Integrated Pest Management in international cooperation projects with partner countries

A Guideline

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Foreword

Pests, plant diseases and weed infestation have caused crop losses or threatened human livelihoods since the dawn of agriculture. Based on traditional and often holistic approaches, as in India, farmers have developed a wide range and huge variety of concepts and techniques at different levels, arising from an understanding of the natural sciences that govern pest organisms and plant health. These approaches led to the use of Integrated Pest Management (IPM). Various permutations of this concept have been incorporated into everyday practice in developing countries, and it is constantly evolving.

Since the start of German development cooperation, pest management and sustainable agriculture have been key components of technical cooperation. Securing food supplies and the livelihoods of the rural population crucially depend on whether it is possible to favourably influence the interplay of biotic and other environmental factors in agriculture by means of suitable concepts and processes. Technical cooperation and capacity building has made a vital contribution towards introducing and further developing Integrated Pest Management in developing countries worldwide.

These guidelines on Integrated Pest Management offer practical guidance to everyone interested in pest management issues in international cooperation. The additional aim is to promote Integrated Pest Management in development cooperation as part of good agricultural practice. It thus continues the long tradition of German development cooperation with Integrated Pest Management that began with the 1993 version of the guide (GTZ, 1993).

The new version of the guidelines is intended to help enhance awareness of healthy plant production in projects with partner countries. One of the foremost aims is to minimise risks to human and animal health and to the ecosystems affected by the use of pesticides[1] and to reduce the use of these products.

This guide is aimed at advisors and extensionists in cooperation projects, ministries and partner organisations as well as the interested professional public. It is intended to support the formulation of sector policies and the development of integrated pest management strategies. It may serve as a guide for advisory services and vocational training.

The principles of Integrated Pest Management are binding for GIZ's global activities.

[1] These guidelines use the term 'pesticides' for plant protection and pest control products (pesticides and biocides) as defined in GIZ's procurement regulations; see also the definition in EU Directive 2009/128/EC.

1

Introduction

Integrated Pest Management is the approach that can best be integrated into ecosystems

Agricultural cultivation methods have always included measures to control pests, both in conventional farming[2] and in production methods that are geared to the requirements of organic farming. Agricultural, horticultural and forest crops are threatened by various pests and pathogens. These may be animals (especially insects, mites, rodents, birds, snails and slugs), diseases (fungi, bacteria, viruses) or plants (weeds, parasitic plants). Abiotic factors may also strongly impede plant growth. These include drought, waterlogging, salinisation, lack of nutrients and unfavourable temperatures, all of which lead to yield losses. This may be exacerbated by unsuitable cultivation methods, such as the use of varieties that are susceptible to diseases and pests, poor soil management or monocultures that encourage the spread of pests and diseases. Taken together, these factors may reduce the potentially possible yield and entail economic losses for the farmer. People who work in agriculture, forestry and horticulture are forever trying to keep their crop losses through pests, diseases and plant competition to a minimum.

All production methods including pest control measures must be integrated into the local ecosystem. This is the only way to secure the production site in the long term. Integrated Pest Management (IPM) is the best approach for this purpose and must be seen as part of an agroecological approach.

After the harvest, further losses may be caused especially by insects, rodents and birds that damage stocks of storable crops such as cereals, grain legumes or root vegetables and tubers, and their processed products. Fresh fruit and vegetables may also spoil. This can be solved by methods such as processing, preservation or cooling, which are not addressed by these guidelines. Preventing post-harvest losses due to storage pests and diseases, however, largely follows IPM principles and will be discussed here. In this context, we also speak of integrated stored product protection. For simplicity's sake, we will use the abbreviation 'IPM' as applying to Integrated Pest Management and stored product protection in the rest of this document.

Integrated Pest Management is complemented by integrated stored product protection

IPM is a dynamic and flexible system that must always be guided by local conditions. The guidelines are intended to support the decision-making process at projects in the field. They provide information on pest control measures, the use of plant protection and pest control products (pesticides), the involvement of and guidance provided by governmental partner authorities, cooperation with the pesticide industry and non-governmental organisations (NGOs), pesticide procurement by GIZ in Germany and a number of practical recommendations.

Further, more comprehensive information is available on the internet and from other sources. The document provides links to a number of internet sites to facilitate access to these sources.

A note on how this document is structured: the following two sections present basic concepts and characteristics of Integrated Pest Management. They define the term IPM, name international regulations and present the eight basic principles of Integrated Pest Management in the EU, as well as introducing the concept of threshold levels, forecasting methods and warning services as well as presenting Integrated Pest Management as a component of 'good professional practice'.

[2] Conventional farming encompasses a broad range of different methods.

The third section presents the tools of Integrated Pest Management; indirect measures used in farming, cultivation and plant breeding as well as direct physical, chemical, biological and biotechnological measures. This is followed by a section on pest management in organic land use systems.

In order to use the described integrated pest management tools with success, they must be supported by monitoring systems and international and national regulations, for instance. Trade requirements and modifications due to climate change must also be taken into account and call for specific action. All of these aspects are explained in Section 5.

Section 6 briefly outlines where GIZ stands with regard to introducing or improving Integrated Pest Management in partner countries. Section 7 presents the challenges involved in disseminating Integrated Pest Management in partner countries and the role played by extension services. It also presents possible solutions.

The guidelines are rounded off by comments on classification and further prospects for developments in Integrated Pest Management.

2 Concepts and characteristics of Integrated Pest Management

Integrated Pest Management (IPM) is considered the guiding concept for practical pest management. It covers systems in which all economic, ecological and toxicologically suitable methods are coordinated as closely as possible to keep pest populations at levels below those causing economic injury, with a main focus on the conscious exploitation of natural limiting factors.

As a comprehensive approach for controlling pests, IPM applies suitable measures within a holistic system. Precise knowledge of the life cycles of the pests and how they relate to the growth of host plants and environmental conditions is the basis for being able to intervene appropriately in the production system.

Integrated Pest Management is defined by a large number of international and European organisations. Some of these definitions are presented in the following subsection.

2.1 Definitions and international regulations

The guidelines advocate healthy plant production with minimum use of pesticides

In the International Code of Conduct for Pesticide Management, the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) have defined Integrated Pest Management for all countries.[3]

FAO / WHO-Definition (2014): Integrated Pest Management

Integrated Pest Management (IPM) means the careful consideration of all available pest control techniques[4] and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimise risks to human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption to agroecosystems and encourages natural pest control mechanisms.

Like the European and Mediterranean Plant Protection Organization (EPPO), the International Organisation for Biological and Integrated Control (IOBC) defines Integrated Pest Management as follows: 'Integrated Pest Management is a strategy and procedure that harmonises all economically, ecologically and toxicologically acceptable methods to maintain pest populations at levels below those causing economic injury, with a main focus on the conscious exploitation of natural limiting factors and preventive measures.'

In principle, the aim is to make the necessary corrections in agricultural production systems while maintaining, reactivating or modifying natural processes with minimum effort, where possible using a combination of mutually compatible and synergistic measures instead of one across-the-board method.

Eight general principles are listed in Annex III to EU Directive 2009/128/EC (Section 2.3) in order to implement Integrated Pest Management based on a joint understanding. These principles have been binding for all users of pesticides since 2014, and clearly state that preventive measures should be given preference for preventing pest infestation.

3 www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/en

4 Section 3 goes into the wide range of pest management tools and techniques. These guidelines use the term 'pesticides' for plant protection and pest control products (pesticides and biocides).

The decision regarding IPM practice is based on a weighing up of the different methods and aspects, bearing in mind costs and benefits and ecological and sociological limits, as well as the long-term conservation of the ecosystem and its services.

This calls for systematic monitoring of infestation, possibly using aids to decision-making, specialised extension services and threshold levels.

Using IPM presupposes precise knowledge of the pests, their biology and how they relate to the growth of the crop plant. IPM is therefore not easy to apply in practice. Prominent features are:

- chemical pesticides and biological methods are regarded as equally valid control measures;
- relevant considerations alongside the monetary benefit are ecological aspects in line with environmental compatibility and in particular, social aspects in the development cooperation context.

Many definitions express the fact that the economic threshold (EIL) is an underlying concept of Integrated Pest Management. EILs were originally developed in order to make the most targeted possible use of chemical pesticides. The EIL concept is therefore traditionally closely linked with curative pest control and especially with chemical pest control.

2.2 Integrated Pest Management worldwide

Integrated Pest Management is considered a global model for practical plant protection

How did Integrated Pest Management develop historically and worldwide? The first Integrated Pest Management (IPM) schemes emerged in the 1960s, initially for individual crops and cultivation practices. These were a response to the increasing resistance shown by pests to chemical pesticides. The importance of IPM grew following the identification of further adverse effects of chemical pesticides on humans, animals and the environment. In the Agenda 21 action plan adopted by the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, IPM was specified as being an optimum solution for the future and a global model for all countries for crop protection in sustainable agriculture.

IPM is a systematic, process-oriented and knowledge-based approach that focuses on developing a healthy, resistant plant population within an agroecosystem. The form that IPM takes is therefore largely dependent on the crop being grown, the production system, the natural environment, the political and economic setting, the extension structures in place and the abilities and commitment of the producers.

IPM has been considered the way forward in plant protection worldwide for over 50 years, and is propagated by governmental agencies, the pesticide industry and NGOs. In Germany, pest management may only be carried out in accordance with 'good professional practice' principles (this is a statutory requirement). Good professional practice includes bearing in mind the general principles of Integrated Pest Management and protection of groundwater. IPM is therefore part of good agricultural practice and now even goes beyond this.

The National Action Plans are an example of the implementation of IPM

2.3 Principles of Integrated Pest Management

Within the European Union, eight general IPM principles have been defined that provide orientation for drawing up specific guidelines for given crops or sectors. These principles are the following:[5]

1. The prevention and/or suppression of harmful organisms should be achieved or supported among other options especially by:
   - crop rotation,
   - use of adequate cultivation techniques (e.g. sowing densities),
   - use, where appropriate, of resistant/tolerant cultivars and standard/certified seed and planting material,
   - use of balanced fertilisation, liming and irrigation/drainage practices,
   - preventing the spread of harmful organisms by hygiene measures (e.g. by regular cleansing of machinery and equipment),
   - protection and enhancement of important beneficial organisms, e.g. by adequate plant protection measures or the utilisation of ecological infrastructures inside and outside production sites.
2. Harmful organisms must be monitored by adequate methods and tools, where available. Such adequate tools should include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems, where feasible, as well as the use of advice from professionally qualified advisors.

3. Based on the results of the monitoring, the professional user has to decide whether and when to apply plant protection measures. Robust and scientifically sound threshold values are essential components for decision-making. For harmful organisms, threshold levels defined for the region, specific areas, crops and particular climatic conditions must be taken into account before treatments, where feasible.

4. Sustainable biological, physical and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.

5. The pesticides applied shall be as specific as possible for the target and shall have the least side effects on human health, non-target organisms and the environment.

6. The professional user should keep the use of pesticides and other forms of intervention to levels that are necessary, e.g. by reduced doses, reduced application frequency or partial applications, considering that the level of risk in vegetation is acceptable and they do not increase the risk for development of resistance in populations of harmful organisms.

7. Where the risk of resistance against a plant protection measure is known and where the level of harmful organisms requires repeated application of pesticides to the crops, available anti-resistance strategies should be applied to maintain the effectiveness of the products. This may include the use of multiple pesticides with different modes of action.

8. Based on the records on the use of pesticides and on the monitoring of harmful organisms, the professional user should check the success of the applied plant protection measures.

[5] Annex III General principles of Integrated Pest Management EU Directive 2009/128/EC and www.nap-pflanzenschutz.de/praxis/integrierter-pflanzenschutz/grundsaetze-ips (BMEL)

The member states should implement these eight principles in the EU among other things by putting in place the necessary prerequisites, for example instruments for monitoring pest populations and for decision-making (e.g. threshold levels) and by providing extension services within the National Action Plan. The following section presents the concept of threshold levels that is central to Integrated Pest Management.

2.4 The concept of threshold levels

In order to prevent harmful organism populations from causing unacceptable damage to crops, the pests need to be eliminated at the optimal point in time. To do this, researchers began determining threshold levels more than 20 years ago.

There are different ways of defining the level of damage, which are distinguished as follows:

- the economic threshold and
- the action threshold.

The economic threshold represents the density of a pest population or the extent of disease or weed infestation at which the expected damage is equal to the pest control costs.

However, it has transpired that pathogens and pests, unlike unwanted weeds and grasses, rapidly spread to epidemic proportions and it is then no longer possible to limit the population at a given location once the economic threshold has been reached there. A lower action threshold was therefore defined that bears in mind the course of infection or infestation and thus makes it possible to interrupt the development of the pest population in time.

Economic threshold versus action threshold

The action threshold states that, at a defined population level, a targeted pest control measure ensures that the development of the harmful organism is stopped and the economic injury threshold will no longer be reached.

These guidelines use the terms 'action threshold' and 'economic threshold' throughout, implying that the decision on the form of control to be used is based on economic considerations.

Determining loss/ infestation ratios

In concrete terms, this means that if infestation exceeds the action threshold without the pest population being controlled, economic loss can be expected. The action threshold is therefore the 'profit threshold' of a control measure.

The following parameters must be known in order to precisely determine the action threshold:

- relationship between the pest population and the yield loss, i.e. the loss/infestation ratio;
- yield without the influence of the pest population, i.e. the potential yield;
- price of the crop product, expressed as sales directly from the farm;
- cost of a control measure;
- effectiveness of the control measure.

Clearly, the action threshold is a variable factor that depends on the stated parameters and must always be considered a rule of thumb in actual practice. A new, more resistant cultivar therefore alters the loss/infestation ratio and leads to a higher economic threshold. The loss/infestation ratio is the factor that is subject to the greatest fluctuations.

Determining the action threshold as a range of action

To be successful, a pest control measure must start at the earliest stage possible. When determining loss/infestation ratios, it must therefore be ensured that they relate to the growth or development stage of the pest population at which a control measure can be successfully taken. It follows that strictly speaking, action thresholds only apply to the conditions under which they were determined.

Picture 1
Fall army worm infestation in maize in Ghana. *Photo: © CABI*

In practice, it is hard to determine the action threshold with any degree of precision. For one thing, action thresholds are stochastic values, i.e. they depend on the probability that uncertain events will occur. For another, the isolated calculation of the threshold for an individual pest implies a gross simplification. Dynamic aspects are particularly difficult to consider. These indicate the impacts of a measure in irrigated rice cultivation, for example, which is practised comprehensively and continuously in Asia (example: insect pest control).

Taken together, these difficulties mean that advisors/extension workers always specify that action thresholds imply a certain range of action.

In computer models for using Integrated Pest Management, action thresholds always have to be either mathematically deduced from existing data material or provisionally established by interviewing experts. The choice of method mainly depends on the scope and accuracy of the available data material. The internet now provides many examples of EILs and action thresholds for a wide variety of pests. In every case, the (climatic) conditions on which the level or threshold is based must be known.

Training farmers to handle action thresholds

The provisional threshold levels must be tested with farmers in field trials in order to adjust them to practical and local conditions. In the final analysis, it is important for the individual farmer, gardener or forester to carry out the monitoring required to apply these threshold levels. The role of extension services is therefore not just to determine the current threshold levels. If Integrated Pest Management is to be successful on a sustainable basis, the crucial factor is to familiarise the user with the basic principles of monitoring and the action threshold, and provide access to the relevant aids. Only then are users empowered to find the optimal action threshold for their specific conditions.

Like forecasting methods and warning services, threshold levels are key aspects of Integrated Pest Management.

Picture 2
Meloidae infestation of legumes *Photo: © Stephan Krall*

2.5 Forecasting methods and warning services

Forecasting methods mainly for fungal infection

Forecasting options and models for targeted plant protection, and thus for better IPM and reductions in the use of pest control measures, have improved significantly in recent years.[6] Forecasting methods are an integral part of IPM and form the basis for warning services. In Europe, they have become key tools for extension services. The greater and better availability and use of meteorological data have contributed to this development. The internet also offers many sources of information.[7]

Various models have been developed especially for fungal infections that can also be used in tropical climates. A classic example is the forecasting of late blight of potato *(Phytophthora infestans)*. In coffee, the first models have been created for controlling coffee leaf rust *(Hemileia vastatrix)*. Forecasting methods are additional aids to decision-making that can be used to determine when pesticides are to be used. It should still be borne in mind, though, that all relationships between host plants and parasites are biological processes that may take a different course under extreme conditions than is usually the case.

As listed in the eight IPM principles, it is very important for producers and users to monitor crops and to establish the occurrence of diseases and their development, possibly with sup-

[6] In Germany, the Central Institute for Decision Support Systems in Crop Protection (ZEPP) was set up to coordinate the large number of forecasting models. There are interesting potential applications for horticulture and agriculture.

[7] warndienst.lko.at (Lkwarndienst)

port from extension workers. These data should be provided to extension services, plant protection services and/or agricultural and forestry organisations so that forecasts can be drawn up based on a large body of data and farmers can be correspondingly warned.

2.6 Integrated Pest Management as part of the agroecosystem

Integrated Pest Management is the ultimate goal, good professional practice is the short-term goal

The principles of good professional practice in pest management apply to all cultivation methods (conventional, integrated and organic farming). They form the framework for the available scope for action of the practitioner[8] who plans and carries out pest control measures. The German Plant Protection Act demands a reduction in the use of chemical pesticides, giving priority to biological, biotechnological, plant breeding and cultivation measures for pest control.

Whereas at present, good professional practice is considered the basic prerequisite for correct action in the field of plant protection, IPM aims to use sustainable combinations of all suitable measures.

The important thing is for all measures to be embedded in the local ecosystem and to steer the various factors in the agroecosystem in order to ensure the best possible conditions for growing a healthy, resistant and productive crop. This means preventing the economic threshold from being reached.

Table 1 Comparison of 'good professional practice' and 'Integrated Pest Management'

Criteria	Good professional practice	Integrated Pest Management
Goal	Preventing damage as a function of infestation	Maintaining plant health through a system of ecologically and economically geared measures.
Characteristics	Using IPM based on estimates of infestation	Steering the pest population based on threshold levels, taking into account biological self-regulation mechanisms
Advantages	Reduced volume of active substances applied	Reduced ecological load, further reduction in use of pesticides

(in accordance with BVL 2006, in: Börner, H. et al. 2009. Page 409).

This approach also means that the type of crop and variety must be site-appropriate, thus bearing in mind the natural conditions.

Section 3 goes on to present the tools of Integrated Pest Management.

[8] In the following text, practitioner is defined as the expert user of pest control measures in agriculture, horticulture and forestry.

