic compounds);
- the treatment of fumes and gaseous effluents;
- treatment of cinders.

10.4.2. Elimination by burying

The only recommended method for elimination by burial of pesticides is recourse to an approved dump for toxic products.

Unfortunately, these dumps are not available everywhere.

If one is not available, and if burial is authorized, the instructions given by the FAO (1985) must be followed to avoid any environmental damage.

The hole intended to receive the toxic waste must be dug on high, flat terrain, at a distance of at least 30 to 60 meters from any reserve of fresh water such as a water course, lake, barrage or well. It must occupy a position where there is no risk of flooding or breakdown as a result of erosion. It must be located a good distance away from dwellings and other buildings, as well as crops and cattle. Positioning the hole in a ravine caused by erosion, a depression, a dried-out water course or a quarry, or near to or above the water line or underground water courses should be avoided. It must be deep enough to allow percolation through a layer, preferably clayey, of at least 2 to 3 meters above the bedrock.

The hole must be indicated by a sign notifying DANGER and surrounded by netting to prevent the access of children or domestic or wild animals.
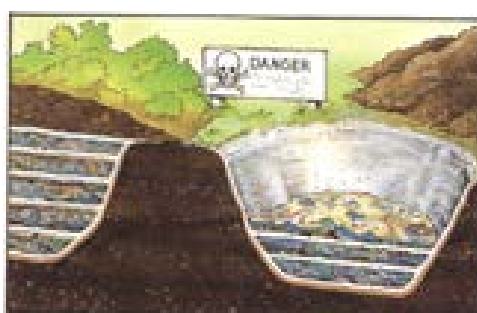
The bottom of the hole must be flat. Waste (rinsed and perforated packaging) must be arranged in layers alternating the deposit with layers of earth to encourage the action of breakdown by micro-organisms in the ground. Do not leave waste deposited in the ditch unless covered by earth.

10.4.3. Use of a small incinerator (on the farm)

At the farm, the elimination of empty packaging is always a problem which is difficult to solve:

- well-rinsed metal boxes can be pierced and buried, in an area far from any from any dwelling and water take-off point, at a depth of at least 80 cm;
- packaging made of paper, cardboard, well-rinsed bottles made of plastic (PE, PET, HDPE etc.) can be burned, but must not be burned in a simple 'hole' as the combustion of materials is incomplete, since the temperature does not exceed 300-500 °C, and toxic fumes will form!

In order to offer a practical solution, the B.A.A. (British Agrochemical Association, U.K.) has studied adapting a metal container using a very specific model described below. Prior to making any recommendation, the B.A.A. carried out advanced studies of interior temperatures obtained and into the nature of the fumes produced (the clearer the fumes, the better the combustion). Even if this solution is not entirely satisfactory, this cheap and simple device can reach 950-1000°C., an adequate temperature for denaturing most chemical products and for reducing the packaging to a few grams of toxic cinders. **This solution is also recommended by the GlobalG.A.P.[3] standard**.

Before using this type of device, always make sure that you are not contravening local legislation and examine the other possible options!

❑   **Adaptation of a 200 L metal container into a small incinerator**

It is **very important** to respect the dimensions, the number of holes and their position on the container. In fact, the B.A.A. tested as many as 9 different models before proposing the final device proved to produce the best results in terms of temperature.

Preparation of the container:

cover

440 mm

150 mm

The grid:

190 mm

The grid is placed inside at a height of 190 mm from the bottom.

8 holes of 60 mm in diameter, regularly spaced out, placed at a height of 440 mm from the base.

11 holes of 50 mm in diameter, regularly spaced out, placed at a height of 150 mm from the base.

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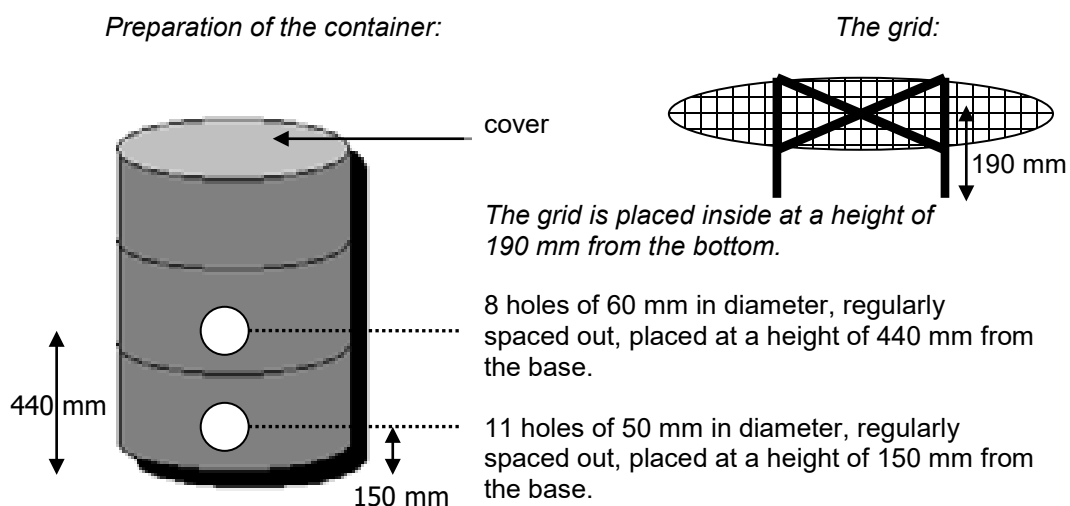
3   GlobalG.A.P., "Smallholder Guide, Plant Protection Module", Version 1.0 – February 2010.

