Training Manual for Plant Protection in Organic Farming

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Content

1 BASIC PRINCIPLES OF A PARTICIPATORY LEARNING MODEL FOR FARMER EDUCATION BASED ON EXPERIENTIAL LEARNING

Organic farming is an overall system of farm management and food production that combines good agricultural practices, a high level of biodiversity, the conservation of natural resources, the application of high animal welfare standards and a production method that meets the preference of certain consumers for products derived from natural substances. Changes in the production technologies of interesting plants and animals require a more subtle approach to organic farming. In general, organic agriculture refers to farming systems that avoid the use of synthetic pesticides and fertilizers. Conversion from conventional to organic farming describes the process of learning and implementing changes on the farm toward a more sustainable and natural way of farming. The more a farmer knows about organic farming concepts and practices, the easier it will be to convert to organic farming. Therefore, education for organic farming is crucial.

Agricultural extension has long been seen as a key element in improving agricultural development. However, the effectiveness of two dominant approaches to agricultural extension services in particular—Training and Visit (T&V) and Farmer Field Schools (FFS)—has been widely debated. The T&V approach relies on the *"top-down"* extension of technical information, with specialists and field staff transferring knowledge to "contact farmers" in villages, who in turn are responsible for diffusing knowledge into the local community. As a response to this top-down approach, FFS were developed as a *"bottom-up"* approach to extension with a focus on participatory, experiential, and reflective learning to improve the problem-solving capacity of farmers through highly trained facilitators working with farmer groups.

1.1 Participatory approach –an alternative system of learning

Learning outcomes

- Describe participatory approach paradigm and explain basic principles of participatory learning.

The participatory approach advocates the active involvement of the public in decision-making processes, with appropriate public depends on the topic at hand. The public may be average citizens, stakeholders of a particular project or policy, experts and even members of government and private industry. In general, policy processes can be seen as a three-step cycle of planning, implementation and evaluation, where a participatory approach can be applied to some or all of these steps (Figure 1.1).

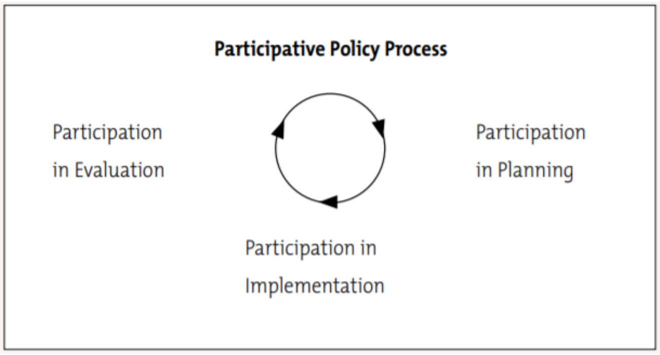


Figure 1.1. Participative policy process

From a pragmatic point of view, it is better to have as much knowledge, experience and expertise as possible in dealing with the complex (and therefore uncertain) nature of social issues and problems. It is necessary to create access for all relevant people to contribute to solutions and planning for the future.

From a normative perspective, new problems and issues in society often raise questions for which existing social norms are inadequate or non-existent, causing uncertainty and anxiety in society. In addition, pluralism (often of conflicting) norms in society, it is often mixed with interests (financial or otherwise) that are unevenly represented in society. It is therefore desirable to allow as democratic a process as possible to ensure that all values and opinions can be represented in discussions and decision-making.

Participatory processes are expected to be able to involve the public directly in planning and implementation. The participatory approach is seen as a way to strengthen social cohesion. It is a useful process for building consensus when differences of opinion and even disputes need to be resolved. When this approach is used at the beginning of the process, participants can share their views, values and reflections on the emerging issue as they are still developing and maturing. Where opinions are already polarized, some methods are particularly useful in mediating between stakeholders to reach a consensus or at least a joint decision after all views have been presented. All views are expressed. At least through these processes, mutual understanding is achieved, and all voices can be heard.

Involvement in participatory processes also builds public capacity. It does this by educating the public and creating networks of relevant people. In doing so, not only the public learns, but also decision-makers learn how to improve their services and products when they receive direct feedback from "users". Rather than creating first and then fixing, it is most effective to involve end-users’ in initial design and planning.

1.1.1 Concept of participatory approach in learning

Learning should be understood as a meaning-construction process. To achieve such meaningful learning, the basic activities in the process of knowledge creation must be directed towards the construction of meanings for the learners themselves. Therefore, learning strategies should be implemented that provide learners with the tools to construct their own corpus of learning strategies and thus contribute to their holistic learning.

The concept of participatory learning emphasizes learning through active engagement, participation, constructing knowledge and participation in the learning experience through collaborative learning, co-learning and engagements. In participatory learning, learners are at the center of learning. Reciprocal processes between learners are essential to create multiple and strong relationships to carry out learning activities for continuous learning by producing knowledge, harvesting knowledge to generate more new ideas and contributing back to the community.

Most participatory approaches involve small groups, usually with learners of different levels of ability, working together to solve a group task where each member is individually responsible for a part of the outcome that cannot be achieved if the members do not participate/work together. Members are positively independent and use a variety of learning activities to enhance their understanding of the subject. In participatory learning, the role of the learner is crucial and vital, as it is the learner who can achieve the distant conditions of his/her learning, and the teacher as a facilitator of the learner's autonomy building. By allowing learners to take control of their own activity, it signifies their involvement in the educational task, as the initiative will come from within each learner, thus responding to their interests and needs.

Participatory learning is a leaner centered approach. Learners take control of their own activity and participate in decision-making. The facilitator and learners negotiate together to define content that reflects the needs and demands of the learners. In participatory learning, the learner does not learn alone, but in the company of a group or peers who learn cooperatively together. In participatory learning, learning is a process that goes beyond the four walls of the classroom and is not confined to the classroom.

Participatory methods comprise a range of activities with the common thread of empowering ordinary people to take an active and influential part in the decisions that affect their lives. This means that people are not only listened to, but also heard, and their voice shapes the outcomes.

Researchers, community members, activists and donors use participatory methods. Because respect for local knowledge and experience is paramount, the results of interventions reflect local realities, often leading to better-supported and longer-lasting social change. Participatory methods can be used in all phases of the project cycle related to development aid, whether people are involved in analysis, joint decision-making, planning or reflection. They are also useful in political processes as a tool to strengthen citizen participation, promote rights and hold the powerful to account.

1.1.2 Basic principles of participatory learning

For a wider range of development programmes, these approaches represent a significant departure from standard practice. Some of the changes being implemented are remarkable. In a growing number of government and non-government institutions, extractive research is being replaced by research and analysis carried out by local people themselves. Methods are being used not only to inform local people externally, but also for people themselves to analyze their own situation.

The interactive involvement of many people in differing institutional contexts has promoted innovation and ownership, with many variations in the way that systems of learning have been put together. There are many different terms, but they have the following important common principles:

- A defined methodology and systemic learning process. The focus is on cumulative learning by all the participants and, given the nature of these approaches as systems of learning and interaction, their use must be participative.
- Multiple perspectives. A central objective is to seek diversity, rather than to characterize complexity in terms of average values. The assumption is that different individuals and groups make different evaluations of situations, which lead to different actions. All views of activity or purpose are heavy with interpretation, bias, and prejudice, and this implies that there are multiple possible descriptions of any real-world activity.
- Group learning processes. All involve the recognition that the complexity of the world will only be revealed through group inquiry and interaction. This implies three possible mixes of investigators, namely, those from different disciplines, from different sectors, and from outsiders (professionals) and insiders (local people).
- Context specific. The approaches are flexible enough to be adapted to suit each new set of conditions and actors, and so there are multiple variants.
- Facilitating experts and stakeholders. The methodology is concerned with the transformation of existing activities to try to bring about changes which people in the situation regard as improvements. The role of the "expert" is best thought of as helping people in their situation carry out their own study and so achieve something. These facilitating experts may be stakeholders themselves.
- Leading to sustained action. The learning process leads to debate about change, and debate changes the perceptions of the actors and their readiness to contemplate action. Action is agreed upon, and implementable changes will therefore represent an accommodation among the different conflicting views. The debate or analysis both defines changes which would bring about improvement and seeks to motivate people to take action to implement the defined changes. This action includes local institution building or strengthening, thus increasing the capacity of people to initiate action on their own.

These alternative systems of learning and action imply a process of learning leading to action. A more sustainable agriculture, with all its uncertainties and complexities, cannot be envisaged without all actors being involved in continuing processes of learning.

Revision questions

1) What is expected from a participatory approach (circle the correct statement – multiple are possible)

1. A particular group of individuals or one institution solves a social issues and problems, relying solely on its own findings and interests.
2. The public is directly involved in planning and implementation. The participatory approach is seen as a way to strengthen social cohesion.
3. The public accepts solutions without taking an active part in situation
4. Builds public capacity by educating the public and creating networks of relevant people/stakeholders.

2) Participatory approach in learning is (circle the correct statement – multiple are possible)

1. A traditional/standard approach of teaching and learning
2. A learner centred approach
3. Where learners take control of their own activity and participate in decision-making.
4. Where the facilitator and learners negotiate together to define content that reflects the needs and demands of the learners.
5. Where the teacher plans all the activities for the participants and the content of the sessions

3) Basic principles of participatory learning (mark true or false)

1. The focus is on cumulative learning by all the participants. **T or F**
2. A central objective is to characterize complexity in terms of average values. **T or F**
3. Group learning processes involving experts from one field. **T or F**
4. The learning/teaching methodology is concerned with the transformation of existing activities to try to bring about changes which people in the situation regard as improvements. **T or F**
5. The approach suit just to a certain situation with specific conditions and actors, and so there is one solution. **T or F**
6. Action is agreed upon, and implementable changes will therefore represent an accommodation among the different conflicting views. **T or F**

1.2 Importance of group learning

Learning outcomes

- Apply domains of learning in a participatory learning approach.
- Identify the participants, form the learning group and determine the role of the participants.
- Recognize the stages of group development.
- Distinguish between the role of the teacher and the facilitator.

1.2.1 Domains of learning

People approach knowledge with an orientation towards technical control, towards mutual understanding in the conduct of life, and towards emancipation from apparently 'natural constraints'. Habermas presents three cognitive interests that are common to all people and that underlie their interest in learning: the technical, the practical and the emancipatory (Table 1.1 and 1.2). These three cognitive interests grow out of three distinct areas of human social existence: work, interaction with others, and power. As cognitive interests, they govern people's interest in acquiring knowledge and are therefore the foundation of human conduct. The following sections outline the characteristics of the learning domains associated with each cognitive interest.

Table 1.1 Domains of learning

Domain of learning	Characteristics
Technical	1. Aims at technical control of environment 2. Characterized by instrumental action 3. Goal: effective prediction and control of reality 4. Use of hypotheses, experiments, critical discussion as in empirical sciences
Practical	1. Understanding and meaning of social processes with others

	2. Characterized by communicative action 3. Goal: the meaning of interactions and patterns 4. Use of discourse, metaphor, and critical discussion as in historical hermeneutic sciences
Empowerment	1. Internal and environmental factors that inhibit our control over our own lives 2. Characterized by self-reflective action 3. Goal: able to differentiate between factors that are beyond our control and those falsely assumed to be beyond our control, in order to expand our area of action 4. Self-reflection, critical thinking

Source: Habermas, 1971

Table 1.2 Application of domains of learning in participatory learning approach

Domain of learning	Characteristics
Technical	1. Group manages the use of agricultural inputs based on their analysis of field conditions and knowledge of plant requirements. 2. Group is able to analyse ecological conditions based on participants' understanding of field ecology. 3. Group designs and implements field studies that will help participants increase knowledge of ecological and agronomic issues
Practical	1. Participants are able to effectively collaborate among themselves and with others. 2. Participants facilitate/participate in group processes aimed at identifying, analysing and solving problems. These processes are characterized by communicative action. 3. Group facilitates learning among others so that integrated pest management (IPM) becomes the accepted approach to plant growing in their village. 4. Group organize community action to solve agriculture problems.
Empowerment	1. Group develops skills that support critical thinking. Participants are able to identify and analyse field problems and take action to solve them in common with others. 2. Analytical skills of group result in expanded area of action. Participants are able to organize community action, information networks, village IPM programmes.

Source: Habermas, 1971

1.2.2 Four stages of group development

When several people come together to work on a single initiative or project, they are not necessarily a productive team. Before a group of people can function together, they must pass through a four stages of group development (Tuckman, 1965):

1. Forming
- Group is not yet a group, but a set of individuals
- Individuals want to establish personal identity within the group and make an impression
- Participation is limited as individuals get familiar with the setting, the trainer and each other
- Individuals begin to focus on task at hand and discuss its purpose
- The group is essentially evolving ground rules on which future decisions and actions will be based

2. Storming

- Characterized by intra-group conflict and lack of unity
- This stage commonly begins on the 2-3 day of a training programme
- Preliminary ground rules on purpose, leadership and behavior are damaged
- Individuals can become hostile towards each other, and express their individuality by pursuing or revealing personal agendas
- Friction increases, rules are broken, arguments can happen
- But, if successfully handled, this stage leads to new and more realistic setting of objectives, procedures and norms

3. Norming

- Characterized by overcoming tensions and by developing group cohesion in which norms and practices are established
- Group members accept the group and each other's behavior peculiar to an individual
- Group allegiance develops and group strives to maintain it
- Development of group spirit, harmony become important

4. Performing

- Characterized by full maturity and maximum productivity
- Can only be reached by successfully completing previous three stages
- Members take on roles to fulfil the group activities since they have now learnt to relate to one another
- Roles become flexible and functional
- Group energy channeled into identified tasks
- New insights and solutions begin to emerge

1.2.3 Group composition

When a group works together, it can achieve a common goal and purpose. To do this, it needs to have members with the right range of skills and knowledge. Small groups may be less effective because of the limited collective range of skills and knowledge. However, if the group is too large, the more active members can have a strong influence on the group (Table 1.3). For optimal productivity and cooperation, a group of 5-7 team members is usually best.

Table 1.3 Group size – productivity and cooperation

Group size and participation
3-6 people: Everyone speaks 7-10 people: Almost everyone speaks Quieter people say less One or two may not speak at all 11-18 people: 5 or 6 people speak a lot 3 or 4 others join in occasionally 19-30 people: 3 or 4 people dominate 30+ people: Little participation possible

1.2.4 Identification of the participants

The following points should be taken into account for the identification and selection of participating farmers:

- Compiling a list of potential local farmers according to the intended activity of the project
- Informing local farmers about the purpose of the project in a joint meeting or through individual presentations
- Identify participants and form a learning group, identify around 30-40 farmers who share a common concern and interest in the topic. Selecting a larger number of farmers at the beginning helps, as the group is likely to shrink after the first few meetings.
- Selecting established groups such as self-help groups, youth groups and/or women's groups.
- It is recommended that the participant is the decision-maker on the farm.
- Should attend most or all sessions and be willing to participate in the group and share ideas and knowledge with other farmers.