3 Tools of Integrated Pest Management

Giving priority to non-chemical pest control

The key tools of Integrated Pest Management can be broken down into four main groups

- cultivation and plant breeding measures;
- physical control measures;
- biological and biotechnological pest control measures;
- chemical measures.

We will start by presenting the indirect measures (Section 3.1), then go on to address direct control measures as part of Integrated Pest Management (Sections 3.2 to 3.6).

3.1 Cultivation and plant breeding measures

Cultivation methods in the context of Integrated Pest Management are taken to be all measures that impair the living conditions of pests, in addition to their agricultural function. In the best-case scenario, a measure has an adverse effect on pest population density or a positive effect on the population of beneficial organisms, but no adverse effect on the yield of a crop plant.

Preventive pest control methods are very effective

In the long run, such preventive methods are the most effective way to prevent damage. In particular, they include:

- choice of location, cultivation system and crop rotation;
- soil treatment;
- choice of cultivar;
- seed and planting technique;
- fertilisation;
- harvesting method and harvesting time;
- use of traps and border planting;
- irrigation and
- field hygiene.

We will go on to discuss these preventive measures in more detail.

The choice of suitable location encourages healthy plant development

The **choice of a suitable location** places the cultivar in a conducive environment that favours its development and resistance to pests. Such favourable conditions may be geographical, topographical, soil-related or climatic. A crop may also be completely protected against pest organisms in locations where these do not exist. One example is potato farming in areas with few aphids.

The suitable cultivation system reduces pest infestation

Some **cultivation systems** reduce the risk of pest infestation, e.g. mixed cropping of maize and beans. In this case, the greater variety of the ecosystem encourages beneficial insects, while the barrier effects of the mixed crop make it more difficult for pests to move on to their host plants.

Picture 3
Seed rows with aubergines as the main crop, sunflowers, coriander and in the background: anise and melon as additional plants to attract and maintain useful insects.
Photo: © Stefanie Christmann

A distinction is made between the following cultivation systems: monoculture, undersowing, strip farming, mixed cropping and agroforestry systems. Strip farming involves simultaneously growing broad strips of different crops next to each other in one field, whereas in mixed cropping the plant varieties alternate every one or few rows. In agroforestry systems, trees and shrubs are grown around or among crops.

Generally speaking, increasing diversity makes the agricultural ecosystem more stable and prevents the rapid spread of pests, diseases and weeds.

Picture 4
Flowering strips of marketable crops (sunflowers and coriander) that attract more pollinators and pest predators to the field of cucumbers.
Photo: © Stefanie Christmann

Correct crop rotation impairs the development of pests

Specific **crop rotation** has for centuries played a key role in maintaining soil fertility and controlling pests. Pests can survive on harvest residues, on other plants they use as intermediate hosts, or in the soil, and thus migrate to the next crop. Their life cycle can also be interrupted by planting a succession of unsuitable crops.

Picture 5
Border strips of canola, lupines and alfalfa help to improve the pollination of thick beans, diversification leads to higher yields.
Photo: © Ahlam Sentil

Targeted crop rotation is the only economically feasible way to control many types of pest (e.g. specific nematodes or soil-borne pathogens). It works on the principle of delaying the re-planting of host plants until the food supply for pests has dropped to the level where they can no longer survive. Suitable crop rotation deprives pest organisms of food. This works on pests with limited mobility or that specialise in particular types of food/plant (are stenophagous, i.e. have a narrow plant host range) and thus depend on a single crop. Rotating specific crops is therefore less effective in combating polyphagous or mobile pests.

Many key pests are monophagous, i.e. they have specialised either in closely related plant species or even in just one species. The continuous cultivation of just one culture (monoculture) improves the living conditions of pests that have adapted to this culture. The chosen crop rotation therefore has a crucial influence on pest infestation and is one of the most important preventive measures in Integrated Pest Management.

Soil treatment is an effective preventive measure

Conventional soil treatment (ploughing, hoeing and harrowing) can be an effective preventive control measure against soil-borne pathogens and pest insects. In weeds, however, the benefits of soil treatment depend on the dominant type of weed. Broad-leaved species can be controlled well, whereas some grasses that propagate vegetatively are encouraged rather than controlled because the tools cut their underground plant organs into pieces and distribute them, thus fostering their reproduction.

Conservation agriculture (CA)[9] is a form of farming based on the principles of minimal soil disturbance (no ploughing), permanent soil cover and crop rotations. It increases the share of organic material and supports biological activity in the soil to improve soil fertility, leading to a more balanced soil flora and fauna. Weeds are suppressed by permanent soil cover through living and dead organic substance; organic substance is added and soil erosion prevented. This is particularly beneficial for erosion-prone soils because the topsoil is only broken up superficially or in strips. Since this practice is linked with direct sowing and does not involve soil treatment, it usually leads to the increased use of herbicides.

The right choice of variety prevents pest infestation

The **choice of cultivar** is a doubly effective pest control measure. On the one hand, crops that are resistant or tolerant to the main pests can be grown, and on the other, early-ripening varieties can be used to reduce infestation pressure. The choice of resistant or tolerant varieties is a preventive measure that may be sufficient to keep pest populations below the action threshold, given average infestation pressure. In years in which infection is severe, complementary control measures may be required.

Resistant varieties are less prone to pest infestation

Resistant varieties are resistant to specific diseases and pests. Integrated Pest Management gives special priority to horizontal resistance, which should therefore be the focus of breeding for pest and disease resistance. This does not aim to achieve complete resistance, but it is not race-specific and therefore offers more stable resistance. Nor does it collapse as quickly as is the case with vertical, race-specific resistance, which fails when it comes up against new races (strains) of pathogens.

Resistance exists in three different forms:

- Chemical stimulants: the plants form substances that attract pests (attractants) or repel them (repellents);

[9] www.ecaf.org and www.fao.org/ag/ca

- Morphological properties: the plants develop forms that encourage or impede pest development. This includes properties such as leaf size, shape and colour, the presence or absence of secretory glands, and especially the toughness of leaf tissue and leaf hairs that impede insect mobility;
- Nutrient supply: the type of nutrients within a plant genotype hardly varies. However, the proportion of nutrients may fluctuate greatly depending on soil type and nutrient supply. That in turn may make a plant appear more or less suitable as a food source or a place to lay eggs for a specific pest.

Tolerant varieties prevent economic injury

While tolerant varieties have no direct influence on pest infestation, they may prevent economic injury through compensatory growth and due to their suitability for limiting plant injury and their tissue's additional resistance to mechanical stress.

Early or late-ripening varieties limit losses

The use of early-ripening or late-ripening varieties is a proven method for limiting loss due to pests without resorting to pesticides. Early-ripening varieties especially of rice, corn, peanuts and cotton have proven useful for shortening vulnerable growth phases and thus offering the shortest possible time for pest insects to develop. This deprives them of the opportunity to build up their population over several generations to a level that causes damage.

In cotton cultivation, for example, an early-ripening variety can largely prevent loss due to the cotton flower weevil *(Amorphoidea lata)*. The pest insect does not have enough time to reproduce over several generations to the extent where its infestation level exceeds the action threshold.

However, other examples are known in which the choice of late-ripening varieties means the crop plant's vulnerable phases no longer coincide with large pest populations.

Seed and planting technique influence the microclimate

The choice of **sowing or planting time** is one of the oldest pest control methods. Because the crop is sown or planted before or after a certain time, it is less exposed to pests during the plants' vulnerable growth stages.

Fertilisation fosters the plant's resistance

Soil cover and thus the microclimate in the crop can be influenced via crop density (spacing of seeds or plants). A closely planted crop with complete soil cover suppresses weeds, but may simultaneously create a favourable microclimate for the development of plant diseases. Here, the crop density has to be chosen to suppress the pest that can cause greater economic injury. In coffee cultivation, for instance, shade regulation and plant density (more ventilation) can be used as part of integrated pest control measures against coffee leaf rust.

Fertilisation can also be included under Integrated Pest Management. In most cases, the different supply of nutrients has an indirect influence on pest development because a plant's nutrient status determines its resistance.

Non-parasitic diseases are caused by a deficiency or surplus of specific nutrients. They are hard to diagnose because the same symptoms may have different causes. Once diagnosed, though, such diseases can be remedied by adding corrective doses of fertiliser.

Parasitic diseases caused by pathogenic organisms such as fungi, viruses and bacteria are much more common. The more specific a parasite is with regard to its nutrient requirements, the easier it is to impair its development by changing the nutrient combination in the host plant.

For example, we know that the excessive use of nitrogen encourages diseases, that potassium boosts resistance and that phosphorus neither encourages nor prevents disease. Pathogens that damage leaves find it easier to penetrate plant tissue that is rich in nitrogen and they develop faster. On the other hand, plants with a good nutrient supply can grow faster and thus escape damage from pests during a susceptible growth stage.

Pest development can also be influenced by changing the nutrient profile in the soil and thus in the plant. However, improving the plant's nutrient base can also lead to an increase in the number of pests.

Changing the pH value in the soil and adding specific nutrients shifts the ratio of weeds to crop plants in the latter's favour. Young corn plants, for example, are fairly weak competitors, i.e. early fertilisation with nitrogen mainly benefits weeds. Dense corn stands are strong competitors, though. Additional doses of nitrogen on grass surfaces give the grasses an advantage over broad-leaved weeds.

The harvesting time and harvesting method influence the development of the pest population

The **harvesting time** can be influenced on the one hand by the choice of cultivar (see above), but the degree of maturity of the ripe crop and the length of time it is left in the field also have an influence on pest development. The harvesting method also plays an important role.

It must be kept in mind whether a field is to be harvested in one go or step by step, depending on requirements and the ripeness of the crop to be harvested; whether and how many harvest residues should remain in the field, and whether the harvested crop is to be temporarily stored for work- or production-related reasons, e.g. for drying in the field. Such measures have a major influence on the survival of pest organisms in the field, and on pest infestation and resulting losses in the warehouse.

Insects, even if polyphagous (i.e. they can live on many different host plants), show preferences in their choice of host. They prefer one crop to another, e.g. due to a more favourable growth stage, better food conditions or suitable protection. This knowledge is used both to control pest insects and to encourage beneficial organisms.

Trap plants and border plants attract pests

Specifically selected **trap plants**, which are planted for instance in strips between rows of the main crop plants, attract pests. There they can either be handpicked, or the trap plants can be sprayed and the pests destroyed. It has proved useful, for instance, to plant one row of tobacco or corn after 15 rows of cotton to attract cotton bollworm *(Heliothis armigera)* to the corn or tobacco and to control them there.

Border planting, with a high-growing crop such as corn, is intended to trap wind-borne pests such as aphids at the field's edge. That means the main crop planted in the middle of the field, e.g. beans, is less exposed.

Trap planting and border planting call for good knowledge of ecological interactions and precise timing. They are only one component in a package of measures that have to be complemented by others to ensure sufficient success. Beyond this, trap plants sometimes offer lower economic crop value or a lower contribution margin than the main crop. The economic efficiency of such measures must therefore always be examined.

The various **forms of irrigation** may influence the occurrence of plant diseases. Water acts as a medium for spore germination, for transporting mobile spores and as a passive transport mechanism for pathogens during dripping.

Irrigation influences plant diseases and weeds

Pathogens can be divided into those that prefer a humid environment and those that prefer a dry microclimate for optimal growth. Water management is therefore an important factor for influencing the microclimate in the system. The more it is possible to manage water supply, the more effectively diseases can be prevented.

In tropical arid and semi-arid zones, irrigation makes it possible to grow crops outside the season without being infested with otherwise common plant diseases, e.g. potatoes without potato late blight *(Phytophthora infestans)*. On the other hand, there are leaf diseases that have become more prevalent since the introduction of sprinkler systems. From the Integrated Pest Management standpoint (and contrary to the recommendations of the irrigation industry), it therefore makes sense to irrigate cruciferous plants by means of sprinkler systems only in the morning so that the leaf surfaces can dry in a matter of a few hours to avoid leaf spot *(Alternaria sp.*). In such a case, greater priority must be given to plant protection or to irrigation, depending on the yield/cost ratio.

Flooding fields prior to sowing is a proven method for regulating pests and weeds. However, wet rice is the only crop for which this method can be used, because waterlogging can cause considerable damage to other crops after only two to three days.

Field hygiene measures: Harvest residues help pests to survive under unfavourable climate conditions. Well-known examples are the American bollworm in cotton *(Helicoverpa armigera, syn. Heliothis armigera)*, the Hessian fly in wheat *(Mayetiola destructor)* and the Asiatic rice borer in corn and rice *(Chilo suppresalis)*. The pest populations are significantly reduced by destroying harvest residues or ploughing them under.

Field hygiene reduces pest populations

Other pests survive on neighbouring plants or intermediate host plants. The sorghum midge *(Contarinia sorghicola),* for instance, lives through the winter in Johnson grass seeds. Cutting the grass on neighbouring land decimates the population of this midge, which can only fly short distances. In tobacco cultures, the young shoots that grow out of the soil after the harvest must be destroyed to reduce infestation by the tobacco hornworm *(Manduca sexta)* the following year.

Physical pest control measures are effective but time-consuming

3.2 Physical pest control measures

Mechanical and thermal measures are usually extremely effective but very labour-intensive and therefore time-consuming. In developing countries, they are a widespread control measure especially in traditional crops.

They include:

- hand-picking and destruction of pest insects or infected parts of plants;
- installing mechanical barriers to pests in the form of nets, ditches, fences, etc.;
- all types of traps;
- controlling weeds through hoeing, harrowing, hand-weeding and cutting;
- heat treatment of plant substrates (soil steaming, soil solarisation) and plant parts, and cold storage of sensitive crop products.

Women and children are often entrusted with mechanical measures such as hand-weeding, which makes little sense given that women could in many cases pursue more profitable activities and children would do better to spend their time at school. Here, ways should be sought to mechanise these methods or preference should be given to suitable methods in the given context.

The physical control measures further include the use of light, heat, sound, electromagnetic waves and radioactive rays. Burning and flame-weeding are mainly used to control weeds. No further mention will be made of these here, since they are special measures only.

3.3 Biological pest control measures

Biological control refers to the use of living organisms to reduce specific pest populations and weeds. The organisms used are either those that occur in the form of natural enemies, or individuals of a pest species are modified so that they damage members of their own species.

Major advantages of biological pest control

3.3.1 Advantages and disadvantages

A successful biological control measure has major advantages over chemical methods. It is:

- specific; the measure is usually directed at one particular pest; it has no direct negative influence on the population of beneficial organisms, the environment and users;
- it is compatible with other measures, even chemical methods, provided they act selectively or are used in a targeted manner;
- it has a permanent effect if beneficial organisms can be naturalised. It aims to stabilise the agroecosystem in the long term in favour of one or more crop plants;
- there are no residues on foods and no waiting times or waiting periods before the field can be entered again.

Biological control measures also have their disadvantages

The disadvantages of biological control are equally clear:

- It is complicated to use and calls for a high level of expertise; the introduction of beneficial organisms is subject to import and quarantine regulations;

- it is often difficult to naturalise beneficial organisms because they call for precise knowledge of ecological conditions;
- it does not show a directly visible effect; it calls for patience because the effect is only fully felt after a long time;
- it is much more expensive to begin with; it often calls for the cooperation or coordination of all farmers in a cultivation area.

Success is only visible in the reduced prevalence of pests.

3.3.2 Use and effect of beneficial organisms

The beneficial organisms used in biological control fall into four groups:

- pathogens;
- parasitoids (parasites);
- predators;
- phytophages (leaf-eating insects).

Pathogens

Pathogens of arthropods (such as insects, spiders and mites) include bacteria (e.g. *Bacillus* species), entomopathogenic fungi (e.g. genera such as *Beauveria* or *Metarhizium)*, viruses (e.g. *Baculoviridae)*, entomopathogenic nematodes (e.g. *Steinernema* and *Heterorhabditis)* and protozoa (e.g. microsporidia and gregarines). Pathogens exist latently in the ecosystem. Under suitable conditions, they spontaneously lead to a general outbreak of a disease (epizootic) in the pest population and its collapse. Epizootics usually only occur at a critical density of the pest population when the crop has already been damaged. If the pathogens are released inoculatively, the outbreak of such an epidemic can often be brought forward. Inoculative release involves the targeted release of small numbers of antagonists (starter populations) at intervals to allow them to reproduce and become effective before the pest population has become fully established. Success depends on good coordination of the antagonists' life cycle and biology with the target organism and on their being used in good time, often as a prophylactic measure.

Parasitoids

Parasitoids are insects that develop in or on the body of a host insect, ultimately leading to the host's death. They are usually specific to a given species and their population density directly depends on that of the host. However, their development is staggered, which means the rapidly growing pest population density already causes damage before the parasitoids can suppress the pest.

For biological pest control, parasitoids are either introduced from other regions and released after being modified and mass-produced, or the population densities of existing parasitoids are prematurely increased. Both methods call for substantial capacities for the necessary maintenance and mass breeding of the parasitoids.

Most parasitoids belong to the *Hymenoptera* genus in the families *Braconidae* (Braconid *wasps*), *Ichneumonidae* (Ichneumon wasps), *Trichogrammatidae* (Trichogramma wasps), *Chalcididae* wasps, *Encyrtidae* wasps, *Eulophidae* wasps and *Pteromalidae* wasps, *Aphidiidae* wasps and *Aphelinidae* wasps. Within the *Diptera* order (two-winged insects), the *Tachinidae* (tachinid flies) are parasitoids.

Predators

Predators destroy pests by hunting and eating them. They are not choosy about their prey and their mobility makes them effective even against low pest populations. Some predators feed intermittently on plants and may be killed by contact and ingested pesticides as well as systemic insecticides. The predators predominantly affected are mammals (such as hedgehogs), birds (e.g. tits), reptiles (e.g. snakes), amphibians (e.g. frogs), fish, snails, arachnids (e.g. predatory mites), insects and nematodes. Key predators among insects are *Hemiptera*, with the families of *Anthocoridae* (minute pirate bugs), *Miridae* (plant bugs), *Nabidae* (damsel bugs) and *Pentatomidae* (stink bugs), *Coleoptera* with the families *Carabidae* (ground beetles), *Staphylinidae* (rove beetles) and *Coccinellidae* (ladybugs), *Neuroptera* (net-winged insects) with the family *Chrysopidae* (green lacewings), *Diptera* including the *Cecidomyiidae* (gall midges) and *Syrphidae* (hover flies) and *Hymenoptera* with the families *Formicidae* (ants) and *Vespidae* (wasps).