The incinerator container, the base grid and cover (Photos A. Diouf)

❑ **Instructions for using the small incinerator**

1. Place the grid inside, and fill the container up to one third with empty packaging (bottles or sachets)
2. Sprinkle with diesel
3. Repeat the operation twice for the other two thirds. Use a maximum of 1 L of diesel to burn 35 to 40 drums or 5 kg of bags
4. Put the cover back!
5. Set alight using a torch through one of the holes located in the base of the container
6. Allow combustion to take place: This generally takes 25-30 minutes. A slightly grey smoke should come out through the openings during the process.
7. Allow the container to cool. After combustion, the cinders (a few grams) can be recovered and buried at a depth of 80 cm.

❑ **Recommendations for caution**

- Install the container in an open area, on a flat surface, away from inflammable products and materials
- Do not leave unsupervised during combustion
- Only carry out incineration if the weather is calm, without any violent wind.
- Remember, as you approach, that the container is burning even when the fire source is out.

10.5. Treatment and disposal of accidental spillage

10.5.1. Solid products

- Spread sand or damp sawdust on the product once it has been tipped out to reduce dust in suspension (especially in warehouses);
- Transfer the product to a sealed container or to a reinforced plastic bag while awaiting its elimination.

Use an absorbent material to fix the toxic product. Keep children and animals away from the location where the product is poured out. If necessary, scrape the surface layer of the ground and eliminate it with the waste.

10.5.2. Liquid products

- Absorb the product with sand or any other absorbent material;
- Sweep and pour out into a sealed container while awaiting its elimination.
- Once the product has been isolated, rinse the ground polluted by spreading carefully with water.
- Do not allow the water to escape, but also use absorbent materials.

Always **use protective clothing** to handle pesticides spread about following spillage activity.

Do not use water to wash spilled liquids, but absorbent substances.

Never eliminate waste pesticides into water courses, drains or any other system for collecting surface water.

10.5.3. Equipment to treat the substances which have been spread

A set of equipment must be kept for emergencies and positioned in a place which is easy to access and indicated by a clearly visible sign:

* container of absorbent substances (**sand or sawdust**);
* sweeping brush, spade and rubber scraper;
* large, resistant plastic bags;
* empty vertical containers opening fully.

10.5.4. Elimination of waste

Waste consists of:

* unused spray mixture;
* polluted absorbent material;
* empty packaging.

Depositing waste in an open container, while awaiting their elimination using an appropriate method, prevents any additional pollution and allows easy handling subsequently.

Waste can be eliminated, according to local legislation and the availability of installations:

* by incineration **in an approved center** (consult the technical specifications for the product or contact the supplier to find out if the product and its packaging can be incinerated without giving off dangerous compounds; **if not indicated precisely**, **do not burn pesticide waste** as there will be a significant risk of poisoning);
* through deep burial, supervised by a technically competent person and in a location well away from wells, water tables, catchment areas and any water course.

> **Pesticide waste must never be put on public tips or into household dumps!**

10.6. Management of non-usable plant protection products (NUPP)

10.6.1. Problems posed by NUPPs

The problem posed by stocks of obsolete or out-of-date pesticides is well known on all continents where they are often the source of serious pollution, and constitute a permanent danger to the health and to the environment, as well as a threat to development in general.

Non usable plant products (NUPP), out-of-date or obsolete products, are mostly residues from crop protection campaigns.

These pesticides, which are out-of-date, prohibited for health, regulatory or environmental reasons or not authorized for use, have accumulated in various countries in Eastern Europe, Africa, Asia, the Middle East and Latin America where there is no adequate installation for destroying this dangerous waste.