The facilitator's familiarity with the history of the community, its cultural practices, gender relations, and potential areas of conflict are important elements in the selection process. Groups may consist of same-gender or mixed gender depending on the culture and topic.

1.2.5 Selection criteria of participants in Farmer Field Schools

Participants shall be:

- Active and practicing farmer.
- Willingness to participate (volunteer).
- Ready to work in a group.
- Socially acceptable.
- Must have good relationship with others.
- Willing to learn for their own development.
- Farmers must have a common interest.
- Must come from same locality (area).
- Willing to follow the norms set by the group.
- Must be willing to share experiences.

1.2.6 'Team Role' of the participants

The term 'Team Role' refers to one of nine clusters of behavioral attributes, identified by Dr Meredith Belbin's research at Henley, as being effective in order to facilitate team progress.

Tree communication-oriented roles:

1. Resource Investigator*:* Uses their inquisitive nature to find ideas to bring back to the team. They are outgoing and enthusiastic. Explores opportunities and develops contacts. Allowable weaknesses are that they might be over-optimistic and can lose interest once the initial

enthusiasm has passed. Don't be surprised to find that they might forget to follow up on a lead.

2. Team Worker: Helps the team to gel, using their versatility to identify the work required and complete it on behalf of the team. They are co-operative, perceptive and diplomatic. Listens and averts friction. They can be indecisive in crunch situations and tend to avoid confrontation. They might be hesitant to make unpopular decisions.
3. Coordinator: Needed to focus on the team's objectives, draw out team members and delegate work appropriately. They are mature, confident and identify talent. Clarify goals. They can be seen as manipulative and might offload their own share of the work. They might over-delegate, leaving themselves little work to do.

Tree knowledge-oriented roles:

4. Plant: Tends to be highly creative and good at solving problems in unconventional ways. They are creative, imaginative, free-thinking, generate ideas and solve difficult problems. They might ignore incidentals and may be too preoccupied to communicate effectively. They could be absent-minded or forgetful.
5. Monitor Evaluator: Provides a logical eye, making impartial judgements where required and weighs up the team's options in a dispassionate way. They are sober, strategic and discerning. Sees all options and judges accurately. They are sometimes lacking the drive and ability to inspire others and can be overly critical. They could be slow to come to decisions.
6. Specialist: Brings in-depth knowledge of a key area to the team. They are single-minded, self-starting and dedicated. They provide specialist knowledge and skills. They tend to contribute on a narrow front and can dwell on the technicalities. They overload you with information.

Tree action-oriented roles

7. Shaper: Provides the necessary drive to ensure that the team keeps moving and does not lose focus or momentum. They are challenging, dynamic, thrive on pressure. Has the drive and courage to overcome obstacles. They can be prone to provocation and may sometimes offend people's feelings. They could risk becoming aggressive and bad humored in their attempts to get things done.
8. Implementer: Needed to plan a workable strategy and carry it out as efficiently as possible. They are practical, reliable and efficient. Turns ideas into actions and organizes work that needs to be done. They can be a bit inflexible and slow to respond to new possibilities. They might be slow to relinquish their plans in favor of positive changes.
9. Completer Finisher: Most effectively used at the end of tasks to polish and scrutinize the work for errors, subjecting it to the highest standards of quality control. They are painstaking, conscientious and anxious. Searches out errors. Polishes and perfects. They can be inclined to worry unduly, and reluctant to delegate. They could be accused of taking their perfectionism to extremes.

1.2.7 Role of the facilitator

A professional facilitation service 'Findafacilitator' defines the role of a facilitator who facilitates or simplifies an action or process in a group. This person has to keep the group focused, take the group deeper into the topic and (sometimes) manage a potentially volatile situation. This is a dynamic role in which the facilitator conveys important content and helps to establish productive interactions without necessarily knowing as much as the individuals they are facilitating.

A good facilitator is focused on the topic at hand, the process of interaction and the participants and the optimal way to achieve the goal. This is a complex balancing that requires many skill sets. There are eight different roles that a facilitator is likely to play during a session:

- Motivator: From the rousing opening statement to the closing words of cheer, you ignite a fire within the group, establish momentum, and keep the pace.
- Guide: You know the steps of the process the group will execute from beginning to end and carefully guide the participants through each step in turn.
- Questioner: You listen carefully to the discussion and quickly analyze comments to formulate questions that help guide a productive group discussion and challenge the group when appropriate.
- Bridge Builder: You create and maintain a safe and open environment for sharing ideas. Where other people see differences, you find and use similarities to establish a foundation for building bridges to consensus.
- Clairvoyant: Throughout the session, you are attuned to signs of strain, weariness, aggravation, and disempowerment, and respond in advance to prevent dysfunctional behavior.
- Peacemaker: Although it is generally better to avoid direct confrontations, should it happen, you step in quickly to reestablish order and direct the group toward a constructive resolution.
- Taskmaster: You are ultimately responsible for keeping the session on track. This entails tactfully cutting short irrelevant discussions, preventing detours, and maintaining a consistent level of detail throughout the session.
- Praise: At every opportunity, you should praise participants for good effort, progress, and results – praise well, praise often, praise specifically.

Facilitator:

- Has much to do with setting the initial mood or climate of the group or class experience.
- Helps to elicit and clarify the purpose of the individuals in the class as well as the more general purposes of the group.
- Relies upon the desire of each student to implement those purposes that have meaning for him or her as the motivational force behind significant learning.
- Endeavors to organize and make easily available the widest possible range of resources for learning.
- Regards himself or herself as a flexible resource to be utilized by the group.
- In responding to expressions in the classroom group, accepts both the intellectual content and the emotionalized attitudes, endeavoring to give each aspect the approximate degree of emphasis that it has for the individual or the group.
- As the acceptant classroom climate becomes established, the facilitator is able increasingly to become a participant learner, a member of the group, expressing his or her views as those of one individual only.
- Takes the initiative in sharing himself or herself with the group - feelings as well as thoughts - in ways that do not demand or impose but simply represent a personal sharing which students may take or leave.

- Throughout the classroom experience, he/she remains alert to expressions indicative of deep or strong feelings.
- In his or her functioning as a facilitator of learning, the leader endeavors to recognize and accept his or her own limitations.

Revision questions

1) Enter three domains of learning

1. _ _ _ _ _ _ _ _ _ _ _ _
2. _ _ _ _ _ _ _ _ _ _ _ _
3. _ _ _ _ _ _ _ _ _ _ _ _

2) How many stages of group development must participants pass that can function together as a group? (mark the right answer)

1. Three
2. Four
3. Five
4. Six

3) In "Norming" stage (circle the correct statement – multiple are possible)

1. Participants begin to focus on the task at hand and discuss its purpose.
2. Participants accept the group and each other's behaviour
3. Friction increases, rules are broken, arguments can happen
4. Roles become flexible and functional
5. Group spirit becomes important

4) When the group works together, it can achieve a common goal and purpose. For optimal productivity, how many members per group is usually best? (mark the right answer)

1. 1-3 members
2. 3-6 members
3. 6-10 members
4. 11-18 members

5) Link the roles in the team (number in front of the role) to the corresponding behavioural attributes

Role in the team	No.	Behavioural attributes.
1. Team Worker		Uses their inquisitive nature to find ideas to bring back to the team
2. Shaper		Most effectively used at the end of tasks to polish and scrutinize the work for errors, subjecting it to the highest standards of quality control.
3. Monitor Evaluator		Needed to focus on the team's objectives, draw out team members and delegate work appropriately.
4. Implementer		Brings in-depth knowledge of a key area to the team
5. Resource Investigator		They are creative, imaginative, free-thinking, generates ideas and solves difficult problems.
6. Specialist		Turns ideas into actions and organizes work that needs to be done.

7. Coordinator		Provides a logical eye, making impartial judgements where required and weighs up the team's options in a dispassionate way.
8. Plant		Helps the team to gel, using their versatility to identify the work required and complete it on behalf of the team.
9. Completer Finisher		Provides the necessary drive to ensure that the team keeps moving and does not lose focus or momentum.

6) Link the roles of the facilitator (number in front of the role) to the corresponding set of skills

Facilitator's role	No.	Set of skills
1. Motivator		You listen carefully to the discussion and quickly analyze comments to formulate questions that help guide a productive group discussion and challenge the group when appropriate.
2. Clairvoyant		From the rousing opening statement to the closing words of cheer, you ignite a fire within the group, establish momentum, and keep the pace.
3. Taskmaster		You know the steps of the process the group will execute from beginning to end and carefully guide the participants through each step-in turn.
4.Questioner		You create and maintain a safe and open environment for sharing ideas. Where other people see differences, you find and use similarities to establish a foundation for building bridges to consensus.
5. Peacemaker		At every opportunity, you should praise participants for good effort, progress, and results – praise well, praise often, praise specifically
6. Praise		You are ultimately responsible for keeping the session on track. This entails tactfully cutting short irrelevant discussions, preventing detours, and maintaining a consistent level of detail throughout the session.
7. Guide		Although it is generally better to avoid direct confrontations, should it happen, you step in quickly to re-establish order and direct the group toward a constructive resolution.
8. Bridge Builder		Throughout the session, you are attuned to signs of strain, weariness, aggravation, and disempowerment, and respond in advance to prevent dysfunctional behaviour.

1.3 Concept of the Farmer Field School (FFS)

Learning outcomes

- Describe concept of the FFS and its background.
- Explain FFS general learning principles.

Farmer Field School (FFS) is a people-centered learning approach that uses participatory methods to create an environment conducive to learning. Participants can share knowledge and experiences in a risk-free environment. Practical field exercises with direct observation, discussion and decision-making promote learning through practice. The field is a place where local knowledge and external scientific findings are tested, validated and integrated in the context of the local ecosystem and socio-economic environment. Community-based problem analysis is the starting point for the FFS team to develop a place-based curriculum. Several technical topics are being addressed in FFS: soil, crop and water management, seed multiplication and variety testing, integrated pest management (IPM), agro pastoralism, aquaculture, agroforestry, nutrition, value chain and linkage to markets, etc.

The FFS provides a space for practical group learning, strengthening the critical analysis and decision-making skills of local people. FFS activities take place on the ground and involve experimentation in problem solving, reflecting the specific local context. Participants learn how to improve skills by observing, analysing and trying out new ideas in their fields, which contributes to improved production and livelihoods. The FFS process enhances individual, household and community empowerment and cohesion.

The complete production cycle linked to the corresponding biological cycle determines the duration of the FFS learning programme. In a typical FFS, a group of farmers/herders /fishermen meet regularly in the local field under the guidance of a trained facilitator. They observe the local production system, focusing on the topic under study and observe and compare the effects of two or more alternative practices to solve the problem, one following local practice and the other testing a proposed 'best practice'. Participants discuss and make decisions based on observations and analyses directly on the plots, using agro-ecological system analysis (AESA).

At the end of the season, the FFS team organizes a field day to share findings with local authorities, agriculture workers and other farmers. Exchange visits with other FFSs are also encouraged. Post-FFS activities strengthen community development.

1.3.1 Background

FFS as an extension approach grew as a response to a rice insect outbreak in the 1980s in Indonesia. Methods of delivering messages were often inappropriate and too simple to deal with complex problems. Instead, it proved necessary to ensure local decision making by farmers in their own fields. The hands-on practical learning in FFS, building on adult education principles and experiential learning emerged as a mean of facilitating critical decision-making skills among farmers to deal with complex farming problems.

FFS is a school without walls that provides a forum where farmers meet regularly to make field observations, relate their observations to the ecosystem and apply their previous experience and any new information for informed crop or livestock management decisions. FFS operates through groups of people with a common interest, who get together on a regular basis to study the *"how and why"* of a particular topic.

1.3.2 General learning principles of FFS

Learning by doing
Participants/farmers do not change their behavior and practices just because someone tells them what to do or how to change. They learn better by experience than by passively listening to lectures or demonstrations. That is why it is all about learning by doing and trying out new ideas and practices on the field.

The field is the learning ground

The field is the main learning space around which all activities are organized. Farmers learn directly from what they observe, collect and experience in their surroundings, not from textbooks. Participants also prepare their own learning material (drawings, etc.) based on what they observe.

Competences, not information, is the goal

The focus is on developing skills and competences, not on learning about new technological possibilities. The emphasis is on understanding the basic science behind the different aspects of the agroecosystem so that farmers can implement the innovation process themselves, i.e. to understand the "why" behind the "how". Technologies are not taught as model solutions but as examples of how to support different agro-ecological processes.

Experiential learning

The basic assumption is that learning is always based on prior experience, which is unique to everyone, and that any attempt to promote new learning must take experience into account in some way. Therefore, exchange and discussion between participants is a fundamental element of participatory and experiential learning.

Discovery based learning

Technical information is presented as much as possible through discovery-based exercises rather than lectures. Discovery-based learning is an essential component as it helps participants to develop a sense of ownership and gain confidence in their ability to replicate activities and results on their own. These exercises usually last between 1 and 3 hours to fit into a regular session and address the learning topic of the day in a practical way, for example: building an insect zoo to observe the behavior and interactions of different insects, digging soil pits to analyze species and soil layers, breeding ticks to understand the life cycle, etc. Groups learn a variety of analytical methods to help them acquire the ability to identify and solve problems. There is no single definition of what constitutes discovery-based exercise, but certain principles form a framework:

- The learning field provides the main learning materials, and any exercise should have its roots in the farmers' fields.
- Activities are based on what is happening in farmers' field at this time. One cannot discover something if it happened in the past or will happen in the future.
- Any activity should build on farmers' experiences of the topic, i.e. include discussion and sharing among participants in order to gain insights from local practices, as well as identify technical gaps.
- The people who are discovering are primarily the farmers. The purpose is to help participants remember more of what they are learning; therefore, exercises are designed for practical discovery rather than only by seeing or hearing something.

Participants owned curriculum

Farmers, not the facilitator, decide which topics are important to them and what they want to cover and address in their curriculum. The facilitator only guides them through their learning process by creating opportunities for participants to engage with new experiences. This ensures that the information is relevant and tailored to the actual needs of the participants. Training activities should be based on existing gaps in the knowledge and skills of the community and consider the community's level of understanding. Each group is different and has its own needs and realities. As participants develop their own content, each of them is therefore unique. As agriculture is usually closely linked to other aspects of livelihoods, the curriculum will also include non-agricultural issues identified by farmers, such as human health, nutrition, environmental issues, etc. These issues are included as specific topics in the weekly meeting schedule. Another feature of the curriculum is that it follows the natural cycle of its subject, i.e. from "seed to seed" or from "egg to egg". Thus, farmers can discuss and observe aspects in the field in parallel with what is happening in their fields, e.g. learning about weeds takes place when it is weeding time, etc.

Group trials and experimentation

Innovation and experimentation are essential components of the learning process and offer opportunities for learning and capacity building among participants to continuously adapt to change and improve the way they manage their resources. Group-managed experiments usually become a meeting place and a space for group learning.

In the learning design phase, an experimental topic is identified, followed by decisions on different technologies or practices to be explored and compared to address a particular constraint. These may be technologies derived from research, or simply innovations by farmers or local practices. Typical experiments might be trials and comparisons of new crop varieties, options for improved soil management, housing and more.