Phytophages

Phytophages are organisms that feed on plants and seriously impede their development. Today it is mainly insects that are used to control weeds, whereas fish are used in bodies of water. In Australia, the caterpillar of the *Castoblastis cactorum* cactus moth was used to control the opuntia (prickly pear) which had become a menace. In rice plantations, puntius fish and various species of tilapia are used to control algae and weeds.[10]

3.3.3 Forms of application for the use of groups of beneficial organisms

Prerequisites for use of groups of beneficial organisms

The following three forms of application are customary for using groups of beneficial organisms: conservation and promotion, naturalisation and periodic release of beneficial organisms. Biological pest control is correspondingly broken down as follows:

- Conservation and promotion of naturally occurring beneficial organisms (antagonists; agroecosystem management, conservation biological control);
- Naturalisation of new species of beneficial species (classical biological pest control), naturalisation of more virulent species (neoclassical biological control);
- Periodic release of antagonists (curative and prophylactic treatment).

Agroecosystem management:

Functional biodiversity, i.e. the structure of the agroecosystem and the diversity, distribution and interaction of species, has a major influence on the stability of agricultural production. Conservation biological control is part of functional biodiversity. Sustainable agriculture will try to promote ecological infrastructures in a targeted manner to support the potential of beneficial organisms.

The benefits of biological pest control are often underestimated, as the following example shows: out of more than a million insect species, about one per cent are potential pests for our crop plants. Out of these, only one in 20 insects needs to be controlled. All the others stay below the economic threshold because of natural regulation processes. The antagonist potential that exists on the land used for agriculture is therefore a key production factor. It is important to conserve, promote and make optimal use of this factor. Incorrect use of production technology can severely disturb the balance between pests and beneficial organisms and entail costly countermeasures. Promotion of the antagonist potential must therefore start by op-

[10] FAO. Fish culture in rice fields. Chapter 5: Fish in rice fields as biological control of weeds, snails and mosquitos. www.fao.org/docrep/field/003/AC180E/AC180E05.htm

timising the use of pesticides. It must be guided by the rules of good professional practice and bear in mind the conditions for use stated in the instructions.

Classical biological control:

Naturalisation of natural enemies of the harmful organism

This involves introducing and naturalising antagonists to regulate alien (invasive) pest populations. Where there are no effective antagonists, pests can spread uncontrollably and cause substantial economic injury. Classical biological control attempts to introduce enemies that usually come from the countries of origin of the invasive species and have developed with the pest in a long co-evolutionary process, and to release them after mass production. One example of classical biological control is the San José scale *(Quadraspidiotus perniciosus)* inadvertently brought in from the USA to Germany in fruit-growing, which can be sustainably controlled by the parasitic wasp *Encarsia perniciosi*, which also comes from the USA.

Key measures within naturalisation programmes are:

1. the search for/procurement of beneficial organisms
2. the development/adjustment of breeding methods
3. the examination of host specificity
4. the examination of freedom from hyperparasites and pathogens
5. impact measurement after release.

Neoclassical biological control:

Making use of predator/prey relationships that have not developed over a long period of co-evolution often leads to highly positive results. These 'new relationships' are the basis for neoclassical biological control. New relationships may develop with or without human intervention. The latter occurred in Australia in 1953, when a millipede brought in from Portugal *(Ommatoiulus moreletii)* initially reproduced on a massive scale without control. A few years later, this population collapsed due to infection with the nematode *Rhabditis necromena*. The nematode lives in an indigenous millipede without harming its host. Following the death of the host, it reproduces massively on the host's body. In the pest that had inadvertently been brought into the country, the nematode develops higher virulence and kills the millipede that has not adapted to its presence. New relationships are only successful if the development cycles are synchronous.

Picture 6
Ladybirds and their larvae are used to control aphids
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Curative and prophylactic treatment:

Prophylactic treatment may take the form of the periodic release of antagonists in small populations. The targeted release (inoculative release) of small numbers of antagonists (starter populations) makes it possible to steer their population growth such that they are effective before the pest population has become fully established. Thus, host-specific cereal aphids can be distributed among small stands of cereal plants in the greenhouse. This poses no risk of infestation for the main crops grown in the greenhouse. Polyphagous aphid parasitoids or predators can be preventively settled on the cereal aphids. As soon as the aphids start to infest the greenhouse plants, beneficial organisms are already in place to decimate them.

The mass application of beneficial arthropods, in particular, can be used curatively to control pests by inundative release. The ratio of antagonists to pests is thus shifted artificially and rapidly in favour of the beneficial organisms. The technical progress achieved in the production, transportation and use of beneficial arthropods means that most large greenhouse cultures in Europe have no need for insecticides. One example is the use of *Encarsia formosa* (parasitic wasp) against whitefly *(Trialeurodes vaporariorum)*. Mass releases of arthropods such as the egg parasite *Trichogramma evanescens* are also used in field crops to control pests such as the European corn borer *(Ostrinia nubilalis)*. *Trichogramma spp*. are also applied in other crops worldwide on over a million hectares, especially against *Lepidoptera* (moths and butterflies).

When introducing a **biological control programme**, the steps below must be followed in the listed order. It is essential to:

1. determine the economic significance of the harmful organism;

2. examine and establish the taxonomy of the harmful organism (whether it has been brought in or is indigenous);
3. collect information about the harmful organism to be controlled;
4. determine existing natural enemies and their effectiveness;
5. analyse the conditions for naturalising a beneficial organism;
6. determine the factors that influence population density;
7. calculate the cost/benefit ratio of the planned biological control measure.

3.3.4 Biological pesticides (biopesticides)

Bacterial products

Many companies manufacture biopesticides from natural sources (animals, plants, microorganisms), sometimes on an industrial scale. Bacterial products are often used to control pests. The most important example is the spore-forming bacterium *Bacillus thuringiensis* (Bt), numerous sub-species of which are used to control the larvae of *Lepidoptera* (moths and butterflies), *Diptera* (two-winged insects) and *Coleoptera* (beetles). The bacterium's effect is based on toxin crystals that are formed during sporulation and are released together with the spores.

With commercially manufactured Bt products, the *Bacillus* spores are sprayed onto the leaves of the host plant and taken in orally by the larvae as they eat the leaves.

The crystals they ingest dissolve in the animals' stomachs. The toxin is then released and acts as a specific intestinal poison to destroy the intestinal epithelium. The bacteria can then develop and finally lead to the death of the insect after about five days. Bt products are applied in large volumes in practice. Recently there have been reports that these agents are becoming less effective against the problematic pest *Plutella xylostella* (diamondback or cabbage moth) in some countries. Experience to date shows that it is much more difficult for insects to develop resistance to Bt than to chemical products, but this cannot be entirely ruled out. This must be taken into account in connection with integrated pest management methods.

Virus products

Virus products are also commercially manufactured. They either consist of polyhedral or granulosis viruses, the two most frequent forms of virus that are named for the shape of their inclusion bodies.

These products are very host-specific and are mainly used against the cotton bollworm (*Heliothis* spp.) and various deltoid moth species. Unfortunately, these agents cannot compete in terms of price with the less expensive broadband insecticides and are therefore only used on a large scale in forestry and special crops. A granulosis virus is available as a highly effective biological product to control the major pest in pome fruit cultivation, the codling moth. The virus acts highly selectively and exclusively against the larvae of the codling moth, which are killed within about a week after oral ingestion. The virus does not exist in mammals, birds, fish and plants. Beneficial organisms are conserved.

However, pathogens cannot be used in stored product protection for reasons of food hygiene.

Naturally occurring plant ingredients may be used in Integrated Pest Management to protect against pests and diseases. In traditional pest management (e.g. in Africa), many herbs, shrubs and trees are used to prevent infestation by a specific pest. These substances are not considered as pesticides, but do increase plant resistance and are termed plant boosters. They are mainly used in organic pest management and are especially important in organic agriculture, although they are sometimes used by conventional farmers and gardeners too. Plant boosters are organic products such as plant extracts and essential oils. The natural ingredients can be produced at the farm itself, e.g. using plant-based pest control preparations, extracts and mixtures, but can also be purchased from commercial traders.

One example from GIZ's work is the use of neem, from a tree that is common in the tropics *(Azadirachta indica)*. Use of the natural active substance azadirachtin from the leaves and the oil of neem seeds has been supported in various countries to familiarise farmers with this active agent that occurs in nature. Today it is relatively widely used, also to protect stored products (see Section 3.6). Azadirachtin impedes moulting (skin shedding) in larvae and has a repellent effect on various insects.

3.4 Biotechnological methods

Biotechnological pest control takes advantage of natural reactions by pests to physical and chemical stimuli. So-called autocide methods and the use of growth regulators are also classed as biotechnological. Plant boosters, plant breeding and genetic engineering measures help to increase resistance. The following three subsections address these aspects in detail.

3.4.1 Physical and chemical stimuli and autocide methods

Physical stimuli may be acoustic, optical or thermal signals. Sticky traps or yellow, blue or white bowls filled with water may be used to monitor pest populations (thrips, fungus gnats, cabbage root flies, onion flies, whitefly, leaf miners, brassica pod midge and sawfly), and light traps can be used to monitor moth and butterfly populations.

Chemical stimuli include volatile signal substances such as pheromones, which influence the behaviour of a species, or allelochemical substances that influence the behaviour of an organism of a different species. Their effectiveness depends on a dual system of emitter and receptor of the semiochemical compound.

Pheromones are used for monitoring or direct control

Pheromones offer ways of controlling pests. A distinction is made between sexual, aggregation and dispersion pheromones. Sexual pheromones can be used for monitoring in attractant traps, or in the confusion method, may prevent male insects from finding their female sex partner. This method is used, for instance, against leafroller moths in wine- and apple-growing. Pheromones are released by dispensers that are installed in the plant stand. Aggregation hormones attract bark beetles to trees that are impregnated with insecticides, or to bark beetle traps, both of which help to keep populations below the economic threshold. Dispersion hormones are alarm or marking substances. The cherry fruit fly always lays one egg per cherry and marks it with a pheromone to prevent other members of the species from laying an egg in the same cherry.

Bait spraying instead of wide-area application of chemical pesticides

Allelochemicals are divided into kairomones, allomones and synomones. The first group is responsible for the recipient, the second for the emitter and the third for both. Kairomones include attractants as food signals and are used in trapping or as poisoned bait for controlling the western corn rootworm, beet cyst nematodes or fruit flies. Protein hydrolysate is used as a bait for the latter. The bait is mixed with an insecticide that kills the female before she can lay eggs. This makes it unnecessary to apply pesticides directly to the crop plants. Repellents play a key role in denaturing seeds, for example. Allomones are either repellents or phagodeterrents. Many substances of plant origin, such as essential oils, terpenoids or phenols, can be used as repellents. Examples are agents to prevent damage caused by game animals, seed treatment with denaturing agents to prevent damage by birds or to deter the European water vole. Phagodeterrents include azadirachtin from the neem tree *(Azadirachta indica)*. Synomones may be beneficial both to recipients and emitters, depending on the co-evolutionary adaptation of recipients and emitters of the signal. Mustard oil in many cruciferous plants has a repellent effect on harmful moth species. Adapted species such as the codling moth can eliminate these toxins and then use them as signal substances to find the host plant.

Attractants such as pheromones are customary in stored product protection as a means of monitoring beetles and moths. In this context, control approaches based on attractants have not proved effective in practice in most cases.

Autocide method: Here, female members of the wild population lay unfertilised eggs, due to the release of sterile or incompatible males. These methods are used against apple leaf-roller moths and the Mediterranean fruit fly, and are especially suitable for closed-off and isolated cultivation areas.

3.4.2 Growth inhibitors

Growth inhibitors disturb moulting or pupation

Growth and development inhibitors (sometimes called plant growth regulators, PGRs) are a relatively small group of active substances. They have to be taken up with food and disturb the moulting process or development into the adult animal. Since they do not have a broad effect and are of low toxicity for warm-blooded animals, they offer major ecological benefits. However, their high price means they are limited to intensive cultures. Neem, which we have already mentioned, inhibits moulting.

Agents are also available that influence plant growth. These include both natural plant hormones (phytohormones) and synthetic substances. They are used, for example, to increase stem strength in cereals by shortening stem length (stem shortening agents, or more accurately internode shortening agents), for improving root formation of seedlings, reducing plant height by compression in horticulture or preventing germination in potatoes. These are phytohormones or synthetic analogues.

3.4.3 Improving the resistance of crop plants

This section goes into both breeding for resistance and induced resistance.

Breeding for resistance

Cultivating crop plants that have acquired resistance through breeding is an important preventive measure, especially in cases where chemical pesticides are not allowed or cannot be used, e.g. against viral and bacterial diseases or in organic farming. Breeding for resistance is very successful, also in tropical crop plants.

The objectives vary depending on crop and region. Today, we find examples of multiple resistance to diseases and pests in a wide variety of cultivars, combined with corresponding yield and quality characteristics. Biochemical and molecular genetic methods have meanwhile become firmly established in order to complement conventional crossing and selection and to speed up the breeding process. The availability of resistant varieties in partner countries varies widely and should be taken into account when choosing which variety to grow. Using resistant varieties may substantially reduce the cost of pest management as well as the burden on the environment, users and consumers.

Induced resistance

The resistance of crop plants to pathogens and pests can also be enhanced by biotic and abiotic factors without genetic modification. In this case we speak of induced resistance. Viruses, fungi and bacteria are possible biotic resistance inducers. Pre-immunisation has been effected by the artificial inoculation of viruses to plants, for instance. This made plants resistant to secondary infection with phytopathogenic viruses. Induced resistance could also be obtained by primary infections with fungi, bacteria and extracts from plants, fungi and bacteria.

Many plant boosters serve to enhance the resistance of crop plants to fungal diseases, in particular. These agents can be taken from the *Manual of Biocontrol Agents.*[11]

3.4.4 Pest control through genetic engineering and biotechnology

The use of genetically modified organisms (GMOs) in agriculture has grown in importance in developing countries as well as in the USA and Canada over the last 20 years. The surface area of land cultivated with GM crops has grown to 185 million hectares around the world.[12] However, the situation varies widely from country to country. In many developing countries, as in Europe, the use of these organisms is a subject of very heated discussion.

Agricultural production with GMOs is taking place especially in Argentina, Brazil, China and India. The most important crops are pest-resistant cotton (North America, Asia and Africa) and herbicide-resistant soya beans (Latin America).

The development of GMOs has focused on breeding cotton, corn and rapeseed varieties with resistance to pests (especially by incorporating genes from *Bacillus thuringiensis* (Bt) to make use of its endotoxin). Further research into biofortification, e.g. enrichment with vitamin A in rice (carotenoid production) or for breeding bananas that contain vaccines against hepatitis, has not led to any significant use so far.

Key reasons for this limited commercial success are the high costs of seed material and other agricultural inputs, which makes cultivation in small-scale farming in developing countries less attractive. When weighing up the advantages and risks, the role played by genetically modified crop plants in reducing poverty is considered of secondary importance in the short term. In the short run, alternative methods such as conventional plant breeding, selection and Integrated Pest Management make a greater contribution to the urgently needed increase in productivity of smallholder farms. An exception is the cultivation of genetically modified cotton, which according to various studies has increased the income of Indian smallholders who engage in contract farming, and at the same time reduced the use of pesticides and with it the risks to humans and the environment.[13]

[11] www.bcpc.org/product/manual-of-biocontrol-agents-online (as at: 2 August 2017) or BCPC 2014. Manual of Biocontrol Agents. 5th edition. British Crop Production Council. Hampshire, UK

[12] Transparenz Gentechnik www.transgen.de based on data from ISAAA.org (as at: 10 August 2017)

[13] GIZ 2015. Briefing Note: Genetically modified organisms in agriculture

Even though GMOs have been used in agriculture for over 15 years now, the opportunities and risks that speak for or against their introduction are assessed very differently. The use of genetic engineering in agriculture attracts great public attention and opinions on the subject are divided. Genetic engineering has continued to develop rapidly in the past few years, though, and the CRISPR-CAS process is now a very efficient method for creating varieties that are resistant to drought or salt, which may be very interesting for farmers in this age of climate change, and also for organic farming.

The German Federal Ministry for Economic Cooperation and Development (BMZ) has issued a clear statement against the use of GMOs. In its frame of reference dated April 2016, it says that the use of genetically modified seed material will not be actively promoted in German technical cooperation projects, such as in the context of field demonstrations.[14]

The further sections of these guidelines advocate limiting the use of pesticides to the required level, or, in accordance with the FAO and WHO definition of Integrated Pest Management, to a level that is economically justified and that reduces or minimises risks to human health and/or the environment. This is also specified by Section 2 of the German Plant Protection Act for the use of chemical pesticides in the context of Integrated Pest Management.

3.5 Chemical pest control measures

This section starts by describing the use of pesticides (plant protection and pest control products) in partner countries. It is followed by Section 3.5.2 on international regulations for the use of pesticides and Sections 3.5.3 and 3.5.4 on statutory regulations on how to handle pesticides in the EU and partner countries. Section 3 is rounded off by sections on training in the application of pesticides, on GIZ's criteria for selecting pesticides (Sections 3.5.5 and 3.5.6) and on the quality of application equipment (Section 3.5.7).

3.5.1 Use of pesticides

The aim is to reduce the risks involved in using chemical pesticides

The term 'pesticide' is often used as a synonym for chemical plant protection products. This is in fact a simplification, since pesticides also include other agents such as biocides. This collective term covers all chemical and synthetic control agents that protect plants or plant products from animals, other plants, microorganisms or diseases. Agents that kill plants (herbicides), regulate growth or inhibit germination as well as biocides are grouped under the term pesticides.[15]

Biocides are pest control agents used in the non-agricultural sector. They are chemicals that destroy harmful organisms, repel them, render them harmless or prevent damage. Biocides are also important for curbing diseases such as malaria.

Chemical pesticides are toxic for their target organisms but not necessarily for other organisms. Their use in agriculture can nevertheless have a harmful effect on the environment and human health, either directly or indirectly, if they are not used correctly (e.g. lack of protective measures, too high a dose, incorrect disposal).

[14] BMZ: Referenzrahmen für Entwicklungspartnerschaften im Agrar- und Ernährungssektor (Frame of reference for development partnerships in the agricultural and food sector, German only) (as at: April 2016)

[15] Definition according to European Directive 2009/128/EG

The incorrect use of chemical pesticides in agriculture may lead to residues in food, and may damage and burden the ecosystem in the long term. Some pesticides may cause severe damage to the health both of users and consumers.

According to the World Health Organization (WHO), the incorrect use, storage and application of pesticides causes many cases of poisoning around the world each year, mainly affecting smallholders and children in developing countries.

The limited range of available chemical pesticides, uncontrolled sales and a lack of expertise and advice in developing countries often leads to incorrect application (e.g. use of unsuitable active substances, incorrect dosage, counterfeit products of low quality). In addition, the specified protective measures for handling hazardous pesticides are frequently ignored, partly due to a lack of awareness of their hazardous nature, or because there is no money to buy protective equipment or it is not locally available. Measures are often taken by workers themselves (e.g. in the cultivation of ornamental plants). Farms often fail to take any occupational safety or environmental protection measures, or these are inadequate.