The state of stocks of pesticides in Africa (approximately 50,000 tons) varies from well-stored products which can still be used in the field to products which are entirely deteriorated. In numerous cases, the products are stored in the open where they are exposed to wide variations in temperature and harsh conditions, which accelerates the deterioration of the pesticides together with their containers. However, even when storage conditions are good, the storage period and the nature of the products have resulted in the corrosion of containers and the penetration of the product into the ground.

Secondly, whenever pesticides are used, empty containers are inevitably generated. These are very popular with the local population, which uses them for storing fuel or even food and water. The problem of empty, dirty packaging, which is also important and recurrent, seriously threatens public health and the environment. With a view to sustainable development, disposing of these stocks of NUPP and dangerous packaging is a priority especially for rural communities which cannot hope to develop if their ground and their water are contaminated by pesticides.

> To resolve the problem of NUPP, a multi-partnership initiative has been launched: the programme entitled « Africa Stockpiles Programme » (ASP) which aims to eliminate out-of-date pesticides and contaminated waste (containers, barrels, packaging) from Africa in the next 10-15 years and above all to promote concerted and coherent measures to prevent their accumulation.
>
> Mali and Tunisia have been selected as pilot countries for implementing the ASP and results could, if successful, be transposed to other countries!

In the short term, up to now the only solution for eliminating this toxic residue, products and packaging, has been to send it to a country with adequate facilities for incinerating them at high temperature. This operation, which has serious risks during collection and transport, is also very expensive (>3,500 $ per ton). In addition, the incineration of this toxic material, which contains numerous polluting and persistent organic products (POPs, such as DDT, aldrine, chlordane, dieldrine, endrine or heptachlorine and others which are sometimes difficult to identify correctly), is often severely criticised by researchers and associations dealing with pesticides (Pesticide Action Network, The Pesticide Trust etc.) given the nature of the polluting waste this causes (production of dioxins, furanes, halogenic acids etc.). Given the dispersion of NUPP, very special attention should be given to aspects associated with safety during collection, repackaging and transport.

In the long term, the only way to definitively eliminate the dangers posed by stocks of out-of-date pesticides is to make sure that they do not accumulate any further. That is why it is essential to understand the causes and mechanisms which lead to the accumulation of existing stocks of out-of-date pesticides before issuing recommendations for action. Given the growth in the use of pesticides (intensification of agriculture, locust control, vector control, etc.) it is a matter of urgent importance to establish a concerted strategy for eliminating and preventing obsolete stocks, based on the FAO guidelines ("Preventing the accumulation of stocks of out-of-date pesticides", FAO Provisional Directives). The FAO has been the flagship agency for managing out-of-date pesticides since 1994, and the recommendations of *Crop Life* ("Elimination of stocks of unused pesticides, guide to assistance in selecting practical options", GIFAP – International Group of National Associations of Agrochemical Manufacturers, 1991).

10.6.2. Fundamentals of a strategy for preventing NUPP

Donors, governments (via calls for tender for example), manufacturers, distributors of pesticides, multinational organizations, aid agencies and NGOs have all contributed in one way or another to the accumulation of stocks of out-of-date pesticides and toxic waste in ACP countries.

In order to reduce and, if possible, definitely eliminate this danger, it would be a good idea to draw up, on a national and/or regional basis, **a strategic action plan** to prevent the accumulation of this waste by means of an agreement between the Ministries involved (agriculture, health, environment, education), organizations such as the cooperatives, the pesticide industry, the distributors, growers and owners of plantations responsible for these stocks. Stakeholders should also be offered an adequate channel to collect and process packaging.

The aim of the action plan must be to bring about a **lasting change** in **the way pesticides are purchased and used**, through communication, training and legislation, , in particular:

- by raising the awareness of decision-makers;
- via training in good practices for purchasing, transport, use, storage of products and for management of toxic waste;
- by promoting rational and integrated use of plant protection products;
- by developing alternative methods of control;
- by improving and popularizing updated crop protocols;
- by promoting sustainable agriculture;
- by establishing a plan for reducing the use of pesticides;
- by promoting 'organic' markets;
- by promoting quality procedures, which can reduce dependency on inputs and the volume of toxic waste generated.

The expected results of this strategy are as follows:

1. The ability of authorities and distributors to manage pesticides will be reinforced and the action plan makes sure that products entering the distribution chain are identified, their quality and packaging are monitored and their use approved by the authorities in agreement with the recommendations of the "International Code of conduct for the distribution and use of pesticides issued by the FAO" (FAO, 1990).

2. The regulations are brought into conformity with the recommendations of the FAO Code of conduct. In this way the authorization systems can be used to ensure that the regulations are applied and the quality standards respected all along the pesticide distribution chain. A "Self-check Guide" for importers and distributors of pesticides may be useful for the sector.