In experimentation, a control treatment is usually included in the design to provide a standard against which different (new) alternatives can be compared. Depending on the objective of the experiment and the topic of the study, different types of control treatments may be used. Often, control treatments are a common practice of farmers. This allows farmers to directly compare new alternatives with their own practice, for example in terms of work and inputs required as well as performance. The process also shows the link between farming practices and results and explains to farmers the reasons for good yields or performance.

Facilitation, not teaching

Facilitators guide the learning process, not by teaching, but by mentoring and supporting participants to take responsibility for their own learning. In discussions, the facilitator contributes, facilitates and enables the group to reach consensus on what actions to take. Researchers, subject-matter experts and external experts are occasionally invited to provide technical support to the groups as needed. During the sessions, the facilitator is expected to take the final role and let the participants lead the learning activities, with the facilitator being more present as a mentor and guide to the process. Facilitators should not answer technical questions directly but instead try to probe and ask counter-questions in order to stimulate reflection and learning. In discussions on technical issues, the facilitator tries to moderate a discussion in which most of the information is provided by the group members. To facilitate everyone's participation, small group discussions are usually used, where participants first discuss among themselves in groups of 3-4 and then discuss the issue in plenary.

Systematic learning process

The group follows the same systematic learning process, based on observation and analysis of field experimental activities. Farmers meet weekly (most annual crops and livestock), twice a week (some long-term crops) or monthly (most perennial crops) according to a regular schedule set by the group members. Farming-related topics are intertwined with the group's organizational aspects and group dynamics to form learning sessions, which are usually weekly and last half a day. All strenuous activities, such as taking care of the plots or animals, sowing, weeding, watering, feeding, etc., take place before or after the learning meetings, or in specially planned meetings on the working day. Between the establishment of the group and the start of the regular learning cycles, there is a period of group establishment, usually referred to as fieldwork. This period includes the formation and organization of the group, the definition of problems, the setting up of on-farm experiments, which usually takes between one and three months.

Special topics of the day

Technical information to complement ‘learning by doing’ and experimentation in the field is usually the special topic of the day. This is an opportunity for the facilitator, researcher or expert to provide the technical information needed for a general understanding of the topic and to even out the knowledge among the participants. The topic of the day is usually related to agriculture but can be any topic. Participants may have other problems and feel the need to discuss the issues. If the facilitator does not have specific expertise, external experts or other community members can be invited to lead the discussion. The facilitator's role is to focus on a particular topic at a time that is most convenient for the group participants.

Agro-Eco System Analysis

The cornerstone of the FFS approach is Agro-Ecological System Analysis (AESA), which is a field-based analysis of the interactions between crops/livestock and other biotic and abiotic factors that co-exist in the crop/livestock field. The purpose of AESA is to teach farmers to make regular observations in the field, to analyze problems and opportunities that arise in the field, and to improve decision-making skills for farm management. The analysis follows a cycle of observation, analysis and action. By conducting AESA on a regular basis (usually weekly, fortnightly or monthly, depending on the topic of the study), farmers develop a mental checklist of indicators to observe when monitoring on-farm practices. The process is holistic, and farmers work in sub-groups of 4 to 5 people under the guidance of a facilitator to enhance the participatory process. Typically, this exercise lasts about 2-3 hours and is carried out throughout the season or learning cycle, so that the problems and decisions studied overlap with similar issues in the participants' own fields, increasing motivation to learn.

Group Organization

Empowerment is facilitated through collective action by providing well-organized groups in which participants have the opportunity to practice different aspects of management and leadership. A detailed timetable and group norms and rules are usually followed to enforce discipline and structure. Groups develop their own vision and learning objectives. The ideal number of members is 20-30 farmers of mixed gender. To ensure participation of all, sub-group arrangements are used where small groups of 3-5 individuals are formed at the beginning of the learning cycle. Each sub-group has its own responsibilities, usually in rotation, such as hosting and running the weekly meetings, hence the term 'host group'. These sub-groups also carry out core field activities such as AESA, and often each group is responsible for one treatment option in the experimental field. By choosing their own names, slogans and mottos, these sub-groups have their own identity and establish themselves. Sometimes groups are further encouraged to register with local authorities and open a bank account for sustainability after the learning cycle is over, when the group can move on to other activities. The group should have an established leadership structure with democratically elected officers and group rules and statutes.

Group dynamic exercises

The FFS group uses dynamic exercises such as energizers, drama, song, and dance to create a pleasant and informal learning environment. These exercises facilitate learning and create a space for reflection and sharing. They also enhance capacity building in the areas of communication skills, problem solving and leadership skills. In addition, group dynamics can be an effective way to address sensitive topics such as domestic violence, alcoholism, as well as to remember key professional messages in oral form. Each learning session includes a group dynamics component, usually led by the host team of the day or by any member of the group.

Revision questions

1) General learning principles of the Farmer Field School concept (mark true or false)

- Systematic learning process – The group follows the same systematic learning process, based on observation and analysis of field experimental activities. T or F
- Special Topics of the day – This is an opportunity for the facilitator, researcher, or expert to provide the technical information needed for a general understanding of the topic. T or F
- The field is the learning ground – Participants learn directly from what they observe, collect and experience in their surroundings. T or F
- Group Organization – To ensure participation of all, sub-group arrangements are used where small groups of 10-18 individuals are formed at the beginning of the learning cycle. T or F
- Competences, not information, is the goal – The focus is on learning about new technological possibilities. T or F
- Group dynamic exercises – These exercises facilitate learning and create a space for reflection and sharing. T or F
- Discovery based learning – Technical information is presented as much as possible through lectures. T or F
- Participants owned curriculum – Training activities should be based on existing gaps in the knowledge and skills of the community and take into account the community's level of understanding. T or F
- Group trials and experimentation – The process shows the link between farming practices and results and explains to farmers the reasons for good yields or performance. T or F
- Learning by doing – Participants learn better by passively listening to lectures or demonstrations. T or F
- Facilitation, not teaching – Facilitators guide the learning process by teaching, takes responsibility for participants' activities and learning. T or F
- Agro-Eco System Analysis – The cornerstone of the FFS approach is Agro-Ecological System Analysis. T or F
- Experiential learning – Exchange and discussion between participants is a fundamental element of participatory and experiential learning. T or F

1.4 Learning cycle in FFS and facilitation of the scientific attitude

Learning outcomes

- Describe concept of the FFS and its background.
- Prepare, integrate, and conduct six steps of study for specialized courses in the field of the organic plant protection.
- Apply different matrixes for each steps aiming to support participants' exploring and reflecting over their practices.

First, the facilitator must be aware that science is not reserved just for professional scientists. To facilitate scientific method enables farmers to learn about the basic principles and processes in their crop ecosystem. They do simple studies, compere treatments, and learn through their observations in the field. This approach (FFS) facilitates scientific attitude. Farmers learn to ask questions and a way to answer them.

Initial basic learning cycle aims to strengthen farmers' skills and knowledge for critical analysis, to test and validate new practices and to assist in making informed decisions on field management. The learning process reinforces the understanding of complex ecological relations in the field. The learning cycle also aims to enhance participants' group cohesion so that they can better work as a group, analyze questions or problem critically, draw on their own experience and observations and the experience and knowledge of others, create a consensus, and prepare for follow-up action once the learning cycle finishes.

The learning cycle below represents six essential steps in conducting a study. It resembles an experiential learning cycle adapted for use in field study (Figure 1.2). Experiential learning is relevant for agricultural extension since it provides a means to work with groups to find their own solutions to problems through testing and experimentation of ideas and practices which are closely related to their own everyday farming activities. This is relevant for study of methods aiming to support farmers' exploring and reflecting over their practices, since farmers' knowledge is by nature experiential.

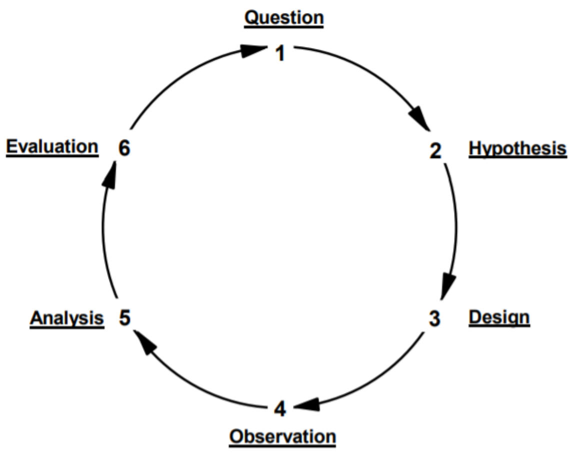


Figure 1.2 The learning cycle (Kolb; FAO. Community IPM)

1.4.1 Six steps of conducting a study

First step: Question (Topic to be selected)

To help farmers formulate a question about their crop, the Topic-selection Matrix is used (Table 1.4).

Table 1.4 Problem based Topic-selection Matrix

Topic-selection Matrix – Problems based				
Problems (causes of low yield)	Current practice	Potential for improvement	Constraint concerning improvement	Suggested topics
Poor establishment of seedlings	Broadcast seeding Uncertified seed	Transplanting may be better Certified seed	Extra labor not available Cost	Seed comparison
Improper application of N	Low use of fertilizers	Use of manure	Probably increases costs	Use of manure
Weeds	2x mechanical weeding	Increased weeding Increased flooding	Labor costs Lack of control over irrigation	Intensity of weeding -
Rats	No control	Area-wide baiting; studies	Time, cost, Collaboration	-

At the end of listing relevant problems, the group discusses the selection of the best topic.

As an alternative to just listening the problems, participants can start listing agricultural operations from seeding, through planting till harvest and identify possible problems. This method takes more time but considers all stages of farming to help farmers select their topic for study (Table 1.5).

Table 1.5 Agricultural operations-based Topic-selection Matrix

Agricultural operations-based Topic-selection Matrix				
Agricultural operation	Current practice	Potential for improvement	Constraint concerning improvement	Suggested topics
Soil preparation	Shallow ploughing	Deep ploughing	Earthworms and other organisms are destroyed to improve the soil to benefit the crops	Organisms living in the ground Difference in the crop in ploughed and unplugged soil
Seeding	...	...	...	...
Harvesting	...	...	...	...

Second step: Hypothesis (Ideas to be tested)

After selecting the topic for study, farmers must specify what exactly they want to find out. Idea Matrix is a tool which encourages farmers to consider all possible effects of the selected topic. It (Table 1.6) is prepared after a topic for study has been determined. It consists of three columns.

In the first column farmers describe their ideas about the selected topic, by asking: "What possible influences will the topic of the study have on the crop system as a whole?"

These ideas should address influences:

- on the crop,
- on the ecosystem,
- on social and economic aspects.

In the second column farmers specify the source of these ideas; some ideas may be proven facts, others just thoughts not based on any facts, or they may be proven under different circumstances. In the third column farmers write what they think about each idea; is it true, is it reliable, is it relevant or applicable to the local situation; this is to determine whether the idea needs to be tested.

An Idea Matrix is of central importance for a study. These are the ideas which need testing. Farmers can use this matrix as a basis to plan their observations: Are yield samples sufficient, or should additional observations be made on weeds, plant growth, and insect levels? After completion of the study, the test results for each of the ideas is evaluated. Therefore, farmers should retain the Idea Matrix throughout the length of the study.

Table 1.6 Idea Matrix

Idea Matrix – Use of biopesticides to control whitefly in tomato production		
Ideas - What possible effects will the topic of study have?	Source of each idea	What do we think about each idea? - Does it need to be tested?
Improved pest control will reduce the damage and increase the yield	Extension officer	Not convinced, needs to be tested locally
Successful pest control will reduce the sooty mold on fruits-more fruits will have good quality	Other farmers	Probably, need to observe
By controlling whiteflies other pest might become more dominant and make the other type of the damage	Experience of one of the farmers	Surely, but to what extent?
More labor and money are required to apply natural enemy	Farmers' provisional calculations	Needs to be tested

Third step: Design

The optimal design for a field study depends on the topic of study, on the condition and size of the field, and on the intensity of the study. Three principles are important for the design of a field study and if farmers consider these principles, they can design better experiments.

Principle 1: Natural Variation

Natural variation is found:
-between plants within a plot
-between different parts of a plot
-between field plots.

A study should compare treatments under the same conditions. Farmer researchers should understand the natural variation in their fields. Farmers may mention differences in land level, plant stand, weed density, soil compactness, soil fertility, non-uniform drainage, or water supply. It's important the participants discuss how natural variation interferes with the experiment and why it is important to reduce natural variation. First, it is important to select a field plot (a square piece of lawn) which is as uniform as possible. At the time of planting, however, some sources of variation may be hidden (e.g. soil fertility, compactness, seed bank of weeds).

To design a study on biopesticide application, we could divide the plot into three parts, or three treatments: 0 kg of biopesticide, 1 kg of biopesticide and 2 kg of biopesticide /ha. Replicates of a treatment should be distributed evenly over the plot, in good as well as bad parts of the plot. Hence, the different replicates give a reasonable representation of the entire plot. Treatments may be distributed randomly or regularly over the plot, but for small studies, with few replicates, a regular distribution is recommended. In a regular distribution, treatment plots do not border on other plots of the same treatment (Figure 1.3).

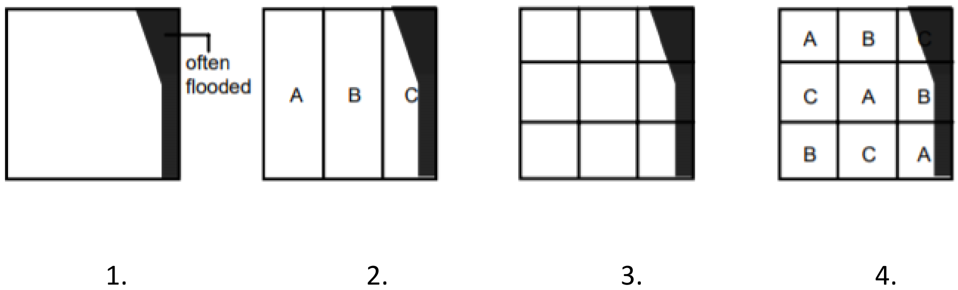


Figure 1.3 Distribution of the plot

Principle 2: Bias

A treatment plot which is bordered by a plot with another treatment may well be affected by the neighboring treatment (Figure 1.4) and thus become biased. Bias, or interference, influences the quality of our results and occurs in the form of insecticide drift, fertilizer drift, movements of insects, etc.

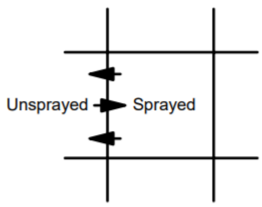


Figure 1.4 Schematic view of the treatment arrangements

Suppose the central treatment plot is sprayed but it is bordered by an unsprayed control (as shown on the picture 1.4). What problems do you foresee? Spray may drift, pests may move away from the sprayed area, or natural enemies may get trapped in the sprayed area. As a result, the control is no longer a pure control, but it has become biased (Figure 1.5). Do you expect bias in a study on fertilizers? How about a study on plant spacing?