Children in particular may be at risk during the entire life cycle of pesticides (from sales to transportation, storage, use and final disposal of surplus product and containers). Under no circumstances should children be made to apply pesticides, as is often the case. GIZ's advisory and training documents point out the special risk that pesticides pose to children, and recommend suitable protective measures.

The registration, storage and transportation of pesticides also pose problems in some developing countries. There are no systems for collecting and safely disposing of empty pesticide containers. Many developing countries are also faced with the problem of safely disposing of obsolete pesticides. The Food and Agriculture Organization of the United Nations (FAO), the GIZ and other organisations have contributed to reducing obsolete pesticide stocks in many countries by means of correct disposal and recycling.

3.5.2 International regulations on the use of pesticides

International regulations that are applicable worldwide

There are many international agreements (conventions) in addition to national statutory frameworks (see Section 3.5.3 below). To counteract the negative impacts of synthetic pesticides and some other hazardous materials, the United Nations created various internationally applicable instruments for handling these products, which have been accepted by all countries, the pesticide industry and NGOs.

These include the International Code of Conduct on Pesticide Management of FAO and WHO, the Rotterdam or PIC Convention, the Stockholm or POPs Convention, and the Montreal Protocol. The International Code of Conduct applies to the sale and application of pesticides (defining in particular the responsibility of governmental agencies and the pesticide industry). The Rotterdam Convention regulates trade with hazardous chemicals and pesticides, the Stockholm Convention the handling of persistent organochlorine pesticides, and the Montreal Protocol concerns chemicals that deplete the ozone layer, such as methyl bromide. These three conventions have been implemented into national law by all industrialised and many developing countries. In this context, mention should also be made of the Basel Convention,[16] which reg-

[16] www.basel.int

ulates the control of transboundary movements of hazardous wastes and their disposal, and therefore plays a role when it comes to the disposal of pesticides and surplus pesticides.

Quarantine for the protection of plant genetic resources against pests and the prevention of the spread of pests through international trade is governed by the International Plant Protection Convention.[17].

3.5.3 Statutory regulation on pesticides in the EU

Pesticides are generally subject to authorisation in all countries. In Germany, this comes under the responsibility of the Federal Office of Consumer Protection and Food Safety (BVL). This Office cooperates with three assessment authorities: the German Federal Institute for Risk Assessment (BfR), the Julius Kühn Institute (JKI) and the German Federal Environment Agency (UBA).

The authorisation of pesticides in the EU is governed by EU Regulation (EC) No 1107/2009 (Plant Protection Products Regulation) and involves a two-tier process. While the active substances are approved at EU level, the member states themselves decide on the authorisation of pesticide products that consist of one or more active substances plus adjuvants. Approval of the active substance at community level is therefore the prerequisite for the zonal authorisation of pesticides.[18]

Since authorisations are granted based on applications, the requirements to be met by the documents submitted for examination are very high, and applications therefore entail high costs for the companies concerned, companies are guided by the market potential in the EU. The range of authorised products is therefore tailored to crops of high economic importance in the EU.

EU authorisations of pesticides for crops in tropical regions are rare. If a product is not authorised for use in the EU, this does not automatically mean it is hazardous and unsuitable for use in partner countries. But neither does authorisation in Europe mean that a pesticide can automatically be used safely under the conditions that prevail in developing countries.

GIZ's guidelines on the procurement of plant protection and pest control agents, biocides and other agricultural chemicals therefore follow the classifications of national, regional and international specialist organisations and corresponding legislation. The International Code of Conduct[19] on the Distribution and Use of Pesticides is of special importance.

The two-tier authorisation process in the EU also applies to biological pesticides (biopesticides). Some of these products are also examined in line with different requirements and criteria.[20] The (risk) assessment of such biopesticides and their registration or authorisation for trade may be especially difficult and time-consuming due to a lack of experience on the

[17] www.ippc.int (FAO)

[18] Representative assessment of the pesticides by a member state in one of the zones (South, Centre, North), followed by a shorter procedure in the zone itself, i.e. mutual recognition, and across zones (e.g. for use in greenhouses or for the treatment of seed material).

[19] International Code of Conduct on the Distribution and Use of Pesticides (last revised in 2013), FAO (see also Section 3.5.2)

[20] The same requirements as for chemical pesticides apply to plant extracts and pheromones. Different requirements (often much less extensive) apply to microorganisms. Beneficial organisms come under national legislation in some EU member states, not under EU Directive 91/414/EEC.

part of registration authorities. The Organisation for Economic Co-operation and Development (OECD) supports the governments of its member states in this process.[21]

3.5.4 Statutory regulation on pesticides in partner countries

Pesticides are substances that may pose considerable risks to health and the environment if incorrectly used, owing to their hazardous properties. Their use, storage and final disposal are therefore regulated by national or regional authorisation rules and by international conventions, agreements and instruments. The national governments bear overall responsibility for complying with these rules, although manufacturers, distributors and users of pesticides also bear a share of this responsibility.

Conditions for authorisation of pesticides promote the safety of users and consumers

The registration of pesticides in developing countries is a key step towards orderly pesticide management. It is important that this process is transparent and that safety standards designed to protect human health and the environment are also complied with for pesticides that have already been authorised.

The authorisation processes in some developing countries tend to be superficial or they do not implement international conventions because authorisation is complex, time-consuming and costly. Since there are substantial gaps in the implementation of statutory regulations in many countries, GIZ bears special responsibility when it comes to procuring and applying pesticides and other critical agrochemicals in the context of its projects.

Pesticides legislation – the basis for effective pest management

National plant protection legislation forms the basis for all the measures of a national authority. These include quarantine regulations; the authorisation of pesticides and application equipment; quality control (formulation control) of pesticides; control of residues in foods and the environment; the granting of licences and trade oversight; training on how to use pesticides (proof of specialist qualifications); the disposal of surplus pesticide and empty containers, and the registration of cases of poisoning.

Quarantine regulations aim to prevent or curb the spread of pests both within a country and to stop them from being brought in across borders. The bringing in of new pests to an area must be prevented in order to protect the crops grown there. This is done by strictly regulating the importation or transportation of plants and plant parts that may be infected with pests or pathogens.

National plant protection legislation must bear in mind the economic, ecological and social aspects involved in carrying out plant protection measures.

Authorisations for pesticides are only granted once it has been examined and proved that the product:

- is effective with regard to the target organism and protects plants or plant products;
- does not contravene the requirements related to protecting human and animal health and the environment during distribution and trading;
- does not have any harmful effects on human and animal health and the environment if used correctly according to the regulations, and does not have any other harmful impacts.

[21] www.oecd.org/chemicalsafety/pesticides-biocides/biological-pesticides.htm

The products are authorised by an independent government authority for a limited period following corresponding examination by national and/or international institutions. Together with the authorisation, the manufacturer or distributor should be required to comply with specific conditions related to distribution, application and final disposal.

In many highly regulated countries, such as in the EU, the precautionary principle is recommended. This questions authorisation of a pesticide product if the scientific community is not sure whether it poses a risk to human and animal health and the environment.

The authorisation can be restricted to use in specific crops (indication), certain times of the year or a specific group of users, such as governmental plant protection services. A key criterion for the selection of insecticides is whether they are tolerated by bees.

Monitoring pesticide formulations ensures product quality

The inadequate quality of pesticides is a problem that mainly affects developing countries. Side-effects of pesticides often pose a much greater threat if they are contaminated or the concentration of their active substances does not comply with regulations. Hence the need for governmental bodies to continuously examine pesticide quality.

Manufacturers and traders are required to stop sales of their product in the event of problems and/or take it off the market.

Residue monitoring protects consumers

Food consumers may be at risk if the food contains excessive pesticide residues, which may occur particularly if waiting periods are not observed and/or excessive dosages are applied. Constant monitoring of residues in foods, mainly in domestically produced and imported fresh fruit and vegetables, helps to recognise such risks in time. The results of this residue monitoring must be published.

Food safety can only be improved if knowledge and insights about residues are integrated into the production process, e.g. translated into extension services and passed on to farmers, or if other methods are developed for storage and processing. Extension work in developing countries often comes up against the problem that users are illiterate, and that extension material and instructions for the use of pesticides are not available in local languages. Tangible sanctions must be imposed on those who are responsible for residues.

To reduce risks during the distribution and storage of pesticides, only licenced traders should be allowed to store and sell them. The granting of a licence entails specific conditions regarding both the trader's qualifications (e.g. proof of specialist qualifications) and how the warehouse and sales premises are equipped. Pesticides should not be stored together with foods, for instance, and should only be sold in rooms or cupboards that can be locked, and only sold to adults. Toxic pesticides must be stored separately in special cabinets. Packaging and labelling must comply with regulations. Only authorised pesticides may be sold. Licences may be revoked in the event of gross infringement.

Mandatory labelling of hazardous products

Labelling is mandatory for all pesticides to classify the hazards they represent. Depending on the hazardous nature of the product, specific hazard symbols must be used, in line with the FAO/WHO Code of Conduct and the Globally Harmonized System of Classification and Labelling of Chemicals (GHS).[22]Special care should be taken to include pictograms in line with the GHS system.

Disposal of surplus pesticides and/or their packaging is becoming an ever more serious problem in some countries. In some, voluntary programmes were introduced years ago to dispose of surplus pesticides and their containers, see also the FAO/WHO Guidelines on Management Options for Empty Pesticide Containers.[23]

Many developing countries now have pesticide authorisation processes and a corresponding authority. This is usually attached to the ministry of agriculture, but may also be part of the ministry of health or the environment. Owing to a lack of resources, these governmental bodies are often hard pushed to deal with the tasks entrusted to them, such as the evaluation of registration documents, monitoring processes and the monitoring or implementation of international conventions. Project officers therefore have a special responsibility when it comes to procuring, handling and applying pesticides.

3.5.5 Training on how to handle pesticides

Training to handle pesticides calls for expertise and further training/education

In many industrialised countries, the expertise required to train people who handle pesticides is formal and legally prescribed. Regulations on expertise have been standardised in the EU. Directive 2009/128/EC specifies that member states shall ensure that all professional users, distributors and advisors have access to appropriate training by bodies designated by the competent authorities. [24] This shall consist of both initial and additional training to acquire and update knowledge as appropriate. The training shall be designed to ensure that such users, distributors and advisors acquire sufficient knowledge regarding the subjects listed in Annex I, taking account of their different roles and responsibilities.

Training subjects referred to in Article 5 Annex I include:

1. All relevant legislation regarding pesticides and their use.
2. The existence and risks of illegal (counterfeit) plant protection products, and the methods to identify such products.
3. The hazards and risks associated with pesticides, and how to identify and control them, in particular:
   - risks to humans (operators, residents, bystanders, people entering treated areas and those handling or eating treated items) and how factors such as smoking exacerbate these risks;
   - symptoms of pesticide poisoning and first-aid measures;
   - risks to non-target plants, beneficial insects, wildlife, biological diversity and the environment in general;
4. Notions on integrated pest management strategies and techniques, integrated crop management strategies and techniques, organic farming principles, biological pest control methods, information on the general principles and crop- or sector-specific guidelines on Integrated Pest Management.

[22] www.ghs-label.com

[23] www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/Containers08.pdf

[24] 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, Article 5

5. Initiation to comparative assessment at user level to help professional users make the most appropriate choices on pesticides with the least side effects on human health, non-target organisms and the environment among all authorised products for a given pest problem, in a given situation.
6. Measures to minimise risks to humans, non-target organisms and the environment: safe working practices for storing, handling and mixing pesticides, and disposing of empty packaging, other contaminated materials and surplus pesticides; recommended way to control operator exposure (personal protection equipment).
7. Risk-based approaches which take into account the local water extraction variables such as climate, soil and crop types, and the terrain.
8. Procedures for preparing pesticide application equipment for work, including its calibration, and for its operation with minimum risks to the user, other humans, non-target animal and plant species, biodiversity and the environment, including water resources.
9. Use of pesticide application equipment and its maintenance, and specific spraying techniques (e.g. low-volume spraying and low-drift nozzles), as well as the objectives of the technical check of sprayers in use and ways to improve spray quality. Specific risks linked to use of handheld pesticide application equipment or knapsack sprayers and the relevant risk management measures.
10. Emergency action to protect human health, the environment including water resources in case of accidental spillage and contamination and extreme weather events that would result in pesticide leaching risks.
11. Special care in protected areas.
12. Health monitoring and access facilities to report on any incidents or suspected incidents.
13. Record keeping of any use of pesticides, in accordance with the relevant legislation.

In Germany, for example, this Directive is implemented in the Plant Protection Act (PflSchG) of 6 February 2012 in conjunction with the Ordinance Governing Specialist Qualifications in Plant Protection of 27 June 2013.

Section 9 of the Plant Protection Act describes the personal requirements to be met by users and distributors of pesticides and by pest management advisors. Accordingly, only these persons may

- apply pesticides;
- give advice on pest management and the use of pesticides as part of their work or as a commercial service;
- give instruction to or supervise persons who use pesticides during training or auxiliary work;
- be professionally engaged in marketing pesticides;
- market pesticides via the internet also outside their professional activities if they have proof of specialist qualifications issued by a responsible authority.

People with specialist qualifications are further obliged to take part in a further training measure recognised by a responsible authority within a period of three years from the first issuance of proof of specialist qualifications. Such training courses[25] and regulations might also provide useful guidance for developing countries, after being adapted to local circumstances.

[25] Processes and their content have been standardised in Germany and are subject to quality control.

GIZ's binding requirements for the procurement of pesticides

3.5.6 General criteria at GIZ concerning the choice of pesticide

The following Integrated Pest Management principles apply at GIZ:

- The use of pesticides is minimised;
- Where pesticides are used, they are applied to control specific pests, in a specific situation and at the lowest possible risk;
- The active substances used are classified in terms of their hazard class and risks are assessed under the conditions in the partner country;
- The selected products are used correctly and in accordance with the regulations;
- Surplus pesticides and empty pesticide packaging are used up and disposed of in a correct manner.

Procedure for selecting pesticides

This results in a three-part procedure with corresponding questions and recommendations for action in order to meet the requirements of IPM and to minimise the risks involved in handling pesticides in partner countries:

1. Is the use of pesticides necessary in the IPM context, or are there alternatives, especially non-chemical methods?
2. Which pesticide involves the lowest risk, given compliance with the instructions for use, in terms of:
   - no unacceptable health risks;
   - environmental pollution (water, soil, air contamination);
   - beneficial organisms and/or other insects, e.g. bees;
   - handling pesticides (which application method or which treatment; e.g. staining, can minimise contact with pesticides);
   - no unacceptable residues in the harvested crop;
   - does the pathogen or pest develop resistance at maximum effectiveness against the pest or pathogen?
3. Application is carried out correctly and in line with regulations according to the label, in the given concentration, i.e. in accordance with the applications tested in the authorisation process and wearing protective clothing, bearing in mind the recommended protective measures. Correct disposal of pesticide containers and cleaning of the application equipment are an obligatory part of each application.

When selecting the pesticides, other criteria must be borne in mind apart from GIZ's procurement guidelines; the pesticide must always be authorised/registered in the relevant country:

- Pesticides that cannot be procured are active substances that are included in the Stockholm Convention, the Rotterdam Convention or the Montreal Protocol, formulations that are classed by WHO as extremely hazardous (Class Ia) or highly hazardous (Class Ib) or substances that have been classified as carcinogenic, mutagenic and/or reprotoxic by the Globally Harmonised System (GHS carc/muta/repro Class 1 and 2). Relevant substances are the insecticides DDT, lindane, endosulfan, methamidophos, methyl parathion, monocrotophos, methyl bromide and others. The procurement of pesticides with active substances that have been proposed for inclusion in the Stockholm Convention is also ruled out. The list of active substances is continuously updated.
- Pesticides whose active substances are listed in the following documents may only be procured in exceptional cases and require detailed examination and justification in each individual case: Notification List, Annex 3 of the Rotterdam Convention; classed as highly

hazardous in the Pesticide Action Network (PAN) International List of Highly Hazardous Pesticides, and included in the European Union list of unauthorised substances in Regulation (EC) No 1107/2009.

- Products that are classed as moderately hazardous by WHO (WHO Hazard Class II) and GHS Class 3 may be applied by trained users only, given strict compliance with protective measures (occupational and user safety).

Pesticides that have been authorised by the EU (EC No.), are classed as slightly hazardous (WHO Hazard Class III) or as unlikely to present an acute hazard in normal use (WHO Table 5), and which do not conflict with other classifications, may be used where consideration is given to correct handling in line with the relevant material data sheets and labelling.

3.5.7 Quality of application equipment

Insist on certificates for application equipment

Conforming to quality and safety standards when using pesticide application equipment is part of correct pest management in accordance with the regulations as defined by IPM. It is important to stick to the precise dose, to prevent spray drift and other factors in order to achieve the expected result with the pesticide and to minimise side-effects. This includes risk reduction when filling and subsequently cleaning the equipment. In many countries, regular technical inspection of the equipment is legally prescribed. This is done at regular intervals to examine whether the equipment meets quality and safety standards. In Germany, such inspections are performed every three years.[26] Such regulations are not in place in many developing countries. Some have voluntary processes, or in-company certification that guarantees a certain standard of quality.

Bear in mind technical inspection procedures for application equipment

Ensuring the quality and correct functioning of the application equipment, especially of the nozzles, is a basic condition for each application of pesticides. It must be ensured whether the type of application equipment has been tested somewhere and whether a corresponding certificate is available for the equipment, together with a test report. International test procedures exist for knapsack sprayers, which are used in many countries and for many different crops.[27]These procedures help to examine equipment before use.

Aerial spraying of pesticides is prohibited in the EU or calls for strictly controlled exceptional authorisations (Article 9, 2009/128/EC).

3.6 Special features with regard to stored product protection

Other conditions apply in stored product protection

Different conditions sometimes apply to stored product protection than to pest management, since the former aims to prevent loss of plant products that have already been harvested. First, it should be borne in mind that stored product protection ranks after agricultural production in the value chain, and that different criteria therefore apply with regard to the economic threshold. In extreme cases, tolerance to pests may drop to zero, for example if a large warehouse is infested by beetles that damage stores and spread rapidly if countermeasures are not taken immediately.

[26] Bavarian State Research Center for Agriculture (LfL) www.lfl.bayern.de (as at: May 2017)

[27] www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/Old_guidelines/Vol1_Agri_application.pdf

Methods that apply to specific crops and cultivation systems obviously do not apply to stored product protection. Plant breeding measures are theoretically conceivable. However, tolerance to storage pests is not currently a priority breeding target for the relevant crop plants.