3. The dependence on, and recourse to, pesticides is reduced thanks to a more rational use of products in the course of production, the use of replacement control methods, better training for operators, the use of more effective methods of application.

4. The balance between the demand for effective products suitable for the intended use (proven biological activity, adequate packaging, quality formulation) and the capacity of the local market to respond to this is improved.

5. Local skills are reinforced: while the use of pesticides is unavoidable, the operators are informed of the importance of correct maintenance, storage and method of use.

6. The national and local authorities, the representatives of aid agencies, decision makers, distributors and users are aware of the dangers represented by NUPP and their empty packaging, and they are encouraged to use them as little as possible in development plans or programmes for controlling plagues or to select products which are less damaging to the health of people and the environment.

10.6.3. Disposal of NUPP. What can the small-scale grower do?

In rural areas, pesticide waste tends to accumulate wherever agricultural and pest control activities are carried out, whether intensive or extensive. Hence, dangerous chemical products are often abandoned in the open, in rural and urban areas, in municipal dumps and even in children's play areas. Re-using contaminated containers for household purposes is a well-known practice in many developing regions and represents an additional risk to health.

Training and information programmes intended for growers and other users of pesticides ought to **promote the principles of integrated management** against pests and make it as easy as possible to apply non-chemical measures to control pest populations and keep them below a harmful level. **Alternative measures** involve crop or environmental checks, physical barriers, and encouragement to introduce the natural enemies of these pests.

Users must only **purchase the pesticides appropriate** for the required use. The product selected must not only be effective against the pest, but its formulation must be appropriate for the type of equipment which will be used to apply it. Products should only be purchased in their original packaging, and be hermetically sealed. Nor must pesticides which have been decanted into a container other than the one originally supplied by the manufacturer or importer be purchased. These cases often arise in certain situations or certain regions: the user only needs a small quantity and the original containers are too big. So pesticides are decanted into empty bottles, small plastic bags, empty cans or containers which previously contained another plant protection product.

This **practice is very dangerous** as it does not allow any identification of the content, which may be muddled up with other products, such as drinks. As a result there have been several cases of poisoning, especially amongst children. In addition, if a pesticide is transferred, its label remains on the original container along with all the information about it, i.e. danger, instructions, etc.

The quantity of pesticide purchased must be the amount likely to be **used within a maximum time period of a few weeks**. Generally speaking, no more than the quantity of pesticide necessary for a given pest situation should be purchased. Thus the user does not have to store large quantities. The purchaser must be able to resist the pressure from the vendor, even if price reductions are often offered for purchasing larger quantities. The purchaser should also negotiate return to the distributor of empty containers and unused product.

When the product is used up, **its container must be cleaned** as much as possible. Empty and washed containers which the pesticide supplier does not intend to re-use must be perforated or rendered in some way unusable. Even containers which seem empty contain residues of pesticides which cannot be completely eliminated. Consequently, they must never be re-used, except with the same product they already contained.

Empty containers of pesticides must not be **burned or buried** when another treatment is available. The suppliers and distributors, some manufacturers and even some national authorities often use their labels to recommend these practices which, however, are extremely dangerous to human and animal health and to the environment. Safe and non-dangerous combustion techniques require good knowledge of the chemistry involved in pesticides, whereas burying under safe conditions requires a knowledge of the local hydrology and the behavior of pesticides in the environment. As soon as possible, empty containers must be **sent back to the distributor or left at an approved collection site**. If no installation is provided, either for collecting or eliminating empty containers, or for undesirable or non-usable pesticides, users must contact the pesticide distributors (recommendations of the *FAO Guidelines*).

Appendix: Procedures for purifying effluents

A.1. ADERBIO STBR 2® Procedure

❑ **Operating principle**

The procedure is based on a biological treatment involving bioaugmentation which biologically breaks down the residues of plant protection products. It works as follows:

- The effluents collected are stored in a buffer storage tank where pre-treatment is carried out by adding a biological activator.
- The washing area must have a screen cleaning and grit removal system. However, an oil separator does not need to be added, as the hydrocarbons are broken down by the station.
- The plant protection product effluent is then directed to the treatment station where it reaches the digester and is broken down by the bacteria cultivated in parallel in a fermenter and also introduced into the digester.
- Once the plant health product molecules have been broken down, the effluent passes into a decanter where it is 'cleared'.
- The sludge collected in this way is recirculated to the digester.
- The cleared part from the decanter (surfactant) then passes through a biological filter in order to refine the treatment.
- Finally the effluent comes back out of the filter and can be discharged. The ADERBIO STBR 2® system functions continuously throughout the year in order to avoid reinoculating the station every year. To allow this, a switch allows two operational modes to be selected: a normal mode when there is a full influx of effluent into the buffer tank, and a slow mode for the rest of the year.