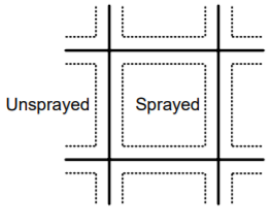


Figure 1.5 Schematic view of the alternatives to treatment arrangements

The extent of bias apparently depends on the topic of study and the type of treatments. How can we overcome bias? First, bias can be reduced by increasing plot size. A study on pest management, where bias is strong, would require larger plots than a study on plant spacing. Second, bias is most important near the border of a plot and, to reduce bias, we could leave a border zone (around 1-2 m at each side) not sampled while we restrict our samples to the center portion of each plot. If we expect a bias through water flow (e.g. fertilizer drift) we should erect bunds as a barrier between plots.

Principle 3: Simplicity

The study design should be kept as simple as possible. It allows more intensive and more comprehensive observations and leads to stronger conclusions. The experiment should address just one aspect/factor (e.g. the biopesticide dosage). If we have more aspects to observe, we need to study the factors one-by-one. Combinations of several factors - e.g. 'biopesticide dosage' and 'plant spacing' - does not provide accurate results.

The number of treatments should be kept to a minimum or the study becomes too complex, which threatens the quality of observations and conclusions. Only two to four most important and most distinctive treatments should be considered. The control is the treatment where a certain practice is not applied (e.g. no spray).

If farmers decide to use replication it is better to use a 3-by-3 design (3 treatments, 3 replicates) it is generally a good compromise with regard to limited plot sizes, within-field variability, and ease of observation and analysis by farmers. Therefore, there may be a need for 'blocks' in certain situations (Figure 1.6).

A block is a complete set of treatments which is separated from other blocks. Because of the separation, each block has its own natural conditions (e.g. different elevation, different soil, different timing of irrigation). It is advisable to avoid the use of blocks, if possible, by using a uniform plot in one location. By using blocks, we increase the extent of variation in our study results which makes it more difficult to obtain clear results.

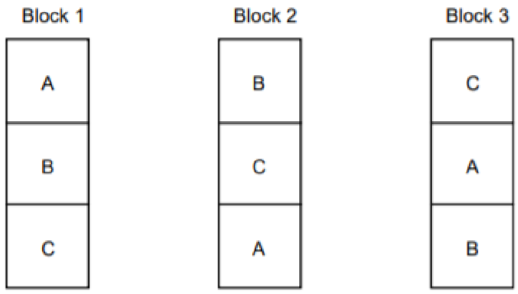


Figure 1.6 Schematic view of the treatment arrangement

Fourth step: Observation

Observation should be carefully planned by farmers. By planning the observation, they should keep in mind to answer following questions:

- What should be observed? The different components of the ecosystem that need to be considered should be identified. For that task we use an Idea Matrix.
  For example, if we expect that an application of biopesticide influences other insects of the ecosystem, these components should be observed. We should avoid a situation where we only realise afterwards that we did not consider a certain component.
- How should observation be made? Observation should be practical and accurate. There are observations of individual plants (e.g. plant high measurements) or whole crop (e.g. yield measurements). Observations should give a reasonably accurate estimate from each replicated plot, realising that there is variation between plants, and between the different parts of each plot. In case of individual plant observation, a sample must consist of at least 10 plants per treatment in order to be representative. For yield measurements (e.g. 5x5 m) one crop cut at the centre of each plot replicate will be sufficient.
- When to observe? Yield measurements are taken at crop matrix or at harvest. Observations on weeds are most important during the early crop stages. Observations on insects, diseases and plant development are ideally made weekly during the entire season.

For planning an observation, it is very useful to prepare an Observation Matrix (Table 1.7).

Table 1.7 Observation Matrix

Observation Matrix – Use of biopesticides to control whitefly in tomato		
What should be observed?	How should observation be made?	When to observe?
Yield	10 plants/ treatment harvested regularly	At each harvest, yield shall be recorded and at the end all yields on each treatment shall be summarized
Percent of fruits covered with sooty mold	At each harvest 50 fruits/ treatment shall be classified according to the presence of sooty mold in two categories: not present, present	At each harvest

Insects/diseases	Observe 10 plants per treatment	Weekly
Natural enemies	Observe 10 plants per treatment	Weekly
Inputs	Calculate and record costs	When inputs are made

Separate records should be kept per treatment, and records of each sampling occasion should be summarised. At the end of the season, records could be summarised over all sampling occasions to allow for easy comparison between treatments.

Fifth step: Analysis

When analysing data from measurements one should be aware that each measurement gives a different result due to natural variation. So, replicates are necessary to confront natural variation in farmers' fields. *The average* of all measurements provides a reasonable sample of the field plot under that particular treatment.

- Importance of variation*:* Understanding variation between the individual measurements is equally important as understanding average. Highly variable measurements are suspected and should be treated with caution before any conclusions are drawn. Uneven field conditions or poor observations can obscure results.
- Overlap test*:* A statistical tool was developed to examine variation between the measurements of each treatment. If variation is not inspected, premature or faulty conclusions might be drawn. The test consists of two steps:
  In step 1 (Is the difference between treatments large?) the average is calculated for each treatment, in step 2 (Is there any overlap between minimum-maximum ranges of treatments?) we examine how variable or how uniform the measurements are. If data are uniform, we may find a clear difference between treatments, but if data are highly variable a difference between treatments are easily obscured by an overlap.

Sixth step: Evaluation

After all observations have been made, an evaluation of the complete set of data is necessary in order to draw final conclusions. An Evaluation Matrix (Table 1.8) helps to evaluate the data set. It evaluates the ideas formulated at the start of the study (from the Idea Matrix)

Table 1.8 Evaluation Matrix

Evaluation Matrix – Use of biopesticides to control whitefly in tomato				
Ideas to be tested (at the start of the study	Results			Conclusion
	Treatment 1 Untreated control	Treatment 2 Biopesticide 1 (neem oil)	Treatment 3 Biopesticide (*Orius insidiosus*)	
Improved pest control will reduce the damage and increase the yield	30 kg per sample	43 kg	45 kg	Application of biopesticide saved the yield but no clear difference between two biopesticides exist
Successful pest control will reduce the number of fruits covered by sooty mold - more fruits will have good quality	20% of fruits covered with sooty molds	7 % of fruits covered with sooty molds	7% of fruits covered with sooty molds	Application of biopesticide reduce the percentage of low-quality fruits, no difference between two biopesticides exist

By controlling whiteflies other pest might become more dominant and make the other type of the damage	Few pests, but slightly more Tuta absoluta in treatment 1			Other pests exist but did not cause damage on any of treatments
More labor and money is required to apply biopesticides	No extra inputs	Extra input 30 €/ha	Extra input 100 €/ha	Most inputs required for Orius insidiosus treatment

In drawing the final conclusion of the study, the farmer should not only consider their records, but also social aspects, environmental aspects and human health aspects. They can be in conflict with an increased economic benefit.

At the end of the study, it is also important to ask following questions:

1. Which aspects remain unknown?
2. Which new questions are raised, and how could they be addressed?

Revision questions

1) The aim of the basic learning cycle is (circle the correct statement – multiple are possible)

a) To strengthen farmers' skills and knowledge to critically analyze, test and validate new practices.
b) To strengthen the group cohesion of the participants so that they can better work as an individual.
c) To enhance understanding of the complex ecological relationships in the greenhouses.
d) To represent six essential steps conducting a study.

2) Enter the six steps of the learning cycle

First step – _ _ _ _ _ _ _ _
Second step – _ _ _ _ _ _ _ _ _ _
Third step – _ _ _ _ _ _ _
Fourth step – _ _ _ _ _ _ _ _ _ _ _
Fifth step – _ _ _ _ _ _ _ _
Sixth step – _ _ _ _ _ _ _ _ _ _

3) According to the six steps of the learning cycle, indicate in order from 1 to 5 the sequence of making matrixes during field study

No.	Type of matrix
	Idea Matrix
	Observation Matrix
	Evaluation Matrix
	Problem based Topic-selection Matrix
	Agricultural operations-based Topic-selection Matrix

4) How many principles during the field study are important in third step of the learning cycle? (mark the right answer)

a) 2

b) 3
c) 4
d) 5

1.5 The curriculum and integration of four major activities in learning session

Learning outcomes

- Define and explain the main components of the curriculum.
- Structure and employ four FFS major activities in FFS sessions in time of growing, cropping season: field studies, special topics, Agro Ecosystem Analysis (AESA), Group dynamics, icebreakers and energizers.
- Select and use relevant methods and exercises concerning specific context, target group, topic and learning environment.

The curriculum follows the cycle of its subject, be it crops, animals, soil or crafts. This approach allows all aspects of the subject to be addressed in parallel with what is happening in the farmers'/participants' field. For example, potato transplanting during the training takes place at the same time as the farmers' own crops are being transplanted - the lessons learnt can be applied directly.

A key factor is that there are almost no lectures. Most activities are based on experiential (learning by doing), participatory and practical work. This is based on adult learning theory and practice. Each activity has a process for action, observation, analysis and decision making. The focus is not only on the 'how' but also on the 'why'. Experience has shown that structured, practical activities provide a solid basis for further innovation and local adaptation.

Activities are sometimes seasonal experiments, especially those related to soil or plant physiology (e.g. soil or variety trials, plant compensation trials). Other activities in the curriculum include 30-120 minutes on specific topics. Ice breakers, energisers and team/organisation building exercises are also included in each session. The curriculum is combined with other topics.

In the field, it is practical, hands-on topics that provide most of the training and study material, such as plants, pests and real problems. Any new 'terminology' learnt during the course can be directly applied to real-life subjects, using local names that can be used and agreed upon. Farmers usually feel much more comfortable in the field than in classrooms.

The basic activities in the learning process are: agro-ecosystem observation, analysis and presentation of results. Agro-Ecosystem Analysis (AESA) is the core activity and a specific theme and group dynamics activity are designed to support it.

The agro-ecosystem analysis process sharpens farmers' observation and decision-making skills and helps develop their critical thinking.

1.5.1 Elements of the curriculum

The curriculum is a plan which leads the facilitator and the participant to reach the wanted aim and objectives. As a result, curriculum developers must first deal with content or subject matter and then with learning experiences. These two are preceded by formulating objectives, which act as a road map for the curriculum development and implementation process/learning activities.

In curriculum, objectives are usually stated in terms of expected learning outcomes which are defined in terms of knowledge, skills and competences. Outcomes are statements of what participants know, understand and are able to do at the end of the project or learning process. Objectives/Outcomes can be assessed, validated and recognised.

The real contribution of stating objectives is to think of how each objective can be achieved by participants through the content or subject matter they learn. There are four highly interconnected elements of the curriculum (Figure 1.7):

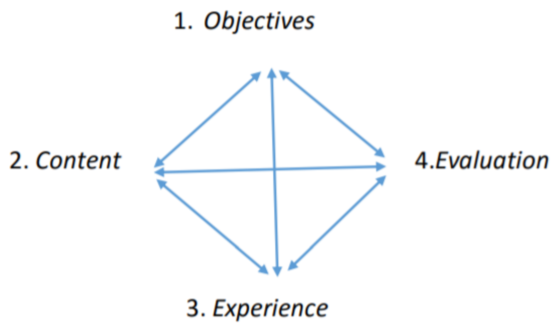


Figure 1.7 Relationship between elements of the curriculum

<u>Aim and Objectives</u>
Each project begins with the aim as a statement of intent or purpose. Why do we want to do this project? Objectives are described more in terms of specific tasks. In which of these specific tasks is the solution path more important than the goal?

<u>Content or Subject Matter</u>
With the content curriculum clearly defines the purpose and what the project was to be acted upon and try to drive at. The content is an element or a medium through which objectives are accomplished. The content of any subject matter is broad. It is analysed into sub-contents which are arranged in a logical sequence.

<u>Learning Experience</u>
Selection of the learning experiences will foster active involvement in the learning process in order to accomplish the expected learning outcomes. Tyler 1949 outlined five general principles in selecting learning experiences:

- The learning experience must give participants the opportunity to practice the desired behaviour. If the objective is to develop problem-solving skills, the participants should have ample opportunity to solve problems.

- The learning experience must give the participants satisfaction. Participants need satisfying experiences to develop and maintain interest in learning; unsatisfying experiences hinder their learning.
- The learning experience must "fit" the participants' needs and abilities. This infers that the facilitator must begin where the participant is ability-wise and that prior knowledge is the starting point for new knowledge.
- Multiple learning experiences can achieve the same objective. There are many ways of learning the same thing. A wide range of experiences is more effective for learning than a limited range.
- The learning experience should accomplish several learning outcomes. While participants are acquiring knowledge of one subject or concept; they are able to integrate that knowledge in several related fields and satisfy more than one objective.

Evaluation

Evaluation identifies the quality and effectiveness of the program, process and product of the curriculum. The level of participant's attainment is evaluated by employing a criteria referenced test. It shows:

- The effectiveness of strategy and provides feedback of facilitating/teaching and other components.
- Whether the objectives and aims have been meet or not. If not, the facilitator could employ another strategy which would be successful.

Curriculum evaluation is an empirical basis for the further 'curriculum development'.

1.5.2 Materials needed in participatory learning

Learning of new content/ideas becomes simpler if the participant is given recognizable materials linked with the subject matter/content. Facilitators can make their sessions really interesting and relevant for the participants by using materials to help them with their verbal presentations. Using a wide range of materials has been found to help improve understanding of ideas and make the learning process appealing.

Today, with the emphasis on student-centred learning, learners need more and more materials to improve their ability to learn collaboratively or independently.

Materials must be attractive to participants. Size, shades (multi-coloured) and in some cases smell and/or taste or sound are part of the characteristics of materials that attract participants/learners.

Participants can also easily control these materials, allowing them to learn new ideas in a meaningful way. Surprising materials or new uses of natural materials are attractive highlights of good materials. The material should have a use value. It is the appropriate use that makes the material positive or negative. Many useful materials, such as sticks, beads, three-dimensional shapes and cards etc., can be reused in virtually any session.

Materials that are commonly required or useful at participatory events:

- paper – several large tablets for recording ideas
- flipchart
- tape or tacks to attach paper to walls

- several broad tipped, bold colour markers
- pens, pencils, markers
- computer
- projector and screen
- a microphone
- printer and paper
- video camera or audio recorder
- small note-papers that are sticky on one side (in multiple colours)

1.5.3 Application of the of four major activities in FFS learning sessions

The process starts with observing plots with and without IPM in small groups. During the observation, participants collect field data such as insect species and populations, and insect and plant samples. These data are collected in several plots. A facilitator is present throughout the observation and assists the participants with their observations. After that, farmers return to the meeting place and draw what they have just observed in the fields on a large piece of poster paper with crayons. The drawings include:

a) the pests and natural enemies observed in the field (pests on one side, natural enemies on the other);

b) the plant (or animal), indicating its size and stage of growth, along with other important growth characteristics such as number of stems, plant colour and visible damage;

c) important environmental characteristics (water level in the field, sunlight, shade trees, weeds and input).