Biological and chemical products are used to protect stored products

Preventive measures can be divided into mechanical and physical methods in the wider sense. This includes prevention by construction measures, i.e. building warehouses that are as insect-proof as possible. Small and tightly closing metal silos offer good conditions for long-term storage on farms, provided the stored product is dry enough and the silos are protected from direct sunlight to avoid condensation and subsequent spoiling due to mould fungi. Metal sheeting on the piers on which many farm stores are built may deter rodents.

Another key preventive aspect is storage hygiene, i.e. orderliness and cleanliness. The basic principle is to offer no hiding places for storage pests, as far as possible (rats like to hide in piles of junk, for instance) and not to leave any cereal grains or other products lying around that might attract storage pests and provide them with food. Warehouses are often empty before the new harvest is brought in, or only contain small surpluses of stored goods. It is advisable to use or remove these products, which may be partly spoiled or infested, and to clean the empty warehouse completely and thoroughly (disinfect it) so that the new harvest can be brought into a warehouse that is free from pests and diseases.

Hermetic storage of cereals or grain legumes has become more important in recent years. It is used both in warehouses and in small stores in particular. Traditional containers and the new foil sacks that are now available can be used for this purpose. These multilayer bags can be made on site at relatively low cost, which has made them much more popular than previous systems. Storage in these bags is designed to absorb the oxygen they contain so that any pests in them gradually die.

Taken together, these measures for the prevention, early detection and control of organisms that are harmful to stores (three pillars) are termed 'integrated stored product protection'. Corresponding guidelines need to be drawn up and followed.

At farm level, biological methods have proved effective for controlling the larger grain borer *(Prostephanus truncatus)* using the predator *Teretriosoma nigrescens* in West and East Africa. This beneficial insect from Central America has become sustainably established in Africa and helps to keep losses caused by the larger grain borer in stored corn cobs and manioc chips to comparatively low levels. Large warehouses offer less suitable living conditions for beneficial organisms such as egg or larvae parasitoids, which need to be continuously reintroduced. Little use is made of this practice owing to the effort involved and the relatively gentle action of the beneficial organisms.

Attractants are mainly used to monitor pests in stored product protection. Pheromone traps in large warehouses offer an ongoing overview of the development of pest populations so that countermeasures can be taken in time when their levels start to rise. Methods that reduce pest populations (confusion method, attractants for laying eggs) have not yet become widespread, although their broader use would be desirable.

Repellents, substances that deter pests, are the opposite option. In farming practice, such repellents, which are mainly based on active plant substances, are traditionally used quite often because some of them are very effective. As long as these substances do not impair the stored goods (which may be possible when added to chili, for instance), these practices would appear perfectly acceptable.

There are also a variety of plant ingredients with an insecticide effect, such as products based on neem. Their use has been propagated in many projects and they have meanwhile become quite widespread. In some cases, for example the treatment of grain legumes with neem oil, the stored goods need to be specially cleaned before cooking, e.g. washed several times.

Chemical products for stored product protection have become well accepted also on farms due to their good effectiveness, but they pose special risks. In stored product protection, a distinction must be made between two groups of products that call for completely different application techniques: fumigants and various formulations of contact insecticides.

Following the abandonment of methyl bromide, the only fumigants that are relevant to GIZ projects are preparations used to produce phosphor hydrogen (aluminium or magnesium phosphide). It must be stated quite clearly that these products have a very high hazard potential for users and uninvolved third parties owing to their extremely high acute toxicity and excellent penetration properties. They should only be used by trained and licenced users, never by untrained farmers or workers. Fumigation may be necessary in large cereal warehouses (e.g. silos) or in containers designed for export (e.g. on cocoa), but never on farms. Unfortunately, though, in many countries fumigants are sold in the form of pellets to just anyone. This leads to a multitude of health risks and incorrect forms of treatment, which among other things also helps pests to develop resistance to them. There is a need for much more advice and regulation at all levels in this area.

Contact insecticides for stored product protection are available as sprays, foggers and powders. The greatest risk their application entails is that excessive quantities of the active substance are applied to the treated product due to dosing errors. This leads to maximum values being overstepped and poses a risk to consumer health. These products for stored product protection are also used to treat storage rooms (surfaces and air) or used on plant products themselves. The maximum dose used is often close to the recommended or legally stipulated maximum residue levels. Such products cannot be unreservedly recommended owing to the fact that their correct application is usually impossible to ensure. They should only be applied by well-trained users. It is absolutely recommended to give preference to one of the alternatives listed above.

4 Pest management in organic land use systems

'Organic Agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.'.[28]

Typical features of this production system are therefore:

- Strict limitations on applications of chemical and synthetic pesticides, herbicides and synthetic mineral fertilisers and on the use of antibiotics, hormones, feed additives, processing aids (used to process the agricultural inputs listed below, among others);
- Absolute ban on the use of genetically modified organisms (GMOs);
- Crop rotation with wide spaces between crops as the condition for the efficient use of a location; use of locally available resources, such as animal manure and feed produced by the farm itself;
- Specific choice of plant and animal species that are disease-resistant and adapted to the local conditions;
- Animal husbandry systems that give animals outdoor access, free range and the use of organic feed;
- Animal husbandry practices that promote animal welfare.

As a system approach to sustainable agriculture, organic farming aims to effectively manage ecological processes whilst lowering dependence on off-farm inputs. Plant health in organic production is managed mainly by preventive and indirect measures internal to the agroecosystem.[29] In this respect, organic farming plays a very important role as a pioneer in the development and the introduction of preventive measures and biocontrol solutions for plant health care.

Millions of farmers in developing countries, often on marginal land with no or minimal external agricultural inputs and high labour intensity, frequently produce their goods in a comparable way to certified organic agriculture (*'organic by default'*). The differences between organic and conventional farming that are typical of industrialised countries do not always apply in Africa, for instance, where low numbers of animals per surface area, high labour intensity, low yield per hectare and similar volumes of milk and meat to those produced on organic farms are the norm.

Whereas organic production and markets in Africa are still rudimentary, as shown by the African Organic Network (AfrONet)[30], these are relatively developed in some Asian countries such as India. These are aligned with international standards[31] and are engaged in developing traditional farming methods using biodynamic farming concepts.

[28] IFOAM 2009. www.ifoam.bio (Definition of organic agriculture)

[29] IFOAM 2016. Plant Health Care in Organic Farming. Position paper.

[30] afronet.bio; FAO 2013. Organic Agriculture: African Experiences in Resilience and sustainability

[31] Organic Farming Association of India (OFAI.org) hosted the IFOAM World Organic Congress 2017; Bio-Dynamic Association of India (BDAI) aims for Demeter certification (www.biodynamics.in)

5 Accompanying measures for the introduction of IPM

In order to be able to deploy the described integrated pest management tools to maximum advantage, partner countries need to not only install and make use of monitoring systems but also to take account of international and national regulations, commercial requirements and climate change. These aspects are dealt with in the sections below.

5.1 Monitoring systems

IPM requires ongoing supervision and monitoring

Field-based monitoring systems deliver the information that is required in order to be able to use integrated pest management tools properly. To this end, the degree or frequency of infestation must be calculated, i.e. the existing pathogens, pests and beneficial organisms need to be counted and placed in relation to one another or symptoms of disease need to be considered in relation to the leaf surface so as to be able to estimate potential damage.

In the pest monitoring process, quantification of pests is systematised so that numbers can be compared. Data relating to time and place are compiled and evaluated.

Such pest monitoring systems pursue two objectives:

Objectives and methods of monitoring systems

- The short-term objective of reaching a decision on whether spraying a particular field at a given point in time is economically beneficial or not;
- The long-term objective of establishing a reliable information base by compiling and evaluating agronomic, economic and infestation data in many different fields over longer periods of time which may subsequently be used as a basis on which to develop or adapt pest management strategies.

The approach adopted depends on the objective. Repeated attempts to achieve both objectives using the same survey methods have not achieved the desired success as the requirements in terms of the data differ too much. The most significant differences are:

- the number of field surveys and their chronology;
- the number of observations made per unit of area;
- the quality and quantity of data to be collected;
- the availability of the evaluation.

While farmers ideally achieve the short-term objective either alone or as part of a group, e.g. through the introduction of the participatory Farmer Field School approach (FFS), trained and responsible technicians and extension officers are required for the long-term objective. Such monitoring systems cannot be implemented and evaluated by individual farms but, as a general rule, only by institutions such as a plant protection service or extension service, or by co-operatives for example.

Pesticide resistance is becoming commonplace nowadays

In addition, it is important to stay informed about local problems regarding the use of pesticides, e.g. potential resistance of certain groups of substances to insects or pathogens. For the main pesticides, such as insecticides (substances used against insects), fungicides (against fungi) and herbicides (against wild plants/weeds), there are scientific bodies which publish the relevant data, namely the Insecticide Resistance Action Committee (IRAC),[32] the Fun-

[32] www.irac-online.org

gicide Action Resistance Committee (FRAC)[33] and the Herbicide Resistance Action Committee (HRAC).[34] Government and/or parastatal agencies collect data on cases of poisoning involving certain pesticides; in Germany, for example, these are the Poison Centres (PC), or the Poison Control Centers (PCC) in the USA.[35]

Overall, these monitoring systems provide information regarding the local situation in terms of pests and diseases as well as possible problem areas in the use of/handling of pesticides.

5.2 International and national regulations

Compliance with international regulations is a must.

Nowadays, adherence to quality standards in food production is an important criterion for the buyer/consumer. At the international level, the standards of the Codex Alimentarius serve as a reference point,[36] and basically ensure that food is safe and can be traded. Codex maximum levels are the benchmark values for the World Trade Organization (WTO). Industrialised countries have national food standards, including maximum residue limits for pesticide residues, for a variety of reasons; in many cases developing countries adopt the figures set out under the Codex Alimentarius. Compliance with these maximum levels and limits is monitored in particular in industrialised countries, while the practice remains relatively scarce in developing countries. It is important that data are published and are available for use as part of extension measures, consumer protection measures, etc.

There are two international conventions which list pesticides that preferably should not be used; first, the Rotterdam Convention,[37] the so-called Prior Informed Consent (PIC) procedure. This Convention administers the import and export of certain hazardous chemicals. Under Annex III, it places obligations on companies wishing to export these chemicals. It aims to promote shared responsibility and cooperation in the international trade of hazardous chemicals, and to protect human health and the environment by providing developing countries with information on how to store, transport, use and dispose of hazardous chemicals safely. The PIC Regulation applies to banned or severely restricted chemicals in the EU, containing pesticides and biocides, for example, atrazine and permethrin. The Stockholm Convention, otherwise known as the POPs Convention,[38] is the other treaty which restricts or prohibits the manufacture and use of nine pesticides.[39] These substances are organochlorine compounds that are persistent and toxic, accumulate in the environment and are transported over large distances. They are termed the 'Dirty Dozen'. To date, these conventions have been ratified by roughly 180 countries.

Both the EU and USA publish annual reports on the monitoring of pesticide residues found in agricultural products which have either been imported to or manufactured in the EU/USA. When interpreting this data, the national legal framework should always be taken into consideration; e.g. in the USA, excess limits are punished if the pesticide is not authorised there. This procedure always poses a problem for crops that are not grown in the USA, such as tea

[33] www.frac.info
[34] www.hracglobal.com
[35] www.aapcc.org
[36] www.fao.org/fao-who-codexalimentarius/en
[37] www.pic.int (UNEP and FAO)
[38] chm.pops.int (UNEP)
[39] Aldrin, Chlordan, DDT, Dieldrin, Endrin, Heptachlor, Hexachlorbenzol, Mirex, Toxaphen

or coffee. However, the data do give an indication of which crops could easily contain residues and, consequently, where particular attention is therefore required when using pesticides.[40]

5.3 Requirements of the formal market

Voluntary standards are an important tool

For a number of years now, major supermarket chains in several industrial countries have demanded that products comply with the company's own standards, so-called voluntary standards.[41] In so doing, they are trying to satisfy consumer wishes for greater transparency and knowledge regarding the production of foodstuffs. Providing information about a product's actual origin and how it was made have become part of marketing strategies. While this includes agricultural practices, social and hygiene measures, close attention is paid in particular to chemical pest management and IPM is required in principle. Producers and/or collectives that are focused on exports grow food in accordance with these standards. The standards are part of sales strategies and often do not have any scientific foundation. Complying with these standards requires producers to adopt innovative approaches. As part of the compliance process, the entire chain of production is assessed (from production, harvest, storage, processing and transportation, through to sale). In this respect, these standards may lead to new procedures and techniques that might also be of interest to other producers (where applicable for local markets) as well as to providers of extension services.

5.4 Climate change and pest management

Pests and disease infestation increase as a result of climate change and higher temperatures

The changes to the climate that have occurred in recent years are having an impact on agriculture and thus on pest management as well. Where there is sufficient availability of water, higher temperatures stimulate not only plant growth but also the development of certain pests and diseases. This applies to both temperate and tropical climates. In addition, extreme weather conditions such as prolonged dry spells or more intense rainfall make plants more vulnerable. The rate of infestation can increase, with more generations of aphid developing for instance, leading to an increase in their number. Furthermore, the length of time that systemic fungicides and herbicides remain effective can decrease. As temperatures increase, so too does the rate of degradation of these pesticides. More rapid plant growth can alter the microclimate within a crop and require sowing intervals to be adjusted. The range of weeds may also change as a result of different climate conditions.

All of these factors increase even more the importance attached to monitoring of the ecosystem, plant populations, the environment as well as pest management measures and the weather. Monitoring data need to be compiled and evaluated so as to be able to adapt the content of extension services accordingly. Plant breeding too faces additional demands in order to be able to develop varieties that can survive prolonged spells of dry weather. Farmers should grow species or varieties of crop that are better adapted to conditions such as longer dry periods, where these are available. Even if they are not resistant to or tolerant of certain pests, they will nevertheless be more resilient than plants that are stressed and weakened by (extreme) environmental conditions.

[40] www.fda.gov/Food/FoodborneIllnessContaminants/Pesticides/ucm2006797.htm (USFDA)

[41] www.fao.org/food/food-safety-quality/capacity-development/standards/en

6 Objectives of GIZ in relation to Integrated Pest Management

The position of GIZ in relation to Integrated Pest Management is as follows:

IPM aims to achieve a sustainable increase in yields and income

Objectives of GIZ

IPM is an important building block in achieving sustainable increases in yields and income and should be introduced into all conventional cultivation systems, including the protection of stored products, that have so far relied solely on plant protection using chemical synthetic pesticides. From a macroeconomic perspective, however, the introduction of IPM will prove beneficial for both humans and the environment even if, in individual cases, there is no increase in yield in the short term, as the effects of preventive and non-chemical pest management measures often only become apparent in the longer term.

Governments must improve the framework in developing countries

Statutory regulations and control mechanisms for chemical pest management measures need to be improved and subsidies for the use of chemical pesticides curtailed. Safeguards are also required as far as product quality, user safety and local conditions for pesticide application are concerned in order to guarantee the protection of both the environment and human health. These measures will also make alternative measures more competitive. The provision of information from an independent source (e.g. from an extension service) is also essential.

Profitability a convincing argument

The profitability of IPM measures and use of participatory training and extension methods makes producers more amenable to accepting them. Active exchange of experience by parties in the partner countries working in agriculture and forestry and the demonstration of the economic profitability of IPM, in combination with the inextricably linked factor of environmental protection, are essential for this. IPM strategies therefore include economic aspects as well as social and ecological considerations.

Using and handling products for the protection of plants and stored products[42] requires care and attention. In addition to safeguarding yields and, by extension, food security and income levels, other factors which play a key role in all pest management measures include the reduction of risks for users, the environment and consumers. For GIZ too, pesticides are a relevant topic in terms of the development policy debate within the public sphere in Germany.

Traditional and Integrated Pest Management

Justification for traditional pest management

In these guidelines, it is assumed that chemical pesticides are applied in practice in developing countries and are frequently used incorrectly. Routine or too frequent use (e.g. calendar-based spraying) as well as the selection of the wrong products and incorrect dosage constitute a burden on the resources of a farm (in terms of time and money) and on the ecosystem (in terms of soil degradation as well as air and water pollution), with negative implications

[42] These guidelines use the term 'pesticides' for plant protection and pest control products (pesticides and biocides) as defined in GIZ's procurement regulations.

for humans and the environment. Under such circumstances, sustainable increases in yield are not possible. In these cases, the concept of Integrated Pest Management is designed to significantly improve the situation not only for plant production, but also for humans and the environment. Moreover, there are farms or areas in which highly experienced practitioners apply traditional pest management methods without chemical or synthetic pesticides.

Pest management in GIZ projects

Given that many countries fail to implement international conventions and regulations in full, GIZ bears a particular responsibility when it comes to procuring and using pesticides as well as other agrochemicals within the context of its projects.

Pest management requirements at GIZ

As a result, certain general principles apply to GIZ in the area of pest management. The criteria for selecting pesticides (see Section 3.5.6), together with a number of other key provisions, are defined in the 'procurement regulations' for pesticides and biocides (procurement of plant protection and pest control products (pesticides and biocides) as well as other agrochemicals).

When procuring agrochemicals – in general via GIZ in Germany – adherence to and implementation of these procurement regulations is obligatory, in line with GIZ's Orientation and Rules (O+R). The general principles and remarks apply to all GIZ activities, i.e. project implementation, policy advice, agricultural extension services as well as training and publications.

7

Dissemination of the IPM approach

Objectives of IPS programmes

In developing countries, Integrated Pest Management is a good way of reducing the risks involved for users, consumers and the environment. The attainment of higher, more secure yields through IPM can make a decisive contribution to food security and improving levels of income for the rural population. The spread of IPM was analysed extensively by Pretty and Bharucha.[43]

Despite its considerable potential, IPM is used less in developing countries in production for the local market or in subsistence farming, but is applied instead mainly in products intended for export, in particular to the EU, USA and Japan, where the requirements in terms of quality standards and maximum residue limits (of pesticides) are more stringent. Despite intensive efforts by extension services, the research community and development cooperation to disseminate IPM to small and medium-sized farms, e.g. through the introduction of the FAO's participatory Farmer Field School approach (field-based training and exchange), so far it has not proved possible to mainstream IPM throughout agricultural practice. There are a number of different reasons for this, including the following: insufficient training and technical support for farmers, a lack of enabling policies and government support, a shortage of well-trained extension officers and the challenge of implementing collective action at local level.[44]

Possibilities for promoting IPM as part of international cooperation exist in several areas, including agricultural projects, policy advice for the agricultural sector and regional and rural development programmes. In order to develop new integrated pest management techniques and to refine best practices, specific objectives and indicators, to be defined together with the competent institutions, are required. The primary focus is on obtaining long-term stable yields, cutting the use of pesticides and permanently reducing the costs of pest management measures. The impacts of these measures may be quantified at the level of individual farms as well as in macroeconomic terms.