❑ **Pre-treatment conditions**

Pre-treatment takes place in a buffer storage tank. It consists of adding a bacterial activator (Biobactiv 250) to the effluent which comes in the form of a white powder. It must be introduced into the storage tank at the start of the campaign, then every 2 to 3 months during the period of effluent influx at a dose of 100 g of Biobactiv 250/m^3 of pesticide effluent collected in the buffer tank. Among other things Biobactiv 250 allows the medium to be balanced and the pH to be buffered.

❑ **Description of operations**

The effluent from the washing area is collected in the buffer tank via a screen cleaner and a grit chamber. An agitation pump located in this tank allows good homogenization and helps to limit the deposits in the buffer tank and also pressurizes the supply network. Pre-treatment with the Biobactiv 250 is carried out in this tank at a dose of 100 g/m^3. The supply pump, located in the station, pumps the effluent from the buffer tank and takes it to the digester.

The influx is carried out 12 times a day, 365 days a year, according to an outflow fixed in advance, to reach a daily volume allowing a minimum residence time of 30 days (volume of digester/daily flow). A biological culture containing specific bacteria is also introduced into the digester automatically according to a frequency planned in advance. This culture is automatically prepared in a fermenter. The biological culture consists of water, lyophilized bacteria and nutrients.

The digester is the area where the pollution is broken down with micro-organisms. It consists of a continually ventilated tank therefore receiving the effluent to be treated in 12 daily sequences as well as the biological culture from the fermenter. Once the effluent has been treated, it passes into the decanter by overflow. The digester is individually sized to allow the duration of treatment of 30 days to be respected and to absorb all of the pesticide effluents generated in a year. The decanter is the clarification point of the effluent treated. The bacteria contained in the treated effluent fall to the bottom of the conical decanter (in the form of liquid sludge) while the supernatant is carried to the biological filter by overflow. A flocculent may be introduced by an operator at the start of treatment in order to improve the first decantations. The purpose of the biological filter is to refine the treatment. Its mechanical action associated with its porosity is able to retain the remaining materials in suspension. Its continuous aeration, coupled with its humidity and its porosity, encourages the development of a microflora which will break down the materials retained.

❑ **Treatment capacity of the apparatus**

The procedure is able to treat different volumes of plant protection product effluent. Selecting the size of the elements of the station allows the quantity of pesticide effluent it is possible to treat to be increased or decreased. The 30-day residence time given by the volume of the digester/the supply output determines the size of the digester. Subsequently the size of the decanter, the filter and the fermenter must be selected according to the daily output treated.

❑ **Treatment limits**

The procedure treatment limits are determined by the time spent by the effluent in the digester. Consequently they are fixed at the time of designing the treatment station and in consultation with the client. They relate to standard, non-pre-concentrated plant protection product effluent. The limits of treatment by volume are specified clearly to the client. There is no restriction of temperature, as the station equipment is produced in a heated and ventilated container.

A.2. BF Bulles Procedure

❑ **Operating principle**

BF Bulles are filtration units. The pollution control of effluents is carried out using ultrafiltration over activated charcoal.

❑ **Description of pre-treatment conditions**

The washing area must have an oil removal, screen cleaning and grit removal system.

Pre-treatment of effluents takes place in a storage tank. Agitation of the effluents is carried out using an immersed pump in the case of a buried tank, and a lift pump in the case of an off-the-ground tank. The products used are:

- oxidation: 35% hydrogen peroxide. Concentration 1 litre/cubic meter;
- coagulation: specific solution. Concentration after test of 1 to 3 liters/cubic meter;
- flocculent: acrylic polymer. Dose 80% of the concentration in coagulant.

In the event of foam appearing during the agitation phases use an anti-foaming product (dimethylpolysiloxane at 250 g/liter, maximum concentration 1.4 ml/cubic meter).

❑ **Treatment capacity of BF Bulles**

The BF Bulles® procedure is a physical procedure whose treatment capacity depends on the size of the treatment unit. There are currently 2 treatment units:

- the first (BF 8) has a treatment capacity of 1000 l/h;
- the second (BF 16) has a treatment capacity of 1800 l/h;

❑ **Treatment limits**

BF Bulles systems are intended to treat all water from the interior and exterior washing of treatment systems, collected after rinsing on the plot, all the effluents from the overflow of sprayers when filled and all the water used for rinsing an area of accidental spillage of plant protection products. The minimum and maximum temperatures for use are + 2 to + 40 °C.