All participants of the small groups work together to produce the drawing and analyse the data. During the drawing process, farmers discuss and analyse the data collected. Based on the analysis, they identify a set of management decisions to be implemented in the field.

A summary of these management decisions is also included in the drawing and agreed by the group. One member of each small group then presents these findings and decisions to the larger group.

After this brief presentation of the results, there is time for open questions and discussion. Large group discussions often involve alternative scenarios, for example questions such as "What would you do if...". This cycle of presentation, question, answer and discussion is repeated until all small groups have presented their results. Keep the agroecosystem drawings from previous weeks handy as reference and discussion material for later in the season.

The role of the facilitator is central to the AESA process. In the field, he or she will guide participants to see what they may not have seen before, such as small predators or changes in the soil. To ensure a balanced and participatory discussion, a good facilitator recognises that the more participants talk, the more they learn, so encourages discussion rather than lecturing. During presentations, the facilitator ensures that all participants in the season have the opportunity to present and that the group addresses all relevant issues. The facilitator needs agricultural and technical skills and must be able to ask good questions, guide the participants in the exercises and ensure that the group makes sound management decisions by presenting new information as necessary.

The four main activities that take place in the learning process:

1. Field studies
2. Agro Ecosystem Analysis (AESA)
3. Special topics
4. Group dynamics, icebreakers and energizers

Field studies

Field studies collect original or unconventional data via face-to-face interviews, surveys, or direct observation. This research technique is usually treated as an initial form of research because the data collected is specific only to the purpose for which it was gathered.

Field studies should be carefully planned and prepared in order to ensure that the data collected is accurate, valid, and collected efficiently. The equipment needed will depend on the type of study being conducted. The process first starts with clearly stating the problem and defining the area of study. From there, a hypothesis, or a theory of explanation, is set forth to explain any occurrences expected for the specified group or phenomena. Therefore, before a field study is conducted, it is important to identify the data/phenomena to observe.

Once the hypothesis has been established, the data can be classified and scaled so that it will be easy to know how to categorize information. Observations are classified because not all field observations will be needed; therefore, the observer can know what to look for and what to disregard. Observations are also scaled to give the observer a way to rank the importance or significance of what has been observed. Once field observations are concluded, this data will be analyzed and processed in order to resolve the problem initially presented or to accept or reject the hypothesis that was presented.

Application of the Field study

It is expected that participants take the initiative in the organization as well as in the three implementation stages of the field study.

Stage 1: Preparation
Preparation involves facilitator action:

- Studies the course books and locates subjects suitable for field study
- Studies the places of the students' areas of residence and explores all possible places for field study in those areas
- Creates an archive containing the name and place of the area, as well as what this area can offer in terms of learning together with any other useful information
- Makes a preliminary visit to «the field study» in order to familiarize
- Study object should be exploited by the entire group of the students during the sessions
- Prepares activities for the students together with a list of the required materials
- Secures co-operations and selects the best time for implementation

In the sessions facilitator explains the field study technique and sets the rules. More specifically, the facilitator organizes a preliminary discussion for the determination of:

- The subject of the field study

- The aim and the goals of the field study
- The place where the field study is to be carried out
- The activities to be carried out (if group work is involved, every group must be assigned certain activities).
- The duration of the field study
- The sources to be utilized
- The final product

Stage 2: Work on the field
On the field, the participants, either in groups or independently, are assigned certain activities. These activities can vary and their nature depends on their aims and objectives as well as the opportunities offered by each particular field. Activities on the field can include observation and comparison, mapping, sample taking, taking of photographs, etc.

Stage 3: Composition and Presentation within the sessions
After the on-the-field work has been completed, processing of the data collected follows leading to composition (analysis and interpretation of the collected data). During this stage, the students could either carry out one or more activities included in their course books or prepare a report containing the basic points of their research, draw up a brochure containing photographs, diagrams, sketches, plans, histograms, or they could merely exhibit the material they have collected by means of written texts, and so on. The electronic or otherwise communication between the students is considered important at this stage. The students can use elements from the field study for their assignments. The presentation of these assignments in the common sessions is considered exceptionally useful.

Agro-Ecosystem Analysis (AESA)

Agro Ecosystem Analysis (AESA) is a decision-making tool used to make weekly field observation throughout the crop life cycle to determine plant health and its compensation abilities, population fluctuations of pests and natural enemies, soil conditions, climatic factors, agronomic practices etc. and analysis of situation taking into consideration the inter-relationship among the factors. The analysis leads to taking a quality decision on appropriate management practices (Table 1.9).

AESA is tool to guide farmers to learn how to develop skills and knowledge about ecosystems and to make better decisions. Working in groups farmers observe field situations and make notes about the ecosystem e.g., crop, insects, diseases, weed, water, weather etc. These observations are then placed on a sheet of paper to be examined before making crop management decisions. AESA may include the following information: Location, Date, Crop age, days after sowing (DAS), Variety, Beneficial insects, Harmful insects, Diseases, Weeds, Plant height, Weather and soil conditions, colour of leaves, flower and fruit initiation.

Application– Main components of the AESA

a) Field observation

Example: Agro-EcoSystem Analysis in maize with special emphasis on the Fall Armyworm (FAW) Spodoptera frugiperda (Lepidoptera; 2021 not yet proven in Europe but likely introduced in the near future)

Objective:
To build the capacity of farmers to understand their agro-ecosystems, and to make informed decisions for the management of the crop based on thorough observation, discussion and analysis.
Procedure:
Recall and record the climate prevailing in the preceding one week. Record the stage of the crop. A total of 20 plants per field must be sampled. The plants within one to two meters from the edge should not be included to avoid border effect on samplings. Randomly select 20 plants.

Of these 20 plants, mark 5 plants with permanent labels for recording the plant growth parameters. Record all findings in a table.

- count the flying insects in and around the plant canopy without disturbing the plant
- examine leaves on both sides and stems for egg masses (count number of egg masses per 20 plants)
- collect egg masses, if any, for rearing and recording the percentage egg parasitism
- next examine leaves for 1-2 instar larvae. Collect 10 to 25 healthy as well as inactive larvae/pupa for rearing and recording the larval parasitism
- examine whorl (funnel) and leaves for three types of damage: windowpane (scratching), pinhole damage (small holes), rugged damage and frass (sawdust-like appearance)
- observe natural enemies
- look for larvae dead from pathogens and count number
- observe growth parameters of plants: stage of growth, age, height, colour, number of leaves, presence of pests and pathogens. To assess the damage to leaves, count the total number of leaves and number of damaged leaves and calculate the percentage defoliation. Leaves with less than 25 percent leaf area damage may be ignored
- observe soil conditions: moisture, weed spectrum (observe around the plant in one square meter area and record the type of weeds, size in relation to maize population density in terms of either number or percentage area affected)
- record weather

b) Discussion in small groups

Now the group discusses about the field situation by raising many questions. For this purpose, referring the previous weeks' charts are essential to note the population fluctuation of pests and defenders as well as the trends in plant infestation levels. Discussion points should include the following:

- plant stages, health and compensation ability
- changes in pest population in comparison to previous weeks
- corresponding changes in natural enemies' population
- diseases – presence of inoculum, favorable climate, availability of susceptible varieties
- climatic factors – temperature, rainfall, humidity, wind velocity and their influence on pest, defenders, crop growth etc.
- weeds – susceptible stage of the crop, alternate host for pests' shelter for defenders etc.

- agronomic practices – irrigation, fertilizer application and inter cultivation, etc.
- after considering all related factors, the group members arrive at a conclusion and recommendations
- written in the lower part of the chart

c) Synthesis including drawing

- Make the drawing on the manila paper/flipchart paper. Use live specimens as models for drawing.
- Top two third portion of the sheet is used for drawing and the remaining one-third portion for writing conclusion and recommendations.
- Draw the plant with the correct average number of leaves found.
- For weeds write approximate density and size of weed in relation to the size of the plant. Draw the kind of weeds (broad-leaf or grass type).
- For pest population intensity, draw the pest as found in the field on the right side of the plant. Write the average number (per leaf for sucking pests and per plant for others) and local name next to the insect.
- For defender population abundance, draw the organisms as found in the field on the left-hand side of the plant. Write the average number per plant and their local names next to the drawing.
- Use natural color for all the organisms. For instance, draw green for healthy plant and draw yellow for diseased plant or deficient plant. Draw pests and natural enemies nearer to the plant where usually they are seen.
- If fertilizer was applied, place a picture of hand throwing N, P, and K depending on the type used.
- If insecticides are used in the field, show sprays with a nozzle and write the type of insecticide coming out of the nozzle.
- If the preceding week was mostly sunny, draw a sun, just above the plant. If the week was partially sunny and partially cloudy draw the sun but half covered with dark clouds. If the week was cloudy all day for most of the week, put just dark clouds.
- Discuss in the small group what should be the decision for the days to come in the IPM field, and record those, based on AESA. What is the decision in local practice for the days to come?

d) Presentation to the large group

One representative from each group presents their analysis report before the larger group and invites discussions and interactions. Decisions on management practices are finalized and implemented in the field. Key message: On a daily basis, AESA refers to the major observation done and the decision made (recommendation) and validated by the whole group to guide the management options/practices for the FAW. A comparison should be made also with the previous AESA in order to evaluate the effectiveness or appropriateness of the management options imposed.

Table 1.9 Agro Ecosystem Activity Matrix

Agro Ecosystem Activity			
Activity	Critical Steps	Notes	Indicators

AESA A basic activity that develops good habits: observation, analysis, decision-making Farmers become experts	Observation and Drawing of Agro ecosystem	Participants need to understand the process of observation and its purpose and objectives. Participants observe in the field, take notes, collect samples The purpose of the drawing is to summarize the observation, focus on the analysis	1. Before the start of the activity, participants set: a. The aim of the activity b. The procedure to be followed in the activity 2. All participants are in the field 3. The observation procedure involves the whole plant 4. Recorded observation 6. Drawing summarizing the observations
	Presentations and Analyses	The results of the analysis are presented to the large group by at least one member of each group. Problems raised, questions asked. Purpose: to discuss the situation on the ground and to address "what if" scenarios. Objective: to improve decision-making and analytical skills based on ecosystem observation. The facilitator helps the group to achieve the objective by asking questions that help the analytical process.	1. A presentation by a member of each small group 2. Participants ask questions of the representative 3. The facilitator asks questions suitable for analysis 4. The group discusses the situation on the ground and the relationships between agroecosystems 5. Discussion of 'what if' scenarios 6. The agroecosystem drawing from the previous weeks is used for comparison 7. The group critically examines management decisions in the field 8. In addition to economic thresholds, other factors are analyzed, e.g. plant stage, natural enemies 9. The facilitator uses leading questions to help participants analyse what they have learned during the activity

Source: FAO, Fisheries and Aquaculture Management Division, 2008

Special Topics of a day

Technical information to compliment the 'learning by doing' and field experimentation is usually brought in as a special topic of the day. This provides an opportunity for the facilitator, researcher or specialist to give technical inputs needed for a general understanding of the subject and to level knowledge among the participants. The topic of the day is normally a farming related topic but could be any subject of concern. Participants may have other problems and feel a need to discuss issues. If the facilitator lacks the specific expertise, external specialists or other community members can be invited to lead the discussion. The role of the facilitator is to target a specific topic at the most relevant time for group participants.

Application of Special Topic of a day

Example: Insect Zoo – the role of natural enemies (farmer friends)

Insect zoos are an important special topic in FFS. Participants can set up insect zoo experiments which allow them to follow and observe behavior of insects that are alive (discovery learning). The insect zoo also helps find out more about functions of an insect in the field, which is very important information when managing insects through IPM. It can help farmers get a better understanding of insects even if they have limited access to information from outside. Insect zoos also motivate farmers to continue observing and exploring their agro-ecosystem, as they realize that they can make important and useful discoveries by themselves to improve their farm management. Overall, learning in the insect zoo generates knowledge and information that help to take informed management decisions for the IPM of FAW and other pests.

Purpose of insect zoos:

- Study the function of an insect – is it eating plants? Other insects?
- Understand more about natural enemies – including rate of predation (for example by putting together a natural enemy with pests and finding out how many pests a natural enemy can consume during a day) and rearing egg masses, larvae, or pupae to observe parasitation.
- Explore life cycles of insects – setting up experiments to observe the life cycle of an insect, where different stages can be found (on or in the plant, in the surroundings), and how long different stages of the life cycle will last.

Rationale:
Natural enemies provide a natural pest regulation mechanism. There is a wide range of natural enemies (insects–predators, parasitoids, birds, frogs, and micro-organisms – fungi, viruses, bacteria, nematodes) in our fields. Many of them can help manage FAW. Farmers usually are not aware of the presence and the benefit of friends of the farmer (natural enemies) to control pest populations in their field.

Objectives:
To build the capacity of farmers to recognize natural enemies in the maize field and their impact, by:

- getting to know the function of an insect in the field (e.g. what does it eat or do)
- understanding/observing predation and parasitation and pathogen infection
- observing rates of predation and parasitation
- understanding its life cycle through life cycle studies

Time required:
Season-long

Materials needed:
Field plots; hand lenses/magnifiers; vials or plastic bottles for field collection; mosquito nets; small knife; cutlass; sticks.

Procedures and parameters for observation:

- Collect various insects and arachnids (i.e. “spiders”) you can find and make direct field observations on what they are doing.

- Set up a simple experiment using empty bottles or jars (make sure the bottle has small aeration holes or cover the lid with veil/net)
- Predation: put a caterpillar and/or egg masses in a bottle with the suspected predator and make observations (approx. 5 min). Observations can be repeated daily, as homework for interested FFS participants to observer predation. Note how many FAW a day are eaten. However, note that the predator might not be able to exhibit his natural behaviour under these circumstances. This may lead to a substantial underestimation of the efficacy. You can also just observe - for example count digger wasps visiting their holes and count the number carrying larvae.
- Egg parasitism: Parasitized eggs are likely to have a darker colour (which can sometimes be confused with eggs close to hatching) – if parasitism is suspected, collect eggs masses with the leaf, put it in a clear, aerated plastic bottle and observe daily and discuss the results. What happens? What are the differences with hatching of non-parasitized egg masses?
- Larvae parasitism and diseases: Look for larvae with abnormal behaviour; collect each such larva into individual transparent bottle or jar with some leaves and make observations.
- Field study monitoring for observation, data collection and analysis for learning and informed decision-making will be done using the AESA process regularly.
- It is possible to do a systematic comparison between IPM and local practice (LP) as part of the AESA – by collecting a fixed number of egg masses in each field and observing if there is a difference between the treatments.

Results–discussion:

- diversity and numbers of natural enemies
- function and behavior of natural enemies; predators' vs parasitoids
- diversity of insect pests
- crop growth and vigor
- yield

Table 1.10 Special Topics Activity Matrix

Special Topics Activity			
Activity	Critical Steps	Notes	Indicators
Special Topics focus on topics such as ecology, biology, other fields etc.	Statement of Goal	Participants need to know the purpose of the activity and what they will learn.	1. Before the activity starts, tell participants what the aim of the activity is.
	Small group	It is clear to participants what they need to do and why. All the material is at hand.	1. All participants are active and involved in the activity 2. No small group dominated by one person to the total exclusion of others.
	Presentation	Activity analyzed by participants. Facilitator asks leading questions so that participant know what happened during activity and why. Special topics provide opportunity to learn of topics important to the subject	1. Participants present the results of their work during the activity and summarize what happened and why. 2. The facilitator asks leading questions to help participants reflect on the steps in the activity process and apply the learning to 'real life'.