IPM projects are successful with the effective participation of farmers

As far as cost effectiveness is concerned, an approach can only be successful if the developed pest management measures are applied on a large area of farmland by as many farmers as possible. In some integrated pest management strategies, such as the use of certain biological pest control measures, the participation of all farmers within a region is imperative in order to ensure success.

Even as early as the design stage, developing an approach for a dissemination strategy or, even better, developing the approach together with all other stakeholders (farmers, traders, extension officers, specialised services) is therefore absolutely essential in promoting Integrated Pest Management. Only by doing this is it possible to set priorities for the development of integrated pest management measures, agree on a joint approach, and establish expectations of and an identification with the project in a manner which not only provides encouragement but also ensures that the project runs smoothly.

The following subsections examine more closely not only the challenges involved in disseminating IPM and the role of extension services, but also solutions for strengthening Integrated Pest Management.

[43] Pretty and Bharucha 2015. Integrated Pest Management for Sustainable Intensification of Agriculture in Asia and Africa. Insects. 2015 Mar; 6(1): 152-182

[44] Parsa et al. 2014. Obstacles to Integrated Pest Management adoption in developing countries. PNAS 2014 Mar 11; 111(10): 3889-3894

7.1 Challenges

Willingness and capacity to innovate

Disseminating technical progress in the agricultural sector of partner countries is difficult as the willingness and capacity of the rural population to innovate is often limited. There are a number of reasons for this:

- Older people and women are often barely able to read or write;
- Socio-cultural patterns of behaviour or religious norms often stand in the way of innovations;
- Households living on the edge of subsistence adopt a risk avoidance strategy or do not want to take any financial or revenue-related risk;
- There is no or little monetary income available to purchase inputs for new production techniques (liquidity shortages);
- Traditional values are dominant in society.

In many developing countries, little importance is attached to agricultural extension services provided by the state since often:

- Extension officers lack sufficient qualification and have few opportunities for further training;
- Material bottlenecks exist, such as insufficient means of transport;
- Bureaucratic organisational factors prevent extension officers from working efficiently;
- The coordination needed between the fields of extension and research is lacking;
- Centralised decision-making structures have little motivating impact on extension officers where the flow of information is poor;
- Extension officers are entrusted with other tasks, such as conducting surveys and controls in different specialist areas;
- Modern extension aids are still used far too seldom;
- The content of extension services does not match farmers' needs.

In recent years, the following developments have determined the context in which agricultural extension services are provided:

- Ongoing structural change in agriculture;
- Changing framework conditions and processes of adaptation with the growing influence of regional and supraregional developments as well as the influence of the global market and global trade;
- Increasing volume of agricultural and environmental regulations;
- Increase in the complexity of issues and the wealth of information, especially in the case of IPM;
- Stricter requirements in terms of specialist knowledge for farmers; increasing demands in terms of quality management, strategic planning and information and communications technology in extension services;
- Increasing privatisation and commercialisation of extension services; specialist advice on individual crops, for example, can make it harder for farms to gain access to extension services.

A change in the landscape for extension and advisory services

(see Rural 21: Focus on rural advisory services; Davis/Oberthür. 'Rural advisory services – back on the development agenda'. Rural 21 2014/01: pp 6-8

Agricultural extension and advisory services are increasingly seen as a key means to promote innovation. Extension as part of innovation systems builds on many different sources of knowledge and focuses on interactions between actors. This paradigm is reflected by a wide range of actors providing extension as well as training, commercial services (e.g. soil cultivation, pest management) or intermediary services ('brokers') for farms: farmers' organisations, commercial service providers, private agricultural trading houses, pesticide manufacturers as well as technology providers, traders and processes that are both upstream and downstream of agricultural production, local and international NGOs as well as government extension organisations and programmes that are often supported by development projects of various donor organisations, as well as micro-credit programmes and rural development banks.

Specific problems involved in disseminating Integrated Pest Management

Quality of food and environmentally friendly production are now increasingly important in partner countries too, even more so than the quantity produced. The role of the farmer is no longer constrained merely to that of a food producer and, as is the case in Europe, is developing into that of a manager and steward of agricultural areas, resources and landscapes. This trend is also apparent in some developing countries, for example when farmers are paid for protecting water catchment areas.

The majority of the developments listed not only delay the introduction of technological progress but also make it more difficult, regardless of the area of specialisation. The dissemination of IPM brings with it a number of additional difficulties and some problems assume particular significance.

The following subsections discuss the specific difficulties involved in disseminating an integrated approach. These include:

- Highly complex nature of Integrated Pest Management;
- Low operating costs of expenses of chemical fertilisers;
- Influence of the chemical industry;
- Extension services without the basic principles of Integrated Pest Management.

7.1.1 Complex nature of Integrated Pest Management

The holistic approach – a challenge for extension

Integrated Pest Management is a holistic approach (see Sections 2 and 3) which, in contrast to chemical plant protection measures, requires an understanding of the complex interrelationships in the agroecosystem and clear-sighted planning. This complexity poses an additional challenge when it comes to preparing the content of extension services using detailed information.

Benefits of chemical pesticides soon become apparent

In order to ensure success both in preventive measures, which play a very important role in Integrated Pest Management, and in curative measures, a whole range of factors need to be taken into consideration. In addition to this, there is the difficulty of conveying a concept to the target groups in question, namely farmers, which only requires plant protection measures once the severity or frequency of infestation reaches a certain level. The infestation of their crop by a pest conveys the idea that no action has been taken by farmers and gives them a feeling of helplessness. By contrast, any control measure suggests that something can be done for the crop.

For producers, it is paramount for chemical pesticides to have a direct effect and for them to be able to see results within a short period of time. Moreover, chemical pesticides are supposedly easy to apply, which is an advantage especially for farmers with a low level of education.

7.1.2 Economic considerations in pest management

Integrated Pest Management results in a relatively small increase in contribution margin

Experiences in developing countries show that innovations in agriculture only reach the desired degree of acceptance once they lead to an increase in the contribution margin of approximately 30%.

With the introduction of Integrated Pest Management, such increases in the contribution margin are only seldom achieved. This is primarily because:

Many different factors should be taken into account

- the costs of chemical pest control measures are often low;
- even if the cost in monetary terms is low, the input required for integrated pest management measures in terms of work is much higher than it is when using chemical pest control measures;
- Integrated Pest Management knowingly accepts losses in yields in exchange for achieving a biological balance between pathogens and their enemies;
- where crops are rotated in a manner which corresponds to the integrated approach, yield-maximising and/or profit-maximising objectives need to be limited, at least in the short term, by selecting resistant varieties, systems of cultivation (mixed cropping) or crops that are suited to the area where they are grown.

Although using Integrated Pest Management strategies can lead to savings in operating costs, key indirect effects such as reducing the health risks of chemical pesticides on users or preventing resistance are less noticeable.

Benefits of Integrated Pest Management

By contrast, negative effects of chemical pesticides which only become apparent in the long term and/or are not only barely measurable for individual farms but also very difficult to assess in economic terms, often have no or only very little impact on decisions made at the individual farm level since short-term objectives are more important in most cases.

Apart from this, the only costs borne by farmers are those of procuring and using pest management products. Any consequential costs resulting from negative side-effects of these products are mostly borne not by the individual farm but instead by the public at large. This means that at the level of the individual farm, chemical plant protection measures prove more competitive than non-chemical measures.

7.1.3 The influence of the pest management industry

Extension services provided by industry inhibit Integrated Pest Management

The chemical industry sells its products (chemical synthetic pesticides) through the private agricultural trade, via its own sales networks or via state-run structures or farmers' organisations. From a sales perspective, the industry has a strategic interest in securing blanket coverage of the extension services provided to farmers. It therefore usually assigns more human and financial resources to such services than governments or other actors do (or are able to do). However, extension services provided directly by chemical companies frequently focus primarily on innovative and market-oriented farmers (so-called master farmers).

Better trained extension officers from industry are often more successful

Extension officers representing the pesticide industry are usually better trained than their colleagues in the public sector. The former are more motivated because they have better resources at their disposal, for example in terms of transport and extension materials (leaflets, brochures, posters, videos, etc.), and because they earn higher, often performance-related salaries. This explains why extension officers working in the private sector are often more successful than their public sector counterparts. If agricultural trading companies or industrial companies are not committed to Integrated Pest Management, extension services may result in increased use of chemical pesticides and run contrary to the concept of IPM. On top of this, the extension practices adopted by mainly regional importers and subsidiaries in developing countries are unsound.

Pesticides in developing countries often do not meet quality requirements

Pesticides manufactured in developing countries often do not meet quality requirements with regard to purity and active substance levels as they are produced in technically insufficient facilities and by poorly trained staff. Since government controls are lacking or operate inefficiently, and/or given that tough sanctions either do not exist or are not implemented in the event of breaches, the working practices in place only serve to harm users and consumers.

Extension services provided by industry have a sales focus

Extension services provided by industry often prioritise the objective of long-term stabilisation in sales over other key aspects of pest management, such as user safety, consumer protection or the conservation of natural resources. This is especially true of companies that do not pursue corporate social responsibility. Extension services which focus on sales run contrary to efforts to introduce Integrated Pest Management. The primary aim of integrated methods is to minimise the economic damage caused by pests, by focusing on specific pathogens and limiting any resulting negative side-effects.

The chemical industry is seeking to influence agricultural policy

Many well-known pesticide manufacturers are aware of their responsibility and comply with the FAO/WHO Code of Conduct.[45] Accordingly, when marketing their products they ensure that labels are properly marked in the respective national language, detailed instructions for use are provided and that the products are packaged appropriately.

Sections of the chemical industry play down risks and fail to conduct adequate controls

Nevertheless, the chemical industry is seeking to influence not only farmers and their interest groups in developing countries, but also the regulatory authorities and the respective countries' economic and agricultural policies through the use of its own lobbying activities. In so doing, the pesticide industry is sometimes even able to secure a subsidy or arrangements for its products to be distributed to the agricultural and health sectors.

[45] www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/en

The different companies are well organised and connected at both national and international level. The member companies and associations of CropLife International[46] are committed to observing the FAO/WHO Code of Conduct.

As developing countries often lack the resources to monitor compliance with regulations or to conduct sufficient tests prior to the approval of new pesticides, politicians are largely reliant on information provided by industry. As a result, the plant protection policy adopted in some countries conflicts with Integrated Pest Management, thus making its introduction considerably more difficult.

7.1.4 Trend in the pesticide market

Global sales of pesticides have fallen for the first time since 2014, and recorded EUR 49.6 billion[47] in 2015. As far as the breakdown in sales is concerned, Latin America accounts for 25%, Asia for 29%, Europe for 23.6%, North America for 17.6% and other regions, including Africa, for approximately 4%. China, the United States and Argentina therefore make up 70% of the market. Measured by quantity, sales of herbicides continue to outstrip insecticides, although the latter are now nearly on a par with fungicides.

The market share of off-patent products is roughly 77% while the share of generic products is given as approximately 36%. This figure will continue to increase over the next few years as the recent past has seen relatively few new (classes of) active substances being brought onto the market. There are a range of reasons for this, such as the high costs of research and stringent conditions governing authorisation in countries where registration requirements are more demanding (North America and Europe). Furthermore, there are virtually no new diseases or pests that have emerged which could not be controlled using 'known' active substances that already exist.

Under the Stockholm Convention, a global ban has been placed on a series of substances that are classified as persistent chlorinated hydrocarbon compounds. The Rotterdam Convention likewise severely restricts the sale of such substances. Although the same conditions also apply to some organophosphorus compounds, several products in this same class of active substances continue to be used, as do some carbamates. Because of their toxicity, both groups of active substances require a high level of user protection, something which is difficult to achieve in developing countries and tropical conditions. In addition, because their mode of action is often non-selective, neither group of substances offers any protection to beneficial organisms. Resistance to these active substances will also become more widespread. In Germany, on the other hand, more than 95% of the currently approved active substances do not belong to any toxicity class.[48]

Both specialist manufacturers and the 'conventional' pest management industry have discovered the organic market. In addition to their domain of chemical synthetic pesticides, their development and production activities now encompass all kinds of biological pesticides.

[46] croplife.org (CLI)

[47] Kleffmann Group 2017. Analysis of the crop protection market trends by Bob Fairclough. 13.–14. March 2017 Brussels Global Crop Protection Trade essentials.

[48] Tiedemann, A. von. , Working Group Plant Pathology and Plant Protection, Georg-AugustusUniversität Göttingen. Open letter regarding the television programme 'plusminus'. In DEGA Gartenbau 11/2015 (German only); EU Pesticides database ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=homepage&language=EN

The number of multinational pesticide manufacturers, i.e. those which not only conduct research and development for new active substances, but also sell generic products, has fallen sharply since the 1990s and is likely to decrease further; CropLife International currently still has eight member companies as well as a number of member associations.[49] The member companies have a share of the entire pesticide market equivalent to approximately 71%. By contrast, the manufacturers of generic products have increased in number, both in Europe and, in particular, Asia (i.e. China and India).

In terms of quantity, most pesticides are currently manufactured in China. Many of the manufacturers have joined forces to create national, regional and international associations, such as the European Crop Care Association (ECCA), the Asociación Latinoamericana de la Industria Nacional de Agroquímicos (ALINA), and the global body AgroCare. These associations have pledged to abide by the FAO/WHO Code of Conduct.

A considerable share of the pesticides used worldwide continues to be classified as hazardous (due to their acute toxicity, chronic toxic effects, the persistence of active substances in the environment or because they are not easily biodegradable[50]). Since highly hazardous pesticides have been a special focus area for FAO since 2007 in implementing the Code of Conduct,[51] the export of these pesticides to developing countries, and of poor quality or counterfeit products as a result of weak quality control measures, is a major problem and source of risk (particularly in China, India and Thailand).

7.1.5 Specialist extension services for farmers in the area of pest management

Shortcomings in the training of extension officers

The switch by farmers to cultivation systems based on integrated production and Integrated Pest Management is only possible if it is accompanied by evaluation methods which look beyond traditional criteria (e.g. yield) and allow farms to gauge what actions they need to take in order to comply with the agricultural and environmental objectives of integrated production. A strategy such as this requires an appropriate extension approach. If, in keeping with a holistic approach, extension services cannot be provided by a single organisation, as would be the preferred case, the different extension services offered must at least cooperate closely with one another. However, in many countries this is often not the case and farms are sometimes given conflicting advice.

Extension officers without any additional training are often barely able to practice or disseminate an integrated, holistic approach either in arable farming, horticulture or forestry. Not enough attention is paid to economic questions.

Potential approaches for achieving the objectives of GIZ and for overcoming the difficulties in disseminating Integrated Pest Management in partner countries are set out in the following subsections.

[49] croplife.org/about/members (As at: 7 August 2017): BASF, Bayer, Dow, Du Pont, FMC, Monsanto, Sumitomo Chemical, Syngenta

[50] PAN Germany 2012. Highly hazardous pesticides from BASF, Bayer and Syngenta! Results of an international investigation; pp. 11-17 (broken down by region/country). PAN Hamburg

[51] www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/code/en

7.2 Solutions

Extension services help to make farmers more willing to innovate

Suitable extension strategies and methods, as well as specific and adequate extension aids, can all be used to help make farmers more willing to innovate. This is described in adequate detail both in extension handbooks and in relevant sources.[52]

There is also a lot of information available on general issues of organisation, management, and staffing, or on providing agricultural services with an appropriate level of financial and material resources. For this reason, no solutions to these issues are offered here. The aim of these guidelines is instead to offer solutions for the specific problems in the dissemination of integrated pest management tools described above.

Preconditions for a successful dissemination strategy

Key preconditions for the successful implementation of an Integrated Pest Management strategy, together with an ecosystem-adapted integrated method of production, are as follows:

- Longer-term measures in order to reflect the multifunctional course of action of IPM and the complexity of its approach and to enable sustainable institutional changes.
- Climate data from weather stations including information collected regarding infestation: recording of data over a longer period of time in order to be able to establish correlations, e.g. for the adaptation/development of forecasting models, as setting up and developing stable ecosystems with the relevant populations of beneficial organisms take time.
- Where possible, the value chain should be included, i.e. besides production in the field, other components of the measures are storage, the protection of stored products and, possibly, processing and transport as well.
- The implementation of regulations and indicators needs to be measured over a longer period of time so that changes in the ecosystem can be monitored and consistent conclusions can be drawn.
- Cooperation with the participating authorities and organisations, including NGOs and the pesticide industry, is needed in the longterm in order to establish sustainable cooperation mechanisms and to gain trust.

The subsections below will examine, one by one, the following factors: elements of the extension process; simplifying the content of extension services; the organisation of extension services; the use of extension aids and communication tools for Integrated Pest Management; priorities for the dissemination strategy; checklists for application in practice; the pesticide market at present; cooperation with the pesticide industry; and cooperation with NGOs.

7.2.1 Elements of the extension process

Efforts should be stepped up to raise awareness and develop capacity for the effective application and propagation of appropriate IPM strategies in existing institutions (e.g. agricultural associations). Also important is organisational and financial support for providing agricultural training and extension services. Extension is a process which, naturally, applies to all forms of agricultural production and is very important, especially in the area of Integrated Pest Management. Here, the focus is on a participatory approach in which the extension officer and the party/parties seeking advice work together to try and make sense of problems and to develop viable solutions which will encourage independent and/or joint action.

[52] See fact sheets and the website of the Global Forum for Rural Advisory Services: www.g-fras.org/en/ggp-home.html; Rural 21 No.1/2014, focus on extension services

Interactions between extension officers and those seeking advice, working together in partnership, are characteristic of this type of extension process:

- The extension officer is committed to the individual well-being/common good of the client;
- The tools are intellectual aids that are used to clarify problems and offer alternative solutions;
- Structured, yet open-ended approach;
- The party seeking advice is free to decide whether to accept and implement the extension findings;
- The parties seeking advice remain responsible for the decision.

Analysis of the initial situation acts as the foundation for the extension strategy

The analysis of the initial situation acts as the foundation for the extension strategy as this is when the key aspects governing the choice of extension approach, extension method and extension content are determined. This requires an analysis to be carried out by the organisation providing extension.

In order to carry out further analysis and processing, the party providing the extension services requires technical extension content of Integrated Pest Management and its economic and social aspects, as supplied to project staff or a plant protection organisation.

Inclusion of farmers in the planning of extension services

Farmers and those parties seeking advice should also be invited to take part in the planning of extension services. A particularly important factor at this stage is to take a look at the environmental situation as a whole.