A.3. PHYTOCAT and PHYTOMAX procedures

Fields of application: viticulture, leguminous vegetable crops and *non-agricultural zones* (all pesticide effluents from viticulture or from treating crops of leguminous vegetables [excluding effluents from post-harvesting treatments] and non-agricultural zones).

❑ **Operating principle**

This type of equipment is intended to destroy the plant health effluents from the treatment of leguminous crops and non-agricultural zones by photocatalysis. It must be combined, with a washing area, with a screen cleaner, sludge separator, oil separator. After screen cleaning, sludge separation and oil separation, the effluent confined in the storage tank is pre-filtered and cleaned using the photocatalysis technique. The system is based on the phenomenon of photocatalysis, *i.e.* the irradiation of a catalyst (titanium dioxide, TiO_2) using ultra violet light (U.V.). This then produces an oxidoreduction reaction, releasing free radicals (OH radicals). These radicals attack the organic pollutants in the presence of oxygen and break them down by successive oxidations into non-toxic mineral compounds (H_2O, CO_2, SO_2 etc.).Pre-treatment is provided by mechanical bi-phase solid-liquid filtration.

❑ **Description of how the process functions**

The washing area must have an oil removal, screen cleaning and grit removal system. After screen cleaning, sludge separation and oil separation of the effluent on the washing

area, the confined effluent is pumped, prefiltered and stored. The start-up of the pollution control cycle activates the lifting pump which makes the effluent circulate over the environmental filters radiated by U.V. lamps. The successive oxidations-reductions then take place via the environmental filters, non-woven media covered with silicon and titanium dioxide (TiO_2), which trigger the photocatalytic reaction under the effect of the light.

There is no particular contra-indication regarding the maximum concentrations of effluent, given that the recommendations for use are described with reference to the experiments conducted on variable concentrations ranging from the pure product to the effluent diluted in conformity with good agricultural practices. Temperature has no effect on the efficacy of photocatalysis.

A.4. PHYTOPUR procedure

❑ **Operating principle**

The procedure breaks down into 3 stages: coagulation/sedimentation (pre-treatment), reverse osmosis, absorption over activated charcoal.

> ➢ **First stage: coagulation/sedimentation**
>
> This initial stage takes place in the pesticide effluent storage tank. Initially, the effluent is homogenized using a pump introduced into the storage tank. At this stage, a coagulant is introduced into the storage tank. It ensures the formation of agglomerates of particles (flocs) which will trap all the materials in suspension. The type and dosage of coagulant are determined in situ according to the nature of the effluents, after which the coagulant is incorporated in the storage tank. The coagulants used are trivalent cations, in the form of ferrous chlorine or aluminum polychloride. The separation of effluents/flocs is carried out by sedimentation in the buffer tank. After decanting, a clarified surfactant is obtained, and sludge at the bottom of the storage tank. The sludge must be recovered in order to be eliminated as hazardous waste in an approved center.

> ➢ Second stage: membrane filtration (osmosis)
>
> This second stage is carried out in the treatment unit. Before carrying out reverse osmosis, the phase of clarified effluent is filtered in order to eliminate the flocs which have not been decanted. Osmosis is carried out on organic membranes, which have the property of only letting through the molecules of water and of retaining the pesticide molecules.

> ➢ Third stage: absorption on activated charcoal
>
> On exiting the reverse osmosis unit, final treatment is provided by passage over an activated charcoal filter. This retains the micropolluants which have not been stopped by the osmosis stage by absorption.
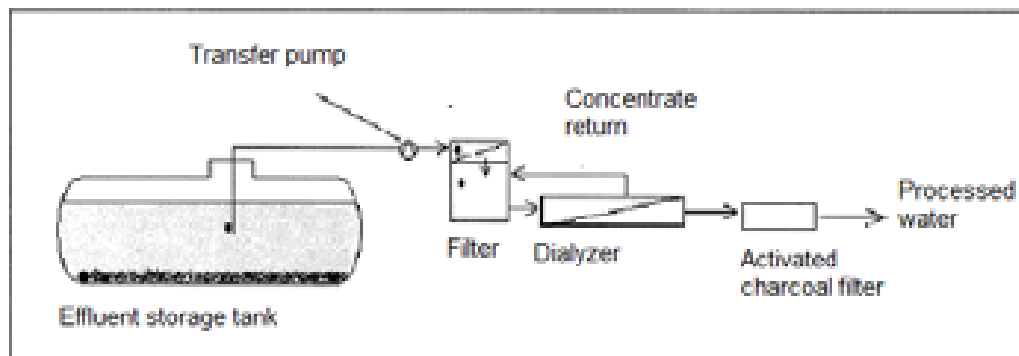
Diagram of the way in which the Phytopur® procedure functions