Source: FAO, Fisheries and Aquaculture Management Division, 2008

Group dynamic

Dynamic of the group or implementation of the learning process and activities are undertaken collectively by group members with participatory methods during joint planning, management, implementation, monitoring and evaluation.

Participation calls for collective analysis and good rapport. Facilitator must work closely with local people. Ideally, though, teams of participants work together in interdisciplinary and intersectoral teams. By working as a group, the participants can approach a situation from different perspectives, carefully monitor one another's work, and carry out a variety of tasks simultaneously. Groups can be powerful when they function well, because performance and output are likely to be greater than the sum of the individual participants. But shared perceptions, essential for group or community action, must be carefully negotiated. Various workshop and field methods are used to facilitate this process of group formation.

The creative ingenuity of practitioners worldwide has greatly increased the range of participatory methods in use. Many have been drawn from a wide range of nonagricultural contexts and were adapted to new needs.

Application of participatory methods

Some group dynamics exercises are physical and active, while others are more as 'brain teasers'. The facilitator's role is to help participants analyze their own experiences to better understand how people behave in different situations.

Many didactical exercises and games can be used to enhance learning process in the group. The principal emphasis is on creating an environment in which individuals and groups feel free to experience, reflect and change. Additional reading about each exercise is available on online at: www.researchgate.net/publication/288832171_Trainers'_Guide_for_Participatory_Learning_and_Action http://danadeclaration.org/pdf/ChattyBaasFleig.pdf .

There are eleven main categories of group process exercises and games which are effective in participatory learning (Table 1.11).

Table 1.11 The description of the main categories of group process and examples of games

Category of the group process	Description	Examples of the exercises
Introduction and icebreaking	It is important to make everyone feel welcome and part of a group. It is critical to get everyone, especially the shy people, involved and talking to one another by breaking the tensions and nervousness at the beginning.	Paired interviewing, Expectations and ground rules in writing, first name introduction, Hopes and fears, Self-portraits, something from home, Stepping stones, Symbolic introductions, Drawing concepts, The seed mixer, Name game, Who are we?

Energizers	Energizers are games that energize the group. This can be vital in maintaining the momentum of training. A quick, amusing game that gets everyone moving reactivate their minds.	Fruit Salad, 'A's and 'B's, Numbers game, Move to the spot, Move if, Streets and avenues, Robots, Family members, Breakthrough, Statue stop, Countdown, Group self-select, Group sculpture
Group formation	Group formation is necessary on participatory methods as they should involve a lot of intensive group work. Games can be used for random mixing or for purposive formation of groups. There are times when it is good to allow and encourage people to form subject group with participants with the same interest.	Fruit salad, Numbers game, Move if, Count down, Group self-select, Postcard or Jigsaw puzzle
Group dynamics exercise	These exercises can be valuable in helping participants through the various stages of group development. The general aim of these exercises is to demonstrate the power of working in groups, to encourage individuals to respond openly to others. Such exercises can bring difficult issue of conflict and dominance out into the open in a non-threatening way.	Nominal group technique, Group profiles, Kmotty problem, Trust walk, Group problem solving and team contrast, Chairs, Group strategies: prisoner's dilemma, Cooperative squares, Postcard or Jigsaw puzzle, Look who's talking, Rope square, My corner, Group roles, Excluding numbers
Listening and observing exercises	Adopting a listening and learning attitude is central to training for participatory learning, particularly when it comes to field work and direct work with local people. These exercises can help to shift people's views, allowing participants the chance to reflect on how they behaved in the exercise debriefing discussions following listening and observing games are crucial.	Matches, Pillow game, Watch it, Non-verbal circles, Voting debate, Folding paper game, Drawing bricks, Empathetic listening, Noodders and shakers, Wayward whispers and story sequences
Analytical exercises	Participatory training should permit and encourage reflection on how we learn and observe, including realization of how our personal experiences and our personality influence what we see. These exercises focus on how we observe and remember, what we ignore, how we assimilate new information, and how difficult it is to be objective.	Learning by association, Seeing the Ks or Hs, Fact, opinion, rumor, Swap over, Playing detective, The coat of rucksack, Which watch? Whose shoe? Margolis wheel, Johari's window, Beans in a jar, Map reversals, Handclasp
Evaluation exercise	As a facilitator, it is important continually to evaluate how the training is developing and how to adjust your programme to meet changing conditions. The exercises are helpful for quick updates on the group's	Margolis wheel, Scoring individuals and groups, Resents and appreciates, Mood meter, Graffiti feedback boards, Monitoring representatives, Evaluation of session, Evaluation

	mood and for more thorough evaluations at the end of training.	wheel, Hopes and fears scoring, Role play for creative evaluation, Problem hat, Mental gifts
Semi structured Interviewing	It is a guided questioning/ interviewing and listening process, where only some questions and topics are pre-defined, and other questions arise during the interview. Interviews appear informal and conversational but are in fact carefully controlled and structured. The multidisciplinary team, using a guide or checklist, asks open-ended questions and tests themes as they emerge. During the interview, new possibilities for asking questions are explored.	Many types of interviews can be combined in sequences and chains. These include key informant interviews, where we ask who the experts are and then construct a series of interviews and group interviews, which can be groups convened to discuss a particular topic.
Diagraming and visualization	Diagramming is a way of clearly structuring information, visualizing the links between certain objects or factors and providing a basis for further analysis. Diagrams can be tables, "trees", pie charts or any other format suitable to support a discussion on a particular topic. The flow diagram and the relationship diagram or Venn diagram the most common. Try to include both in any training on participatory tools, as they are essential for analyzing problems and identifying patterns of social interaction/conflict. Venn diagrams involve the use of circles of paper or card to represent people, groups, and institutions. These are arranged to represent real linkages and distance between individuals and institutions. Flow diagram is a collective term for a diagram representing a flow or set of dynamic relationships in a system. Overlap indicates flows of information, and distance on the diagram represents lack of contact. The element is the emphasis on diagramming and visual construction. In formal surveys, information is taken by interviewers, who transform what people say into their own language. By contrast, diagramming by local people gives them a share in the creation and analysis of knowledge, providing a focus for dialogue which can be sequentially modified and extended. Local categories, criteria, and symbols are used during diagramming. Rather than answering questions which are directed by the values of the outside professional, local people can explore creatively their own versions of their worlds. Visualizations therefore help to balance dialogue and increase the depth and intensity of discussion.	
Ranking and scoring	These methods are for learning about local people's categories, criteria, choices, and priorities. For pairwise ranking, items of interest are compared pair by pair; informants are asked which of the two they prefer, and why. Scoring takes criteria for the rows in a matrix and items for columns, and people complete the boxes row by row. The items may be ordered for each of the criteria (e.g., for six trees, indicate from best to worst for fuelwood, fodder, erosion control, and fruit supply).	
Mapping and modeling	This involves constructing, on the ground or on paper. It provides a good starting point for discussions with local people about their problems, potential and needs. It is recommended that facilitators provide an overview on the different kinds of mapping and their objectives. Maps or models are made on paper using materials such as sticks, stones, grass, wood, boxes, tree leaves, sand and soil, colored chalk	

	and pens. As the maps are created, more people are involved and want to contribute and make changes in turn. There are many types of maps: resource maps showing catchment areas, villages, forests, fields, farms, home gardens; social maps of residential areas; topical maps, such as aquifer maps drawn by a well-digger or soil maps drawn by soil experts; impact monitoring maps, where villagers record or map the incidence of pests, the use of raw materials, the prevalence of weeds, the quality of the soil and so on. Some of the most informative maps combine historical views with views from the present.

Table 1.12 Group Dynamics Activity Matrix

Group Dynamics Activity			
Activity	Critical Steps	Notes	Indicators
Group Dynamics (Enhance teamwork and problemsolving skills)	Process	Participants informed about objectives and process before activities begin. Materials for activities, if needed, are on hand before activity begins. Time allowed for activity is sufficient to achieve objective	1. Before activity begins participants tell goal and activity 2. All participants involved/active, no single individual dominates activity.
	Synthesis	Leaders take time to: review objective of activity; lead discussion concerning what happened during the activity; help participant to make conclusions based on their experiences during activity.	Leader: 1. Reviews goal and process of activity 2. Helps participants identify key learning points based on activity 3. Ask questions which help participants learn from their experience

Source: FAO. Fisheries and Aquaculture Management Division, 2008

1.5.4 Ideas for structuring the curriculum

There are different ways on how to structure the curriculum. The role of facilitator is to help the group and facilitate the discussion and the process of the structuring curriculum and be sure that it contains all the necessary elements. Some examples are shown in Tables 1.13 to 1.15.

Table 1.13 Ideas for structuring the curriculum – Example 1

Week	Stage	Activity	Topic	Learning objective	Content	Method	Material	Time	Responsible person	Evaluation indicators
1st	Pre-planting	Introductory training on the FAW		To create awareness on how to recognize FAW and implement prevention measures	FAW identification, life cycle (biology) and ecology; Prevention, scouting and actions to manage the FAW; Biological control and cultural control; If already present, collect FAW specimen at different stages (egg masses, larval instars, adult male and female moth), damaged plants, natural enemies, potential local botanical plants, weeds etc. for observation and discussion; Collect existing green list of botanicals available and develop simple factsheets on each and their preparation; Integrate indigenous practices into the reviewed existing lists of pesticides and develop a green list for each site/ country	Brainstorming discussion, whenever possible: visit infested fields/ vegetation, group work, practical demonstration	Flip-chart, markers, masking tape, knife, plastic bottles/jars; veil to seal them, magnifier, nets to collect adult moth	4 hrs x 2 days	Facilitator / Resource person	Feedback on how to recognize, and to manage FAW
8th	Seedling to Maturity	Regular field scouting / monitoring (from seedling to maturity stages)	Crop & FAW management requirements	To identify pests / natural enemies, any emerging problems for immediate action, To assess effectiveness of the management options undertaken, records To identify problems in the field/crop, evaluate previous management decision made	Agro-Eco System Analysis (AESA); Stage of growth/ development; Pest, weeds and disease infections, pest infestations, natural enemies and host plants identification; Identify/collect FAW and natural enemies' specimen at different stages, damaged plants, potential local botanical plants, weeds etc. for observation and discussion; Infestation evaluation: incidence & severity; Evaluation and comparison of the effectiveness of treatments applied; FAW population monitoring; Weather effects Soil/water/plant conditions: Soil structure, drainage and organic matter.	Brainstorming, group discussions and field practical	Flip-chart, markers, masking tape, field for field practice, knife, plastic bottles/jars, nets, vials magnifiers…	2-3 hrs /session	Facilitator	Feedback Know how to manage the main pests and diseases.
11th	Seedling to vegetative	Soil health and Fertilizer application	Soil fertility and moisture management	Understand soil health Able to correctly apply basal fertilizer	Concept of soil health Soil characteristics: composition, texture, structure, water holding capacity, etc.; Importance of organic matter, Composting, manure; Types of organic and in-organic fertilizers and their characteristics; Sources of fertilizers; Methods, rates and timing of application; Basal and top dressing; Organic and inorganic fertilizers; Suitable rate for nitrogen fertilizer.	Brainstorming, discussions and field practical	Flip-chart, markers, masking tape, field for field practice, material for soil health exercises	3.0 hrs /session (multiple times)	Facilitator	Feedback Know how to manage soil fertility.

Table 1.14 Ideas for structuring the curriculum – Example 2

Timing	Main activities	FAW IPM Integration	Learning objectives
Preseason, preparation for FFS	Awareness raising on FFS Organizing FFS group problem analysis with FFS group – fine tuning the curriculum, designing learning plots Identifying FFS plots	Introduction to the FAW Is FAW present in the community? Field observations with FFS groups to find FAW in fields, surrounding vegetation Integrate FAW focus into learning plots – IPM and Local Practice (LP) plots; compensation studies; fertilization studies, other relevant studies	To create awareness on how to recognize FAW, ensure that FAW is integrated in proper way in problem analysis, discuss study designs for FFS
Pre-season, preparation for FFS	Land preparation layout and prepare study fields for the FFS Seed selection	Reflect FAW management options in selected study designs Healthy seeds as the start for a healthy crop that can compensate damage Any varieties or crops that are resistant/tolerant for FAW? How to use them in learning plots? Is seed dressing an option for FAW management – test in the field and compare? What is soil health? Healthy soils for healthy crop	How to lay-out fields, how to prepare IPM plots and LP plots, discuss differences within seed quality (germination capacity) How good seed quality can help get a good crop How healthy soils are the basis for a healthy crop
Seeding/planting the field studies	Seed the study fields What are IPM principles? – discussion on what and why	FAW reflected in study designs Understand IPM approach, and link to FAW as well as to other pests, diseases in the agroecosystem	How to lay-out field, prepare and seed – IPM compared to LP plots. Differences, why (seeds, lines, distances, seed dressing, etc.) IPM principles, relevance of principles better understood
FFS session 1– crop germination	Introduction to AESA, including observations for FAW Group dynamics special topic	If FAW is present – what stages, what crops, where on the crop and surrounding vegetation	Building understanding of FAW – development stages, life cycle, natural enemies, host plants, where to find FAW on the plants
FFS session 2	AESA Group dynamics	Compensation study for FAW insect zoo if FAW is present, life cycle, natural enemies	Not all plant damage leads to yield loss – to be explored in compensation studies

	Start crop compensation study and fertilization studies FAW – observations and insect zoo		How fertilization can influence FAW oviposition and yields
etc.			