Table 2 Examples of elements in the extension process for the area of pest management

Extension element	Example
Information	
Facts, without any reference to individual actions (often transmitted by mass media, no dialogue, high degree of self-initiative required)	Comparison of pesticides, results of regional trials, mixing recommendations, warnings, pictorial evidence of damage
Education	
Acquisition of problem-solving skills in advance (without any reference to a current problem; educational aims and contents are generally predefined)	Training course to obtain proof of specialist qualifications
Case-based extension	
Development of individual solutions to a current problem (reference to facts and how to act upon them, information is selected and processed individually, possible actions as a result of the extension, developed jointly by the party seeking advice and the extension officer)	Individual extension for problems, field inspection for group extension (e.g. integrated land management working group)
Product-related extension	
Development of solutions for current problems using a defined range of products	Information and recommendations for using a defined number of products
Advertising	
Relaying of facts as incentives for action in relation to a defined range of products	Advertising, booklets, scientific reports (from research carried out by industry), product lists of a provider

(Source: based on information taken from Albrecht et al. 1987 and Boland 1991[53])

Use the knowledge of field officers

Field officers are often the only link so their experience and knowledge needs to be taken into account during the planning process. Whether the aims set are achieved also depends on religious and social norms and values, as well as sometimes on the gender of the officer. For example, in many societies the extension content provided by a male officer will not be able to reach women, and vice versa.

Guaranteed and improved harvests, in terms of both quantity and quality, are the result of successful pest management activities. This means that complementary areas such as marketing, lending and the provision of production inputs can become major difficulties if they are not given sufficient consideration. In such cases, the first task of extension officers is to identify the difficulties. He/She then needs to pass on his/her knowledge so that measures supporting the implementation of the Integrated Pest Management strategy may be taken in cooperation with other organisations, such as marketing cooperatives for example. However, this does require a well-functioning communications structure to be in place.

Means of communication such as mobile telephones and the internet are already established and are usable in many developing countries. They provide excellent opportunities for setting up a communications structure. To this end, basic information sources must also be expanded

[53] ALBRECHT, H. et al. 1987. Landwirtschaftliche Beratung. Band 1. Grundlagen und Methoden. 2. Auflg. BMZ und GTZ, Rossdorf und BOLAND, H. 1991. Interaktionsstrukturen im Einzelgespräch der landwirtschaftlichen Beratung. Wissenschaftsverlag Vauk Kiel KG and Handbook: see also Hoffmann et al. 2009. Rural extension Vol. 1 (3rd edition). Basic issues and concepts. BMZ-GTZ-CTA. Margraf Publishers Weikersheim.

and improved, especially those of relevance to IPM (knowledge of pathogens, assessment of the risk of infestation and weather data). To collect these data and put them to extensive use, there is a need to set up agrometeorological stations and make greater use of new media (information and communications technology – ICT). Using the websites and apps of the Centre for Agriculture and Biosciences International (CABI), Plantwise and the company Progressive Environmental & Agricultural Technologies, PEAT[54] are just some of the ways in which plant diseases and pests can be diagnosed.

7.2.2 Simplifying the content of extension services

Improving the framework for Integrated Pest Management

IPM needs an enabling framework in order to be effective. Policy advice can help here. One aim should be to establish more efficient national regulations and controls for chemical pest management and to introduce incentive mechanisms for the development and distribution of alternative plant protection products. Based on the underlying principle of 'as much as necessary, as little as possible', the focus of many companies, and sometimes of extension services too, is not the risks associated with pesticides but the use of the substances instead.

Farmers need to understand the strategy

The complex Integrated Pest Management strategy is not always easy to understand or to convey in great detail. What is important is that farmers understand the strategy so as to be able to accept and apply extension content. The basic tenets of the strategy, such as taking account of and conserving natural resources like soil, flora and fauna are familiar to farmers, which should make them easy to impart. It is also in the long-term interest of the farm to preserve and improve the location where it is situated, for instance by increasing biodiversity, which will strengthen the balance between beneficial organisms and pests.

Field trials conducted with 'pilot farmers' can point to problems in dissemination

It is also important to involve users in the development and testing of individual plant protection measures. This way, all trials and demonstrations are carried out together with farmers on their land under real-life conditions and the findings are discussed. The actions and comments of the 'pilot farmers' allow initial conclusions to be drawn concerning the difficulties which will arise in dissemination. In Germany, so-called demonstration farms, where farmers are able to monitor and identify the effects of Integrated Pest Management under comparable conditions, have proven to be a valuable instrument in the implementation of 'National Action Plans'.

Small learning units and practical exercises make it easier to understand the content of extension services

The complexities of the Integrated Pest Management strategy are broken down into individual steps so that they are easier for farmers to take on board. The content of extension services must be straightforward and easy to understand, clear and concise, have a logical structure and be illustrated with examples.

For the purposes of extension services, the IPM strategy is divided into individual parts, giving clear and easy instructions to follow. Active, practical learning should be combined with passive learning (listening). The lessons learned should be highlighted, for example by drawing comparisons between plots of land which have been treated differently or by demonstrating the difference between beneficial and harmful organisms. This approach is roughly equivalent to that of the Farmer Field Schools, where groups of farmers work together to identify and solve problems.

[54] CABI: Plantwise (www.plantwise.org); Progressive Environmental & Agricultural Technologies (PEAT): Plantix (http://plantix.net), an app for diagnosing plant diseases.

7.2.3 Use of extension aids and communication tools

New media (information and communications technology) are now used for a wide range of applications and purposes in agriculture and extension.[55] ICT tools can be used to raise awareness and develop capacity, obtain information or help in making decisions for the effective application and propagation of appropriate IPM strategies in existing institutions, among advisors and the pesticide industry. Applications which combine information on plant protection[56] with meteorological data and market information for farms are now also being used.

Use a variety of media to spread information

The target groups, namely farmers, are not only users and recipients of this information but also supply information themselves. In this regard, not only is it important for the information to be up-to-date, but the quality and orientation of the content should be right as well. Information may reach farmers in a variety of ways, for example via radio, television, text message, the internet or in printed form (press releases, brochures, etc.). On-farm demonstrations, carried out under comparable growing conditions, remain the best method and should be an integral part of every extension strategy.

Make use of extension aids

Ensuring that there is a diverse range of extension aids which not only help extension officers to communicate extension content but also make it easier for farmers to understand such content, is key. The possibilities offered by ICT should therefore be used to visually display harmful organisms and their antagonists, for example, and to have weather data, warnings or market prices readily available. This also extends to information on risks and any environmental damage that may be caused by pesticides, such as in water catchment areas. Models forecasting the development of diseases are another example of ICT being put to good use.

All extension aids need to be able to present the content of extension services in a plain and simple fashion. ICT can do this in many different ways and can now offer much more support in terms of disseminating Integrated Pest Management than was the case in the past.

Aids must be tested to ensure not only that they work and operate correctly but are also user-friendly, thereby facilitating their acceptance among extension officers and the target groups of farmers. Often, it is not technical perfection that is crucial to achieving success, but instead the capacity of the aids to reach farmers seeking advice.

Provide training in extension methods

The use of extension aids can offer essential support to extension officers when carrying out their work, especially if the officers in question do not have the ideal level of training. Although most field officers know the required technical information, they often lack knowledge regarding the methods used in extension. Appropriate training and professional development are particularly important factors here: field officers should be equipped with the skills that will allow them to analyse the local situation, thereby enabling them to recognise and overcome resistance to extension services.

[55] FAO 2013. ICT uses for inclusive agricultural value chains. Rom; World Bank 2011. ICT IN AGRICULTURE. Connecting Smallholders to Knowledge, Networks, and Institutions; IRRI Rice Crop Manager Advisory Service Version 2.1 (webapps.irri.org/ph/rcm)

[56] CABI: Plantwise (www.plantwise.org)

7.2.4 Priority factors for the dissemination strategy

The greater the direct economic and individual benefits of recommendations, the more likely it is that the content of extension services will be accepted. In this regard, the priority when disseminating integrated pest management measures should be placed on the following factors:

Develop and test extension aids

- crops which are of most importance to farms;
- crops which offer the highest potential for cost savings in terms of chemical pest management;
- control measures for pests which cause the greatest economic damage and strategies in which the economic risk for farmers is lowest;
- support measures which ensure the availability of inputs for Integrated Pest Management, including the introduction of appropriate inputs (equipment, varieties, selected pesticides), for example through revolving funds;
- areas where pesticide use can easily be reduced, e.g. by controlling buffer strips;
- agricultural areas where an ecological benefit is directly measurable/visible (forgoing the use of pesticides near rivers or in water catchment areas);
- use of pesticides that are friendly to beneficial organisms so as to prevent any negative impacts on bees and pollination;
- creation of ecological buffer zones and refuges to increase local biodiversity and improve habitats for beneficial organisms;
- choosing crops to be grown based on existing forecast models so as to reduce pesticide use.

Priority factors for the IPM dissemination strategy

Besides technical pest management factors, economic aspects are also taken into consideration and implemented into extension content when drawing up extension strategies. This is done in order to encourage farmers to accept recommendations. Once the first positive results are achieved, farmers' trust and confidence in extension services will increase and they will be more willing to accept recommendations where the primary focus is not short-term economic success.

Farmer Field Schools, a tried-and-tested approach for IPM

In developing countries around the world, the Farmer Field School (FFS) approach[57] has proven to be a successful method of extension and dissemination for Integrated Pest Management. In Asia, however, FFS was developed in response to the negative impacts of the Green Revolution on health and the environment (move towards more intensive agricultural practices).[58]

As such, it is not surprising that the concept has spread, first in Asia from the 1980s onwards and then followed by Africa and Latin America during the latter half of the 1990s, albeit initially in just a few countries such as Ghana and Egypt.[59]

Today, Asia is by far the largest market for pesticides and it continues to grow (see Section 7.2.7). By contrast, with a somewhat stagnating market at a low level, Africa plays a marginal role, with the exception of a few countries and crops, such as Ghana, Nigeria, South Africa and North Africa.

[57] www.g-fras.org/en/good-practice-notes/farmer-field-schools.html

[58] Braun et al. 2006. A global survey and review of Farmer Field School experiences. Report for ILRI

[59] International Initiative for Impact Evaluation (3ie) 2014. Farmer Field Schools. From agricultural extension to adult education. Systematic Review 1. Report by Waddington and White

It is understandable, therefore, that countries such as Indonesia, where the problems proved to be most pressing, were among the first to introduce the FFS approach. Countries such as Vietnam, in which this development and the strong growth in agricultural exports were slow to take hold, today farm very intensively with some of the highest levels of mineral fertiliser and pesticide use per hectare. With the support provided by CropLife International in introducing IPM, the requested GIZ extension services (including the training of trainers) had success here,[60] with sharp reductions in levels of pesticide application, among other factors. Together with the Philippine Government (Department of Agriculture), the Better Rice Initiative Asia (BRIA) project is testing the sustainability standards for rice cultivation developed by UNEP and the International Rice Research Institute (IRRI).

Based on a shared learning approach together with a group of farmers, Farmer Field Schools are a way of integrating ecological topics as well as community development issues into the extension strategy, for example when determining pathogens, beneficial organisms and the injury level. It is also a cost-effective approach in which local knowledge in particular is used. Strategies are drawn up on a joint basis and are then supported by extension officers. Joint pest management strategies can also be produced, cutting the number of spraying applications or reducing the size of an area of application by means of boundary spraying, thereby preventing pest migration for a large area. Farmer Field Schools can also be used to introduce protection measures, such as for bees, on a joint basis.

7.2.5 Checklists for the application of Integrated Pest Management in practice

Checklists can be used to raise awareness, plan and evaluate

In recent years, the EU and its member states have developed a number of different checklists which can be used to assess the implementation in practice of sustainable farm management or, in particular, Integrated Pest Management. In Germany, this was prompted by the National Action Plan on Sustainable Use of Plant Protection Products (NAP) as well as by the requirement to establish how well pest management targets are being met and to examine the implementation of EU provisions. Both checklists are presented here as examples; where necessary, checklists adapted to the particular context in the project setting can be developed on a participatory basis and used for raising awareness, planning and evaluation purposes.

Under the NAP for Germany, demonstration farms for Integrated Pest Management are involved in implementing IPM on a model basis. Using a points system, checklists based on guidelines developed by the Julius Kühn Institute can be used to ascertain the degree of implementation.[61] The requirements are in line with the holistic approach, starting with the procurement of information and training before going on to cover preventive measures and pest management measures, through to the measurement of results and documentation. The points system follows the traffic light principle, thus leading to three possible levels of evaluation: Green (performance satisfies the requirements of the IPM guidelines in full); Yellow (performance can be improved); and Red (performance does not satisfy the requirements).

As defined in Regulation (EU) 1306/2013, the granting of agricultural payments is subject to compliance with rules in the areas of the environment, climate change, good agricultural condition of land; public, animal and plant health; and animal welfare. This requirement is termed

[60] Better Rice Initiative Asia (BRIA) 2017. IPM training helps farmers stay profitable. Monthly Update. Vietnam. July 2017 www.better-rice-initiative-asia.org

[61] Example: Arable farming checklist (Julius Kühn Institute): demo-ips.julius-kuehn.de/dokumente/upload/Checkliste_Ackerbau_2016.pdf (German only) (As at: 10 August 2017)

cross-compliance (CC). These rules cover standards for maintaining farmland in good agricultural and environmental condition and regulations on statutory management requirements. The rules are based on a whole-farm approach. This means that a farm in receipt of CC-relevant payments must comply with these obligations in all areas of production (e.g. arable farming, livestock farming, greenhouses, specialised crops) and at all of its sites. In addition to an information brochure (including approximately three pages on pest management), Germany's federal states have also issued a cross compliance checklist (CC checklist) which is updated annually.[62]

7.3 Cooperation between actors in the area of extension

7.3.1 Interaction between actors

In keeping with the holistic approach of Integrated Pest Management, the strategy is not simply confined to the provision of advice on pest management but instead covers plant cultivation in its entirety. The aim of this is to achieve an integrated method of production that is adapted to local ecological conditions. Integrated production and sustainable farm management would require all measures to be selected and combined in such a way that healthy soil provides the basis for the growth of a strong crop which is largely resilient to pathogens and abiotic influences (weather conditions) and reduces the frequency with which pest management measures are required.

Coherent advice is ensured by involving all rural extension actors

The basic aim should be to achieve a coherent IPM strategy which can be used as a common basis for the work carried out by different actors (public, private, NGOs as well as government- or donor-funded development programmes). In order to do this, government agencies need to coordinate the various extension service providers accordingly. This is the only way to ensure that different measures complement one another and support the implementation of the IPM strategy. This applies in particular to measures that focus on a particular region or target group. It is important that there is transparency with regard to service providers and that farms are able to find out information about the range of extension services available.

Setting up of a communication network

This requires effective communication, both within the respective organisations providing extension services as well as between the different actors offering extension and other plant protection services.

Accordingly, regular meetings organised by the project management agency can be held to ensure effective and ongoing exchange. A semi-annual meeting that gathers together all groups for the purpose of developing project planning further can have positive effects, both on priority areas of research and on the selection of extension methods and extension content.

Another key basis for the design of an IPM strategy is the joint development and use of ICT tools (see below) or joint training/skills development courses for extension officers representing the various actors and extension services. This will ensure that a coherent understanding of IPM is put into practice or that access to updated extension aids such as posters and videos is obtained.

[62] Example for Baden-Württemberg (processing for Germany, German only): www.landwirtschaft-bw.info/pb/,Lde/3339788

Cooperation with research facilities

In order to convince extension officers of the Integrated Pest Management strategy, these should be actively involved in the development and testing of relevant measures. In particular, this means that extension officers will set up and monitor on-farm trials or demonstrations as well as analyse and interpret the results.

Working together closely with research institutions is also important as this means that research can be geared to meeting practical needs and research findings can be implemented rapidly into the content of extension services.

The aim of extension services is ultimately for IPM measures to be broadly applied within a suitable period of time, while at the same time minimising expenditure in terms of staff, materials and resources as far as possible.

7.3.2 Cooperation with the pesticide industry

Measures to promote Integrated Pest Management lead sooner or later to the question of whether cooperation with the chemical pesticide industry is possible and, if so, in what form, and what is the best way to act towards such companies.

At international level, multinational pesticide manufacturers have joined forces to create CropLife International (CLI),[63] which represents a network of national associations in almost every country in the world. National and regional associations have also been set up by generic pesticide manufacturers.

In leading industrialised nations, IPM has become part of policy and statutory regulations as well as good agricultural practice. The member companies of CLI are officially committed to the principle of Integrated Pest Management and also undertake to comply with the FAO/WHO Code of Conduct and thus to minimise the risks involved in using pesticides. Similar pledges have also been made by some of the associations of generic pesticide manufacturers. As a general rule, it is more difficult to assess the situation in developing countries where the focus is much more likely to be on short-term sales targets, where awareness of the shared responsibility in the use of pesticides is not as strong and where the statutory foundations for legal consequences are lacking.

Chemical pest management subsidies are unsustainable

In order to solve specific pest management problems in keeping with the spirit of IPM, GIZ projects cooperate with individual (international) companies that have agreed voluntarily to comply with international conventions, focus on longer-term objectives and bring their experience to bear in the projects (in the form of diagnosis, forecasting, a combination of measures, training, etc.). In areas such as training, it is recommended to work together instead with the associations representing companies. As far as cooperation between GIZ and the private sector is concerned, there are a range of reasons and criteria for this, and various forms which the cooperation may take.[64]

[63] croplife.org

[64] BMZ 2013. Kooperation mit dem Privatsektor im Kontext der Entwicklungszusammenarbeit. Aktuelle Situation und Ausblick im Sektor Landwirtschaft und Management natürlicher Ressourcen. (German only)

The framework conditions for cooperation in the agricultural sector, including pest management, are set out in the BMZ document entitled 'Reference framework for development partnerships in the agri-food sector'.[65]

Notifying users and the public of the risks and hazards of chemical pest management as well as of any potential long-term negative side-effect remains important. In response, the pesticide industry has developed more efficient and also less hazardous agents in recent decades. However, for farms, especially those in Africa, these substances are often unavailable or inaccessible on grounds of affordability.

Although there is a need for a suitably restrictive practice for approving pesticides, with stringent testing criteria, this is often difficult to achieve in developing countries due to the scarcity of resources (in terms of personnel and infrastructure). The opportunities afforded by today's information society, such as global internet searches, mean that the risks to human health and/or the environmental damage caused by pesticides can be pointed out to support the presentation of particular arguments.