❑ **Treatment capacity**

The PHYTOPUR® procedure is a solely physical procedure whose treatment capacity depends on the size of the treatment unit. There are currently 2 treatment units:
- the first one has a treatment capacity of 12 m3/day, i.e. a mean output of 500 l/h /24 hours and a peak output at the start of the procedure of 900 l/h;
- the second one has a treatment capacity of 16 m3/day, i.e. a mean output of 650 l/h /24 hours and a peak output at the start of the procedure of 1,000 l/h;

The duration of treatment depends on the volume of pesticide effluents to be treated, and this varies from 2-3 hours for small volumes (< 3 m3) to several days for large volumes (> 25 m^3).

❑ **Treatment limits**

The PHYTOPUR® procedure is a physical treatment whose principal stage is filtration by reverse osmosis, which is not limited by any maximum volume.

Osmosis is a physical barrier, so the initial concentration has no effect on bringing down the concentration of the effluent.

The PHYTOPUR® procedure can work in a range of temperatures from 2 °C to 45 °C. Beyond 45 °C, there is a risk of membrane deterioration. In fact, the pores of the membrane close irreversibly and therefore the treatment output becomes zero.

A.5. SENTINEL procedure

Fields of application of the procedure: treatment of effluents from post-harvesting treatments on fruits and vegetables.

❑ **Operating principle**

The SENTINEL device was developed to purify pesticide effluents.

The purifying capacities extend from 100 to 1,500 liters of effluent treated per hour.

A SENTINEL station consists of a principal tank with agitator, a unit for filtration over activated charcoal and a compartment to receive and dry sludge.

Unlike stations working continuously, SENTINEL treats effluents by batch. The SENTINEL procedure concentrates pollutants in the sludge and activated charcoal. For 1,000 liters of raw effluent treated, we obtain on average:
- 996 liters of purified water;
- 3 to 4 kg of sludge;
- 0.5 to 1 kg of contaminated charcoal.

The washing area must have an oil removal, screen cleaning and grit removal system.

❑ **Description of how the process functions**

A full cycle of treatment comprises 5 stages:
1. Filling: filling of the main tank by manually opening a valve; automatic cut out of the pump when the tank is full and agitating.
2. Assay: subsequent addition of 4 chemical reagents following the recommended order of introduction and agitation times.
3. Decanting: agitation is stopped and decantation of sludge (minimum 1 hour); autocheck no. 1: a sample is taken to check that the flocs have decanted properly.
4. Filtration: start-up of the pump to allow the surfactant to cross the pre-filter and the columns of activated charcoal; autocheck no. 2: effluent colorless on exiting the first column (if the effluent is red, the first column must be replaced then inverted with the second column and the system must be re-started).
5. Handling sludge: evacuation of sludge (which has remained at the bottom of the main tank) to the basket and the filtering bags for dehydration.

The effluent must be diluted if it is too concentrated.

Chapter **10**
*The
management
and disposal of
effluents and
waste*

For the treatment of plant health product effluents from post-harvesting treatments, the SENTINEL device designed by WMEC (UK).

Most useful abbreviations and acronyms

Most usefull abbreviations and acronyms

2,4-D	2,4-Dichlorophenoxyacetic acid
2,4-DP	Dichlorprop
2,4 MCPA	Dimethylamine salt
ACP	The African, Caribbean and Pacific Group of States (countries within the ACP Group, which have signed a series of special agreements with the EU known as the *Cotonou Agreements*)
CGIAR	CGIAR
AP	Action potential
ARfD	Acute Reference Dose
a.s.	Active solution
As	Chemical symbol for arsenic
ASP	Africa Stockpiles Programme
ARN	Ribonucleic acid
B.A.A.	British Agrochemical Association
Bt	*Bacillus thuringiensis*
Ca	Chemical symbol for calcium

CAB	Centre for Agricultural Bioscience
CERVA	Veterinary and Agrochemical Research Centre (*Centre d'étude et de recherches vétérinaire et agrochimiques*)
CGIAR	Consultative Group on International Agricultural Research
CO_2	Chemical symbol for carbon dioxide
CP	Constant pressure
Cu	Chemical symbol for copper
DDT	Dichlorodiphenyltrichloroethane
DNA	Deoxyribonucleic acid
DP	Dusting powder
EC	Emulsifiable concentrate, liquid formulation of solvent-based pesticide
ELISA	Enzyme Linked ImmunoSorbent Assay
EPA	Environmental Protection Agency (USA)
EPPO	European and Mediterranean Plant Protection Organization
ETI	Ethical Trading Initiative
EU	European Union
EVPP	Empty Crop Protection Product Packaging and Containers