Table 1.15 Ideas for structuring the curriculum – Example 3

Day	Topic	Learning objectives	Activity
1	Contextualizing the problem	Identify the knowledge gap and bring participants to a common understanding of the problem	Brainstorming on the existing maize pest complex, existing management practices Zero down to FAW (history and situation in the country) Outcomes of the Baseline studies if any, mapping the problem in areas of work of facilitators FAW management – what is currently happening at farmer level, at government level Present FAO's Programme of Action on FAW Management, if relevant
	Biology and ecology	Know the FAW life cycle and the preferred development conditions of the pest	Field work: collect FAW in the field, and in surrounding vegetation; find as many stages as possible Group work to sort out found insects (FAW and possibly other insects – how to distinguish, different development stages) Groups to propose insect zoo exercises to learn about life cycle of FAW Presentations – how to recognize FAW, life cycle and conducive environments Groups set up insect zoos
	Identification of the pest and damage	To identify/recognize the pest and its behaviour, and differentiate from other pests/armyworms	Field work – collection of FAW and other pests, and samples of damage on maize and other plants Group work: describe and draw Signs and symptoms Discuss feeding behaviour: what stage of FAW feeds on what parts of the plant, why? Where can you find eggs, larvae, pupae, adults? (preference on young soft leaves; if not, will migrate to tassels and cobs) moving, oviposition What other insects are found? Functions? Which insect zoos are useful? Differentiate FAW, AAW (*Spodoptera exempta*), other worms Set up/observe insect zoos
2	Management of FAW Monitoring and early warning	To know how to carry out regular field monitoring using AESA	Tools (pheromone traps...) Process for scouting Parameters to observe Techniques for the sample collection and handling Preparation for the field
3	Field immersion	To build the capacity of participants on regular	AESA (Identification, sampling, collection, decision-making - observe and identify correctly FAW egg

		field observations and informed decision-making for FAW management.	masses, young larvae and damage, observe natural enemies (coccinellids, earwigs, lacewing, ants, parasitized eggs, etc.) Data analysis, presentation and synthesis of the key learning points Set up new insect zoos, report on earlier insect zoos
	Field work	Plant compensation	Introduction and discussion on plant compensation. How to set up a study in the FFS Set up plant compensation study in the learning field, to know how it can be done in FFS

Revision questions

1) Enter four elements of the curriculum

a) _ _ _ _ _ _ _ _ _ _ _
b) _ _ _ _ _ _ _ _ _ _ _
c) _ _ _ _ _ _ _ _ _ _ _
d) _ _ _ _ _ _ _ _

2) The learning experience……… (circle the correct statement – multiple are possible)

a) Must give participants the opportunity to practice the desired behaviour.
b) Must give to the participants satisfying experiences to develop and maintain interest in learning.
c) Must "fit" the participants' needs and abilities.
d) Should accomplish several learning outcomes.
e) Multiple learning experiences can achieve the same objective.

3) What are the four major activities in FFS learning sessions? (mark the right answers)

a) Field studies
b) Reports
c) Placement
d) Seminars
e) Lectures
f) Agro Ecosystem Analysis (AESA)
g) Portfolio
h) Special topics
i) Assessment
j) Group dynamics, icebreakers and energizers
k) Mentoring

4) Link the activity (number in front of the activity) to the corresponding statement

Activity	No.	Feature
1. Field studies		Technical information to compliment the 'learning by doing' and field experimentation. This provides an opportunity for the facilitator,

		researcher or specialist to give technical inputs needed for a general understanding.
2. Special topics		Is a decision-making tool used to make weekly field observation throughout the crop life cycle
3. Agro Ecosystem Analysis (AESA)		Method helps participants analyze their own experiences to better understand how they behave in different situations.
4. Group dynamics, ice-breakers and energizers		It is an initial form of research because the data collected is specific only to the purpose for which it was gathered. Originals are collected or unconventional data via face-to-face interviews, surveys, or direct observation.

1.6 Participatory evaluation of the project

Learning outcomes

- Outline the reasons of implementation of the participatory.
- Explain the components and necessary activities to be carried out in a participatory evaluation.
- Plan and employ participatory evaluation.

A participatory evaluation is an opportunity for the stakeholders/participant of a project to stop and reflect on the past in order to make decisions about the future.

Through the evaluation process participants share the control and responsibility for:

- deciding what is to be evaluated selecting the methods and data sources carrying out the evaluation
- analysing information and presenting evaluation results

Participatory evaluation can ideally be conducted as part of a broader participatory process or as a separate exercise. Participatory evaluation can be carried out for the following reasons:

The evaluation was planned at the beginning of the project

Participatory evaluation can be planned at different points in the project. These can be in the middle of a project activity or after each activity, depending on when the community decides it needs to stop and review past performance.

A potential crisis is imminent

Participatory evaluation can help avert a potential crisis by bringing people together to discuss and broker solutions to important issues.

The problem has become obvious

Problems such as a general lack of community/participants interest in activities may be obvious. Participatory evaluation can provide more information to help participants find out why the problem has arisen and how to fix it.

To introduce and establish a participatory approach

Participatory evaluation can show the problem why the project is not working well. Results of participatory evaluation can be a starting point for a more collaborative approach to the project in general. The extensive planning phase of a participatory evaluation includes recruiting staff, who will conduct the following steps:

- review objectives and activities
- review reasons for evaluation
- develop evaluation questions
- decide who will do the evaluation
- identify direct and indirect indicators
- identify the information sources
- determine the skills and labour that are required to obtain information
- determine when information gathering and analysis can be done
- determine who will gather information.

The information is then gathered in a database, partially analysed and then presented to the appropriate public, who further analyse the information collectively (Table 1.16). Finally, conclusions and action plans are developed from insights learned.

Table 1.16 Implementation of evaluation

IMPLEMENTATION OF EVALUATION	Sources	Activities
	PERSONNEL AND TASKS The personnel required to conduct an evaluation varies widely, depending upon variables such as the scope of the project being evaluated, its geographical range and the number and type of methods used to collect and analyse data.	Who will be needed: – to supervise the overall evaluation and ensure that the various parts come together to cohesive whole – to facilitate group data collection techniques. – to conduct analyses and facilitate, perhaps with a moderator, group analyses – to organise logistical matters, such as meeting locations, etc.
	PLANNING THE EVALUATION Making plan: The preparatory process helps participants understand what they are evaluating, why and how they are going to do it.	– Review objectives and activities – Review reasons for evaluation – Develop evaluation questions – Decide who will do the evaluation – Identify direct and indirect indicators – Identify the information sources – Determine the skills and labour that are required to obtain information – Determine when information gathering and analysis can be done – Determine who will gather information
	DATA COLLECTION	– Collect the information – Form database
	DATA ANALYSIS	– Review the questions

		– Organise the information – Decide how to analyse information – Analyse quantitative information – Analyse qualitative information – Integrate the information
	PRESENTATION AND ACTION PLAN	– Presentation of initial results – Develop a future action plan – Write up a final report

Source: Elliot at al., 2006

Revision questions

1) Indicate in order from 1 to 9 the sequence of the following steps of participatory evaluation

No.	Steps
	Identify direct and indirect indicators
	Determine when information gathering and analysis can be done
	Review reasons for evaluation
	Determine the skills and labour that are required to obtain information
	Identify the information sources
	Decide who will do the evaluation
	Develop evaluation questions
	Review objectives and activities
	Determine who will gather information

2 GENERAL APPROACH TO PESTS, DISEASES AND WEED MANAGEMENT IN ORGANIC FARMING

2.1 Basic principles of plant protection in organic farming

Learning outcomes

- Define the main differences in plant protection between conventional and organic farming.
- Explain the three-step approach to pest, disease and weed management in organic farming.
- State the EU regulation on plant protection products used in organic farming.

Crop protection from diseases, pests and weeds is the most demanding segment of organic farming. Due to the holistic approach, it requires a lot of producers' knowledge and experience for planning the production and implementation of all technological measures and their impact on the development of certain groups of harmful organisms. The fear that adhering to the guidelines for organic cultivation, where we cannot rely on effective plant protection products available in conventional production, it will not be possible to preserve crops from pests, is often the main reason why growers find it difficult to switch to organic production.

However, organic protection is not correctly perceived as an alteration of the plant protection products, from those that are effective to those that are less effective. It implies changing the entire production system and introducing some new measures that will make our farm, crops and individual plants more resistant to pest attack. Organic protection primarily relies on preventive measures and careful monitoring of conditions for the development of harmful organisms and their populations, and only in conditions when the threshold of economic damage is exceeded, direct measures are implemented, including the use of permitted plant protection products.

The problem of pest management is particularly pronounced in the period of conversion of the farm when self-regulation of the ecosystem is underdeveloped, and producers are inexperienced. Therefore, before the transition, it is necessary to make a detailed plan of conversion that in each segment of production considers its impact on the development of pests.

Plant protection in organic production relies on the three-step approach (Figure 2.1).

2.1.1 Providing good growing conditions for plants to enhance their resilience and resistance

By choosing the appropriate location, production system, variety and technology, it is required to create favourable conditions for the development of healthy and resistant plants, and unfavourable conditions for the development of diseases, pests and weeds. Different agricultural crops, and especially annual and perennial species, have specific growing demands and technological solutions need to be adapted to them, but the principles we are guided by are common. Proper site selection should provide adequate lighting, airing and drainage, while one near potential sources of infection needs to be avoided. The possibility of damage and economic losses will be reduced by growing varieties resistant to the main pests. Planting and sowing healthy reproductive material will prevent the entry of the infection source. The appropriate system of soil maintenance and balanced organic fertilization will improve soil fertility and increase the diversity of soil microorganisms. Plants grown on fertile soil will be more resistant, and among the diverse microbiological population, natural enemies of soil pests will develop as well. By organizing crop rotation and growing several crops in the same field, the accumulation of harmful organisms will be avoided. Selection of the appropriate plant spacing and plant management in the field create an unfavourable microclimate for the development of diseases and weeds, while the monitoring of infection symptoms, pest populations and the application of plant protection products are facilitated.

When establishing an agricultural holding and carrying out technological interventions, it should be always kept in mind that all the implemented measures have an important impact on the development of diseases, population of pests and weeds in the field. By implementing them properly, the problem of important pests of the crops can be permanently reduced.

Figure 2.1 Three-step approach to pest, disease and weed management in organic farming

2.1.2 Encouraging natural control mechanisms of the ecosystem through promotion of natural enemies

One of the main characteristics of natural ecosystems is the ability of self-regulation. These ecosystems exist completely without external influence, and they provide a natural circulation of nutrients that allow the development of plants that serve as a source of food for various animals, insects and microorganisms. Species that live within the same habitat are in different interrelations where they have the roles of predators, parasitoids, prey, decomposers. Their relationships enable the self-regulation of ecosystems, which does not allow the population of one species increases so much that the sustainability of other species is disputed.

Modern agricultural production in which we often grow endless fields of the same culture, choose vigorous and yielding varieties, intensively fertilize with mineral fertilizers, and regulate the population of harmful organisms with effective plant protection products is completely contrary to the conditions of natural ecosystems. Various technological interventions eliminate all organisms from the "ecosystem" beside the culture we grow, both harmful and beneficial. In such circumstances, cultivated plants are very susceptible to pest attacks that have an inexhaustible source of food, and as we have removed all their natural enemies, their population can grow to the point of destroying the entire crop. Such production systems are completely unsustainable without the constant influence of man and the introduction of various inputs outside the farm.

Therefore, in organic farming, one of the main goals is to encourage the diversity of species in and around fields, and to create habitats attractive to natural enemies that will help to regulate pests. Moreover, it is desirable that organic farms are of a mixed type in order to avoid large areas under the same crop, and it is recommended that livestock farming is developed in addition to crop production.

Species diversity is encouraged by organizing different ecological infrastructures suitable for individual crops. Permanent habitats around fields, such as meadows, rocky areas, forests, lakes, etc., hedges and dry-stone walls along the edge of a field, flower strips and cover crops in vineyards and orchards serve as ecological infrastructure. Ecological infrastructure should provide food to natural enemies as well as shelter while there are no crops. Tall vegetation around the fields also serves as a barrier against the introduction of pests from the outside, prevents the drift of plant protection products, reduces wind gusts, etc. In addition, cover cropping has a positive effect on soil fertility, storage of water in the soil, while it prevents erosion and the harmful effects of direct sunlight and precipitation on bare soil. The choice of infrastructure needs to be adapted to the culture we grow to prevent potential negative impacts. The habitat of beneficial organisms can also be a habitat for pests or viral vectors where some plant species are alternative hosts to diseases of agricultural crops. Moreover, a competitive relationship for water and nutrients with cultivated plants should be avoided, as well as shading of the agricultural area.

2.1.3 Application of direct control measures to kill the pests, diseases or weeds in a way that has minimum residual effect to the ecosystem

Direct measures to control diseases and pests are used if preventive measures did not give a satisfactory result. To decide if suppression is needed and to set time limits, it is necessary to establish a system of monitoring environmental conditions for forecasting the development of diseases and pests, monitoring the population of pests and their natural enemies, the appearance of disease symptoms and knowing the thresholds of economic damage. For successful monitoring, it is necessary to be familiar with the biology of pests and the symptoms they cause on plants. Direct measures aim to reduce the population below the critical number with as little negative impact on the ecosystem as possible. These include physical measures (collection of insects, weeding, burning, hoeing, mowing, tillage) and the use of products of different origins that enhance the resistance of plants and ecosystems, while they act to the environment, natural enemies, and other organisms with a low risk. Botanical pesticides, biopesticides, pheromones, mineral-based preparations, etc., are the most used products, whose application is permitted by regulations on organic farming.

Protection against diseases and pests in organic farming defined by Regulation (EU) 834/2007, which will be replaced by Regulation (EU) 848/2018 of the European Parliament and of the Council on the 1st of January 2022. In addition to the basic principles of pest protection, which relies primarily on the previously described preventive measures, the regulation also controls the approval of products and active substances used in plant protection products.

Products whose use is crucial for the control of a harmful organism for which there are no alternative biological, physical or growing solutions, cultivating practices or other effective management procedures are approved to use. These products and substances originate from plants, algae, animals, microbes or minerals. Exceptionally, other products may be approved if their use is crucial for the control of a harmful organism for which there are no alternative biological, physical or growing solutions, growing practices or other effective management procedures. When using such products, the required waiting periods must be kept after contact with edible parts of the crop. Plant protection products used in organic farming must be registered or permitted in accordance with the abovementioned regulation.

Revision questions

1) Which of the sentences about organic farming is incorrect?

a) Organic farming enhances biodiversity.
b) Organic farms are mainly mixed (crops and farm animals).
c) Organic farming promotes biological cycles and soil biological activity.
d) Organic farming requires high input and produces high yield.
e) Organic farming relies on the self-regulation of an ecosystem.

2) Which of the sentences about the plant protection in organic farming are correct?

a) Plant protection in organic farming relies primarily on chemical plant protection products.
b) Healthy crop is grown with the least possible disruption to agro-ecosystems.
c) Organic farming has a holistic approach to plant protection.
d) Organic farming uses chemical plant protection products of high efficacy.
e) Plant protection in organic farming relies on natural pest control mechanisms.

3) Mark the correct statements. In organic farming…

a) The use of plant protection products is not permitted.
b) Plant protection products are used only if preventive measures didn't succeed in maintaining the pest population below the economic threshold.
c) Plant protection products must be pre-approved by the European Commission.

4) Which three steps must be undertaken for successful plant protection in organic agriculture?

a) Providing good growing conditions for plants in order to enhance their resilience and resistance.
b) Growing large areas of the same culture, choosing vigorous and yielding varieties and regulating the population of harmful organisms with effective plant protection products.

c) Encouraging natural control mechanisms of the ecosystem through the promotion of natural enemies.
d) Application of direct control measures for killing pests, diseases or weeds in a way that has minimum residual effect to the ecosystem

5) Mark the correct options. Natural control mechanisms of the ecosystem can be encouraged by:

a) Cover cropping
b) Planting single crops in the field
c) Creating habitats attractive to natural enemies
d) Maintaining meadows, rocky areas, forests, hedges and dry-stone walls along the edge of a field
e) Establishing a diverse cropping system
f) Eradicating all other plant species from plantation by intensive soil tillage

2.2 Enhancing crop resilience and resistance

Learning outcomes

- Discuss the importance of enhancing crop resilience and resistance in organic plant protection.
- Explain the influence of site and cultivar selection and crop planning on the prevention of pest outbreak.
- Describe soil and plant management practices favourable for the regulation of pest population in organic farming.