Arguments against the use of conventional chemical pesticides are more likely to be favourably received if viable alternatives such as the IPM strategy can be presented and disseminated in a way that can be understood and followed by somebody who has no expert knowledge in this area.

Code of Conduct is a way to monitor the conduct of pesticide manufacturers

Lending programmes that are only used to fund a package of agricultural inputs, including chemical pesticides, are questionable since this approach is often unsustainable. This also applies to the granting of subsidies for chemical pesticides. Lending programmes which finance investments in agriculture should be an integral part of a comprehensive extension strategy designed to achieve sustainable improvements for farms.

Unilateral support for the use of inputs that are not tailored to the needs of the farmer target groups is likely to make implementation of the Integrated Pest Management strategy difficult. On the other hand, the setting up of appropriate (upstream) market structures, combined with a suitable range of extension services, can help to bring about lasting improvements in the agricultural sector. Another much-discussed issue is whether a tax should be levied on chemical pesticides to reflect the macroeconomic costs of their side-effects and to encourage Integrated Pest Management.

[65] BMZ 2016. Reference framework for development partnerships in the agri-food sector.

Farmers as service providers for the application of pesticides

(See IPM for Rice Production in Nigeria. Report on a consultancy for the CARI programme by O. Mück)

One particular approach for promoting the effective and safe application of pesticides by smallholders is the concept adopted by CropLife Africa Middle East involving a network of 'Spray Service Providers'. Suitable farmers are identified and given specific training on how to use and apply pesticides (CropLife stewardship programme in cooperation with GIZ, e.g. in Nigeria and Ghana). This can help improve protection for users, health and the environment. The sale of protective clothing, sprayers and other inputs at the same place as pesticides, together with training measures, encourages the adoption of good IPM practices. The trained farmers can then earn extra income by providing pest management services for other farms. The Competitive African Rice Initiative (CARI) programme works together with the agricultural trade, which distributes high-quality pesticides.

In contract farming, also known as outgrower schemes, where there is a binding economic relationship between the farmer and the party selling/buying the crop, inputs including pesticides are often made available and are pre-financed. In the absence of corresponding extension initiatives, this would unilaterally favour chemical pest management. The aim, for example, should be to use resistant or tolerant varieties in a coordinated manner together with crop technology measures and biological measures.

All of these measures help to raise public awareness of the benefits of Integrated Pest Management and at the same time encourage farmers to adopt these strategies even though the individual economic benefits in the short term may not be as great.

7.3.3 Cooperation with NGOs

Cooperation with NGOs provides a number of different possibilities for implementing measures designed to promote Integrated Pest Management. Many NGOs work together with rural and farming target groups on improving their systems of production and on intensifying them in an environmentally and socially acceptable manner (sustainable agriculture), making particular use of participatory extension and development approaches.[66] The international agricultural research centres focusing on the development of IPM[67] should also be mentioned. Examples include the development of tolerant/resistant varieties or the development of biological measures such as Aflasafe in Nigeria (non-toxic strains of *Aspergillus* fungi prevent the spread of aflaxtoxin strains).

A number of NGOs, such as Pesticide Action Network (PAN) International[68] have been calling for the introduction of pesticide reduction programmes for many years and play an active role in drawing up international agreements and in conducting campaigns to raise public awareness of the potential side-effects of pesticides. In many countries, including developing

[66] e.g. www.prolinnova.net

[67] www.icipe.org (International Centre of Insect Physiology and Ecology or www.iita.org (CGIAR Systemwide Program on Integrated Pest Management)

[68] pan-international.org

countries, there are local environmental protection groups that offer support for alternative farming methods and approaches for reducing the risks of pesticides, often in keeping with Integrated Pest Management.

Various NGOs have also specialised in procedures for certifying production methods, a practice that is familiar in the sustainable wood industry for example.[69] In several countries, NGOs also carry out checks to test compliance with the new 'voluntary standards' introduced by private companies and supermarket chains. By doing so, they acquire expertise and experience in promoting integrated production methods and can focus on several elements in the value chain.

[69] www.fsc-deutschland.de/de-de (forest certification management)

8 Concluding remarks

The holistic approach of Integrated Pest Management has been well known in agriculture, horticulture and forestry for more than 50 years and is regarded worldwide as the plant protection strategy.

This 'integrated' approach means that priority is always given to preventive and non-chemical measures before the use of chemical pesticides becomes a consideration. As a result, pesticide use is reduced, thus allowing for the adoption of a sustainable pest management approach that is geared towards ecology as a whole. This frequently necessitates a departure from established methods in favour of alternative ones, which in turn requires openness and trust on the part of farmers, as well as a certain willingness to take risks. It also requires reliable extension services and support on the ground as well as the backing provided by policy guidelines.

IPM needs an enabling framework in order to be effective. Policy advice can help here if one of its aims is to establish more efficient national regulations and controls for chemical pesticides along with the incentive mechanisms for the development of preventive measures and the distribution of biological pesticides. This also includes promoting infrastructure and supporting the scientific community in developing more non-chemical methods of control (e.g. forecasting models, appropriate management and communication systems), so that new findings and procedures are available to those working in agriculture and forestry. Only in this way can efforts that focus on improving the use of chemical pesticides be stepped up further.

Pest management and, in particular, the use of chemical pesticides associated therewith, has been the subject of controversial debate for many years. Integrated Pest Management provides the opportunity to place the issue on an objective footing. These guidelines are designed to help in this regard. The many non-chemical methods of pest management mentioned are merely given as suggestions.

There are, of course, other concepts and approaches. The strengthening of organic farming, including in developing countries, and the demands by policy-makers in Europe to reduce the risks of and dependency on pesticides are creating a positive climate in which new methods and approaches are constantly being developed. Thanks to the internet, it has become much easier to access the wealth of information that is available. Integrated Pest Management is an ongoing process; it is a search for the best ways to manage pests, diseases and weeds so as to achieve optimum crop development, and for methods that will benefit the ecosystem and soil fertility, as well as the production capacity and therefore the economic survival and performance of farmers. However, Integrated Pest Management is also in the best interests of consumers and will help to boost trust and confidence in improvements to the quality of food.

9 Glossary and abbreviations

abiotic	The non-living environment; opposite of biotic.
action threshold	The intensity or density of a pest (including weeds) at which control measures should be implemented for epidemiological or technical reasons or reasons related to population dynamics in order to prevent it from reaching the economic threshold (see definition below). An element of forecasting is contained in the action threshold.
agroecosystem	As agricultural systems of production are human-controlled ecosystems (see below), an alternative term for them is agroecoystems.
ALINA	*Asociación Latinoamericana de la Industria Nacional de Agroquímicos*
antagonist	Active control agent or inhibitor
arthropods	Form of jointed-limbed animal, e.g. insects, arachnids and mites
Basel Convention	The objective of the Convention is to reduce transboundary movements of hazardous wastes and other wastes to a minimum, dispose thereof in an environmentally sound manner as close as possible to the source of their generation and to minimise the generation of hazardous wastes in general. The primary measure in order to achieve these objectives is to control the transboundary movements of hazardous wastes and thus prevent illegal traffic. The Convention was adopted in Basel in 1989 and entered into force in 1992. Today, almost 160 countries, as well as the European Union, are parties to the Convention.
beneficial organism	An organism (usually fungi, insects, etc.) that is used for the biological control of harmful organisms.
BMEL	German Federal Ministry of Food and Agriculture
BMZ	German Federal Ministry for Economic Cooperation and Development
break-even point	Denotes the point at which a business begins to generate a profit. At this point, variable and fixed costs are covered in full by the revenue earned.
BVL	German Federal Office of Consumer Protection and Food Safety
CA	Conservation agriculture, a zero-tillage method of soil management where crop residues provide soil cover to protect against erosion; may increase the risk of diseases in succeeding crops. This term has a number of different definitions.
CABI	Centre for Agriculture and Biosciences International
CARI	Competitive African Rice Initiative
Checklist (NAP)	The demonstration farms for IPM in Germany align their pest management strategies with the JKI's guidelines on Integrated Pest Management and implement these on their demonstration plots. Checklists are used to assess implementation on demonstration farms.
Checklist (CC: cross-compliance)	The drawing of direct payments is subject to the observance of EU cross-compliance requirements. Farms can use the CC checklist to examine whether they meet these requirements.
CLI	CropLife International (international association representing the pesticide industry)
contribution margin	Difference between the market revenue generated by and the proportionate specific costs of a production process. The production process in question contributes this amount to cover the disproportionate specific costs and the fixed costs of the farm as well as to its profit. **The contribution margin must always be calculated for a specific unit (hectare, worker) and be shown for a specific period (per year, per season).
crop rotation	The seasonal and periodic rotation of crops in the same area, often over several years.
curative pest management measures	Pest management measures adopting a therapeutic approach (mechanical, thermal, biological and chemical pest management measures).
ECCA	European Crop Care Association
economic threshold	The amount of disease or pest injury at which the costs of a control measure are equal to the monetary value of the loss in yield prevented by such a measure.

ecosystem	The term ecosystem describes a unit that consists of a group of organisms (biota) and their environment (abiotic factors). Ecosystems may be defined on different scales. An ecosystem is self-regulating. Regulation occurs by way of feedback effects, with negative feedback effects geared towards keeping the system in balance. Positive feedback mechanisms lead to system changes, especially in changes to the environment.
endemic	The occurrence of plants and animals in a specific, clearly defined area; native.
epizootic disease	A density-dependent infectious disease in an animal population.
EPPO	European and Mediterranean Plant Protection Organization
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FRAC	Fungicide Resistance Action Committee (Specialist Technical Group of CropLife International)
fungicide	A pesticide that kills fungi or its spores or that inhibits the growth thereof for the duration of its effectiveness.
generics	Off-patent active substances; generics are pesticides which are a reproduction of products whose patents have already expired.
GFRAS	Global Forum for Rural Advisory Services
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
GIZ	*Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH*
GMO	genetically modified organism
habitat	Place where a particular kind of animal or plant usually lives and grows.
harmful organ-isms	Living organisms, usually bacteria, viruses, fungi, insects or warm-blooded animals that cause damage to agricultural crops.
herbicide	A chemical pesticide used to kill weeds and unwanted plants.
host, host plant	(Macro-) Organism on which a symbiont, pathogen or parasite lives.
HRAC	Herbicide Resistance Action Committee (Specialist Technical Group of CropLife International)
icipe	International Centre of Insect Physiology and Ecology
ICT	Information and communications technology
IFC	International Finance Corporation (member of the World Bank Group)
IFOAM	International Federation of Organic Agriculture Movements (IFOAM – Organics International) (umbrella association for the organic agriculture movement)
insecticide	A pesticide used to kill, get rid of or retard the growth of insects.
intermediate host	An intermediate host is an organism that supports in its body early developmental forms of a parasite (e.g. its larval stage), allows it to develop further (in particular through asexual multiplication and/or metamorphosis) and ultimately transfer to another organism.
International Code of Conduct for Pesticide Management of the FAO/WHO	The objectives of this Code are to establish voluntary standards of conduct for all public and private entities engaged in or associated with the management of pesticides, particularly where there is inadequate or no national legislation to regulate pesticides.
International Plant Protection Convention (IPPC)	This Convention is an international treaty on permissible legal and technical measures against the introduction and transmission of plant diseases and their control. The Convention was established in 1952, amended in 1979 and extensively revised most recently in 1997. The revised version only enters into force once it has been ratified by two thirds of the 127 participating states. For its signatories, the International Plant Protection Convention is the authoritative basis for national and supranational legislative proposals (e.g. EU) in the area of plant quarantine. International Standards for Phytosanitary Measures (ISPM) are developed under the IPPC, for instance on plant quarantine in relation to international trade, risk analysis, monitoring, eradication and plant health certification. The standards are binding and are designed to support signatories in the application of the Convention. They are available in several languages on the IPPC website or are issued by the IPPC Secretariat.

IOBC	International Organisation for Biological and Integrated Control
IPM	Integrated Pest Management
IRAC	Insecticide Resistance Action Committee (Specialist Technical Group of CropLife International)
IRRI	International Rice Research Institute
Lepidoptera	Order of insects comprising butterflies and moths
level, necessary	In the use of pesticides, the necessary level denotes the amount of pesticides that are necessary to secure the cultivation of crops, particularly from the aspect of economic viability (NAP).
M&E	Monitoring & Evaluation
mass breeding	Reproduction of living organisms under laboratory conditions; in pest management, this is mostly beneficial organisms with the aim being to release them as part of biological pest control against pathogens or organisms harmful to crops.
mixed cropping	The practice of growing more than one type of plant on the same piece of land at the same time.
monoculture	The practice of growing a single crop on a continuous basis on the same piece of land, in the absence of crop rotation; the term is also used to denote a regional focus on one crop.
Montreal Protocol	The Montreal Protocol on Substances that Deplete the Ozone Layer was adopted in 1987. Under the Protocol, the contracting states promised to reduce and to eventually prevent altogether emissions of chemicals containing chlorine and bromine which destroy stratospheric ozone. Additionally, they have agreed to work together on research concerning the mechanisms of ozone degradation. Monitoring regulations have been amended and added to continually by the amending protocols of London (1990), Copenhagen (1992), Vienna (1995), Montreal (1997) and Beijing (1999). Substances such as CFC, methyl chloroform, methyl bromide and carbon tetrachloride fall under the Montreal Protocol.
NAP	National Action Plan on Sustainable Use of Plant Protection Products (binding in Germany since 2013), an initiative of the German Federal Ministry of Food and Agriculture (BMEL).
nematode	Roundworm
NGO	Non-governmental organisation
organic farming	The terms organic farming, organic agriculture or alternative agriculture denote the production of food and other agricultural products using the most natural methods of production possible, and applying the principles of ecology and environmental production. Organic farming (largely) dispenses with the use of pesticides, mineral fertilisers and genetic engineering in the way that they are sometimes used in conventional farming.
parasite	An organism that lives off its host, but which in most cases does not kill the host.
parasitoid	An organism that kills its host; insects that spend a portion of their development attached to or within the body of a host insect in a relationship where the host is ultimately killed.
pathogen	An agent that causes an infectious disease.
PCC	Poison Control Centres
PEAT	Progressive Environmental & Agricultural Technologies
pesticide	Plant protection and pest control product; general term used for natural or synthesized substances used to kill harmful organisms, (includes herbicides, insecticides, fungicides).
PIC	Prior Informed Consent
pictogram	A pictogram is an individual symbol or icon that is used to convey information through simplified graphic representation. In pesticides, pictograms are used on the label to indicate hazardous goods/hazardous materials. Example: In accordance with international rules laid down by GHS, there are currently nine globally harmonised hazard pictograms.
pheromone	Semiochemical released by a living organism in order to communicate with other individuals of the same species.
pheromone lure	Carrier that is applied with a specific pheromone to attract pests.

phytophage	An organism that eats parts of plants, thereby considerably impairing their development.
polyphagous	Feeding on many different types of food (host plants or prey).
predator	An animal that preys upon other organisms and destroys pests by hunting down and feeding on them; predators rarely have a specific prey and their movement also makes them effective against low pest populations. Important examples are predatory bugs, predatory mites, ladybirds, ground beetles, spiders, lacewing larvae and hoverflies.
preventive measures	Pest management measures taken on a preventive basis; covers a variety of crop measures such as soil cultivation, crop rotation, fertilisation, seed technology, the selection of resistant varieties as well as the use of pesticides with a preventive effect, the protection and conservation of beneficial organisms.
Prolinnova	PROmoting Local INNOVAtion in ecologically oriented agriculture and natural resources management
repellent	A substance perceived by another organism by the sense of smell and which deters the organism without killing it; used primarily against sanguivorous, infectious arthropods such as mosquitoes, horseflies or ticks.
resistance	Genetically fixed, enhanced ability of crops to withstand diseases or pests, and also pest control products.
resistance, horizontal	Varying degree of resistance of certain varieties against all pathotypes of a pathogen; there are no interactions between varieties and pathotypes.
resistance, vertical	Resistance of certain varieties to a single pathotype or a small number of pathotypes; in most cases the resistance is broken very quickly by the selection of new strains. There are distinct interactions between varieties and pathotypes.
resistant variety	A variety with properties that make infestation by certain pests more difficult or impossible.
revolving fund	A fund whose resources are replenished by the proceeds of projects or initiatives that the fund has financed.
Rotterdam Convention (PIC procedure)	Information exchange on the risks and hazards of certain hazardous chemicals and certain hazardous plant protection and pest control products. Plant protection and pest control products or industrial chemicals can pose a risk to the population's health and the natural environment, especially in developing countries, if they are not used properly. A voluntary 'PIC procedure' was therefore established in the 1980s for providing mutual information on the risks and hazards of certain hazardous chemicals and certain hazardous plant protection and pest control products. PIC (Prior Informed Consent) means agreement following prior notification. The procedure involves the exporters of certain hazardous chemicals acquiring consent from the importing country before a products is imported. In 1988, the PIC procedure was legally consolidated when the Rotterdam Convention was signed. In accordance with the provisions of the Convention, importing countries are provided with the necessary information on chemicals from the PIC List so that potential risks can be recorded. A country may refuse to import a PIC chemical if the safe handling of the substance in this country cannot be guaranteed. The stipulations of the convention, such as labelling requirements for the exporter, contribute to the safe use of the chemicals once consent has been granted for the import. The Convention came into force on 24 February 2004.
selection	Individuals chosen on the basis of particular characteristics (phenotypes), the distinct nature of which impacts on the fixation of the genotype.
selective pesticide	Pesticide with a precisely defined range of impact, generally only effective against one species or species group of pests.
soil solarisation	Partial decontamination and killing of pests and weed seeds in the top layer of soil (to a maximum depth of 10 cm) through exposure to sunlight. The temperature of the soil may be increased further (up to 60°C) by covering the surface of the soil with plastic sheeting. Soil solarisation greatly reduces populations of soil borne fungi, such as species of *Verticillium, Fusarium, Phytophthora, Pythium* and *Sclerotium*, and nematodes.
spray drift	Spray drift refers to the airborne dispersion of pesticides beyond the area of application (e.g. to field boundary strips, to a neighbouring field, to a body of water).
stenophagous	Dependent on a specific diet with a limited variety of food (small number of host plant species or prey)

Stockholm Convention	The Convention is an international treaty aimed at eliminating or restricting the production, use and release of persistent organic pollutants (POPs).
strip cropping	Cultivation in which different crops are grown together at the same time in broad strips next to one another, as opposed to in narrow strips or rows, as is the case in mixed cropping.
taxonomy	The classification of living organisms into a biological system.
toxicity	The degree to which an agent is poisonous.
undersowing	Cultivation of a crop beneath a cover crop, e.g. clover seed under rye
UNEP	United Nations Environment Programme
WHO	World Health Organization
WTO	World Trade Organization

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