EW	Emulsion in water
f.sp.	Specialized form
GAP	Good Agricultural Practice
GMO	Genetically Modified Organism
GMP	Genetically modified products
GPP	Good Plant Protection Practice
GR	Granules
H	Chemical symbol for hydrogen
H_2O	Chemical symbol for water
H_2SO_4	Chemical symbol for sulfuric acid
HDPE	High density Polyethylene
Hp	Horse power
IPHC	Integrated Plant Health Control
IPM	Integrated Pest Management
IPPC	International Plant Protection Convention
K	Chemical symbol for potassium

KCl	Chemical symbol for potassium chloride
kW	KiloWatt
LD_{50}	Lethal Dose 50 (in mg/kg pc)
MA	Marketing Authorisations
MCPP	Methylchlorophenoxypropionic acid
Mg	Chemical symbol for magnesium
MRL	Maximum Pesticide Residue Levels
MSO	motor speed output
MVD	Mean volumetric diameter
N	Chemical symbol for nitrogen
NPV	Nuclear Polyedric Virus
NUPP	Non-usable pesticide product
OECD	Organisation for Economic Co-operation and Development
OJEC	Official Journal of the European Communities
OJEU	Official Journal of the European Union
OP	Organophosphate

ORP	*Observatoire des résidus de pesticides* (Organisation Supervising Pesticide Residues)
P	Chemical symbol for phosphorus
PAO	Proportional to progress output
PCR	Polymerase Chain Reaction
PE	Polyethylene
PET	Polyethylene terephthalate
PHI	Pre-harvest interval
PPE	Personal Protection Equipment
PPP	*Production Plus Propre* (Cleaner Production)
PRA	Participatory Rural Appraisal
RPPO	Regional Plant Protection Organisations
S	Chemical symbol for Sulphur
SC	Suspension concentrate
SL	Soluble liquid
SPP	Direct sowing on permanent plant cover
SPS	Sanitary and Phytosanitary Agreement

SO$_2$	Chemical symbol for sulfur dioxide
TSC	Targeted stepped control
U.K.	United Kingdom
ULV	Ultra-Low Volume Liquids. Concentrated oily solution, liquid formulation of pesticide
UNEP	United Nations Environment Programme
USDA	United State Department of Agriculture
VLV	Very low volume
W	Watt
WG	Water Dispersible Granule
WP	Wettable Powder
WTO	World Trade Organisation

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Useful Websites

Useful Websites

AGRITRADE (CTA): agritrade.cta.int

Bayer CropSciences: www.cropscience.bayer.be/fr-FR.aspx

CGIAR (*Consultative Group on International Agricultural Research*): www.cgiar.org

CIPV: www.ippc.int/en

COLEACP: coleacp.org/en

CTA: www.cta.int

ECPA: www.ecpa.eu

EPPO/OEPP: www.eppo.int

FAO: www.fao.org/home/en

ICARDA - International Center for Agricultural Research in the Dry Areas, www.icarda.cgiar.org

ICRAF (World Agroforestry Centre): www.worldagroforestry.org/af

ICRISAT, International Crops Research Institute for the Semi-Arid Tropics: www.icrisat.org

ORP (Observatoire des Résidus de Pesticides, *French Observatory for Pesticide Residues*): www.observatoire-pesticides.gouv.fr
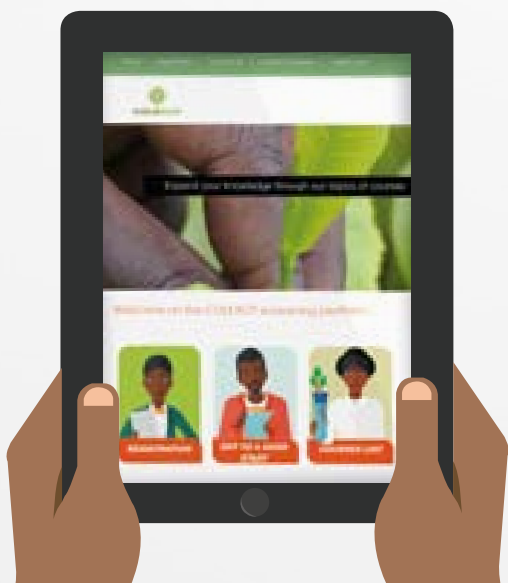
PSD (Pesticide Safety Directorate): www.pesticides.gov.uk

World Bank: www.worldbank.org

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