2.2.1 Site selection

Site selection for the crop establishment is very important for the economic success of any plant production. In the organic farming, even more attention is given to the site selection because it can considerably influence the development of diseases, pests and weeds. Generally, it can be said that organic fields should be established on the best cultivation sites for a particular type of production. Appropriate topography, such as flat terrain for vegetables, or hills and slopes of suitable exposure for vineyards will ensure good lighting and airiness. In such conditions, after precipitation, the vegetative mass dries quickly, so the conditions for the development of fungal diseases are unfavourable. The soil on which organic crops are grown should be moderately fertile and well drained with a high content of organic matter. In this way, the vigour of plants will be moderate, and thus the risk of fungal diseases. Favourable soil conditions are important for the development of crop roots, but also for increasing the diversity of the population of useful microorganisms and other animal species which help to regulate the population of weeds and soil-borne diseases. It is important to consider the natural vegetation or agricultural areas around the future field as well as the vegetation on the future field itself since they can be a source of disease or host plants to problematic pests and disease vectors. Moreover, it is necessary to avoid cultivating near abandoned fields. It is recommended to establish crops in areas where the diversity of agricultural crops is wide and agricultural areas are combined with natural habitats in order to create a more active ecosystem.

2.2.2 Crop planning and crop rotation

The organization of crop rotation, i.e., spatial and temporal change of crops is an inevitable measure in the production of arable and horticultural crops. It has a great importance in organic production since it is a fundamental measure for pest regulation. It is an ancient human experience that long-term cultivation of the same crop accumulates diseases, pests and weeds in the soil, and thus this was the reason for the crop rotation introduction.

Consecutive cultivation of the same culture affects the structure of microorganisms' population in the soil, i.e., it causes a decrease in the number of useful microorganisms and fauna, and the spread of pathogens in the soil. Although soil diseases are slowly transmitted and are initially limited to smaller areas and a smaller number of infected plants, by growing the same or related crops on the same land, the number of pathogens and infected plants will increase from year to year. A particular problem is the accumulation of parasitic nematodes and virus-vector nematodes in the soil. Some crops, such as potatoes, are particularly susceptible to nematodes, while the nematodes are virus vectors in others, such as grapevine. The most successful way to control nematodes is to change crops, grow resistant varieties and destroy their host weeds.

In continual cultivation, weed companions are widespread. Thus, it is required to alternately shift monocotyledons with dicotyledons, narrow spacing crops with wider spacing ones, sowing of broadleaf species after narrow leaf ones, etc.

When compiling the crop rotation, it is necessary to know the characteristics of each individual species, their tolerance to repeated cultivation as well as their interrelationships. It is mandatory to alternate non-related species with diverse growing requirements and characteristics, such as cereals, vegetables and root species, and to avoid the cultivation of related (potato/tomato, celery/carrot) species one after another. Cereals can be grown more often in crop rotation because they are not conducive to the development of diseases in the soil, while the crops that are susceptible to soil diseases should be planted in crop rotation rarely or always on a new surface. By alternating species that a particular pest feeds on with those that a pest does not eat is a long-term strategy to reduce their population.

A well-designed crop rotation will reduce the accumulation of weed seeds in the soil but will also reduce the appearance of new seeds. It is recommended to alternately grow fast developing species that provide high planting density with species that can be dug for a long time. If the population of perennial weeds grows despite all the measures taken, crop rotation is one of the few opportunities to reduce them.

Simultaneous cultivation of two or more crops on the same lot (consociation) has many positive crop rotation characteristics since it provides optimal use of available space in the field and helps with pest prevention. It can be organized in different ways, from sowing two or more species together randomly on the same surface, through sowing intercrops of one species in the interrow spacing of another, to alternating several rows of one species with several rows of another one. The growth of plants in consociation stimulates a rich and diverse life in the soil and thus helps to control both harmful organisms in the soil and weeds. The different species in the field provide a fast-growing and well-covering vegetation layer that prevents weed development. If another crop is grown in addition to a crop with a large space between plants, the vegetation layer on the soil will develop faster and less effort will be needed to regulate the weeds. For example, if tall crops that ripen earlier are grown with those that remain low to the ground and ripen later, the growth of the second crop will be slower at first, but after the end of a high crop growing season, the second crop will start growing more intensively and thus prevent weed growth.

The second crop can be used as the vegetation around the field to serve as a barrier to fungal spores, pests and virus vectors. Furthermore, some species may attract natural enemies or act as repellents for pests of the species with which they are grown in consociation.

2.2.3 Cultivar selection, seed and planting material

Given the narrow range of permitted measures and plant protection products in organic farming, one of the most effective strategies to combat diseases and pests is the cultivation of resistant varieties. Of course, there are no resistant varieties of all species nor those that would be resistant to all pathogens of one species. However, resistant varieties should be sown/planted whenever possible, and they should be preferred even at the cost of compromising with some other important economic characteristics. There are two main reasons for this. Less susceptible varieties are less likely to be infected than susceptible ones and can be grown in the presence of certain pathogens without major damage. The population of pathogens will be reduced by their cultivation, which will allow the cultivation of somewhat more susceptible varieties after a few vegetations. It is also appropriate to simultaneously grow more varieties of different resistance, which is closer to the traditional method of cultivation where the planting material was not so genetically uniform. In this way, less susceptible plants will not develop symptoms or will have fewer symptoms, and part of the spores will retain on them instead of susceptible plants. However, the cultivation of resistant varieties leads to the adaptation of pathogens by the development of new strains that can overcome resistance. Therefore, growing resistant and less resistant varieties together will slow down the appearance of such strains.

One of the strategic controls for diseases and pests in the soil is grafting on resistant rootstocks, for which a good example is the grafting of grapevine on *Phylloxera*-resistant rootstock.

Planting/sowing healthy planting material is one of the standard phytosanitary measures in modern agriculture. It has additional importance in organic production. Infected planting material brings the source of infection and weed seeds into the crop plantation and allows the development of diseases and weeds early in the growing season when the young plants are especially susceptible which can cause serious damage. These pests are regularly well adapted to a particular species, while some new diseases, pests or weeds that were not present before and to which the producers are not accustomed can be introduced to the farm through infected material.

2.2.4 Soil management

Fertile soil is of the principal value of every plant production. In conventional agriculture, favourable conditions for the growth and development of cultivated plants are created by intensive mechanical tillage and by the addition of easily available nutrients in the form of mineral fertilizers. Organic production is based on a completely different paradigm. Here, the soil is considered as a living organism and all measures are directed toward creating favourable conditions for the development of diverse microorganisms and fauna in the soil that will provide the necessary nutrients for cultivated plants through complex processes of organic matter production and decomposition.

Fertile and well-structured soils will provide optimal conditions for plant growth, which increases their resistance to pests. It is important to fertilize in a balanced way to ensure a sufficient amount of P and K, while N should not be excessive. Overabundant amount of N makes the crop tastier for insects. It causes high plant density and robust vigour. High humidity provides favourable conditions for the development of the disease. Moreover, it is demanding to monitor the diseases and pests' symptoms and to apply plant protection products in such conditions, while it is harder for natural enemies to find pests. Therefore, in organic farming, manure is applied almost exclusively with organic fertilizers (stable manure, compost produced on one's own farm, etc.), which are gradually mineralized and mineral nutrients are released from them. Fertilization with organic manures ensures the maintaining and increasing of humus content, which is essential for fertility and microbiological activity of the soil.

Increasing the diversity of species in the soil is an important task in organic production because through their impact on nutrient circulation some of the soil microorganisms, natural enemies or small animals in the soil directly attack pests and destroy weed seeds. Tillage, and in particular the mixing of soil horizons, is reduced to a minimum to provide the conditions for soil organisms to be as favourable as possible. Wherever possible, the soil is maintained by cover cropping or mulching, thus creating a layer of soil with a crumbly structure, rich in organic matter and soil organisms.

Diverse cover crops are also habitats for natural enemies living above the soil. Cover cropping with fast-growing species that cover the soil is one of the most successful strategies for weed control especially in fields where crops are grown with large inter row distances.

Cover cropping with annual species (green manuring) can also be applied between harvesting and the beginning of new growing season/planting of new permanent crops. This is a good way to maintain the soil in areas where due to the small amount of precipitation is not possible to permanently grow cover crops together with perennial crops. Selection of proper species for green manuring can reduce the pest population left over from the previous crop, prevent weed growth and nutrient leaching in the soil. Their ploughing brings in fresh organic matter used to feed on microorganisms and other beneficial organisms in the soil.

Many of the benefits of crop covering, particularly the impact on the soil biodiversity improvement, are also achieved by mulching. In organic production, mulching with organic materials is applied, most often with straw or freshly cut grass. That kind of covering significantly affects the weed development, making it difficult for them to grow through the layer of organic matter and preventing the light necessary for germination.

Appropriate irrigation method can also affect the diseases development and should be adapted to specific crops. The amount of water in one round of watering, the irrigation frequency and technique can affect the spread of disease and the severity of the damage they cause. For example, if furrows are irrigated, it is suitable to water them more often with smaller amounts of water, while the sprinkler irrigation system is better to operate late in the evening or at night when dew is already forming. Considering disease prevention, the most suitable is localized irrigation (drip irrigation) where small amounts of water are applied to the plant root, while the aboveground plant organs are not moistened.

2.2.5 Plant management

The development of diseases and pests, their monitoring and the application of plant protection products are significantly influenced by the various plant management measures that are carried out on the plants we grow. Different interventions are carried out on different crops, yet they should provide balanced vegetative and generative growth for all crops. Thus, during certain critical periods of development, vigour is reduced, while better nutrition of fruits is provided, which increases their fertility and quality. In addition, by removing redundant vegetative organs (such as laterals, tops of shoots, leaves in the fruit zone or shoots from the trunk) ventilation and quick drying take place which create unfavourable conditions for the fungal diseases' development.

Winter pruning is regularly carried out in permanent crops such as vineyards and orchards, which has a similar purpose as the interventions carried out during the growing season. When performing winter pruning, from the phytosanitary point of view, it is important to leave only the shoots without symptoms of diseases and remove all unnecessary parts where pests can overwinter. It is not appropriate to chop the pruning residues and leave them on the ground as mulch or plow them into the soil since they can be a source of infection in the next vegetation.

It is required to remove all the shoots discarded by pruning from fields with perennial crops, and to remove all leftovers after harvesting annual crops since they can be an infection source in the next growing season. This is especially important for highly infectious pathogens that develop early in the growing season from the debris of the previous one. Composting plant debris will ensure the circulation of nutrients within the farm. During the production of compost, a high temperature develops which destroys pests, thus the obtained organic fertilizer can be incorporated into the soil without the danger of spreading the infection.

It is recommended to continuously remove infected plant parts while the level of infection is still low during the growing season.

Revision questions

1) Mark the correct options. Crop resilience and resistance to pest outbreak can be influenced by:

a) Site selection
b) Varieties selection
c) The soil system
d) Marketing strategies
e) Plant management

2) Which of the following characteristics make a good site for establishing organic plantation?

a) Appropriate topography for particular crop
b) Proximity to abandoned fields
c) Good lighting and air drainage
d) Well drained soil with a low content of organic matter
e) Agricultural areas that are combined with natural habitats

3) Mark the correct options. Well-established crop rotation…

a) Reduces the accumulation of weed seeds.
b) Increases the number of useful microorganisms in the soil.
c) Accumulates diseases, pests and weeds in the soil.
d) ontrols the nematode population in the soil.

4) Connect the cultivation practice in the left column with the positive influence that it has on plant protection in the right column. Multiple answers are possible.

	a) Avoidance of the accumulation of pests
1. Cover cropping and organic fertilization	b) Creation of an unfavourable microclimate for the development of diseases and weeds
2. Plant spacing	c) Easier monitoring of infection symptoms and pest populations
3. Plant management	d) Better application of plant protection products
4. Crop rotation and plant consociation	e) Increase in soil fertility and diversity of soil microorganisms
	f) Regulation of plant vigour

5) Which of the following statements about cultivar selection and seed and planting material in organic farming is true?

a) There are resistant varieties of all species of agronomic importance.
b) Less susceptible varieties can be grown in the presence of certain pathogens without major damage.
c) The cultivation of resistant varieties leads to the adaptation of pathogens because of the development of new strains that can overcome the resistance of the varieties.
d) Planting material can bring weed seeds into the crop plantation.

2.3 Biodiversity enhancement

Learning outcomes

- Define what biodiversity encompasses.
- Explain the benefits of improving biodiversity.
- Describe the strategies for increasing biodiversity in organic farming.

2.3.1 The role of biodiversity

Biodiversity plays a crucial role in food security, nutrition, and livelihood and in the provision of ecosystem services. Biological diversity encompasses all species of plants, animals, and microorganisms and the ecosystems and ecological processes of which they are parts. In a common parlance, biodiversity may be defined as species richness (plants, animals, and microorganism) in a given habitat. It may be land, in freshwater or sea or as parasites or symbiosis. Biodiversity encompasses diversity of life on all levels: species diversity, genetic diversity as well as habitat and ecosystem diversity. A rich biological diversity is essential for preserving natural processes contributing to man's ability to live, such as natural pest regulation, pollination of fruit biomass by insects, and the decomposition of organic matter. Agricultural policies are increasingly promoting ecological-oriented farming method that preserves biodiversity and conserves natural resources. In historic times, a more diverse landscape unfolded through farming from what was once an undifferentiated landscape dominated by forests. Today as well, regionally adapted and extensive forms of cultivation are essential prerequisites for a diverse species rich landscape.

A major tenet of sustainable agriculture is to mimic diversity that is commonly found in natural ecosystems but may be lost in agricultural terrain. Biodiversity refers to the variety of plants, animals and microorganisms above and below the soil that interact within an ecosystem. Plants and animals are consistently integrated into diverse landscapes. As a result, these systems are typically more stable, withstanding disturbances and recovering better than less diverse systems. Organic cropping systems promote a diverse, balanced ecosystem as a practice to enrich the soil and prevent weed, insect pest and disease problems. Crop diversity, crop rotations, intercropping, cover cropping, conservation tillage and incorporation of organic matter are all important components of farm biodiversity.

Benefits of encouraging diversity:

- Improves soil quality

Diverse crop rotations improve soil, increase farm biodiversity and boost crop yields. High-quality soils encourage dense populations of microorganisms, enhance natural biological control of pathogens, slow turnover of nutrients, encourage communities of beneficial insects and improve soil aeration and drainage. Crop rotations, management of crop residues, conservation tillage, incorporation of animal manures and the use of nitrogen-fixing crops can increase soil health and productivity.

- Enhances insect, weed and disease control

Diverse plantings often decrease insect pest populations. Specialized herbivores are more likely to find and remain on pure crop stands where food sources are concentrated. Fields containing a variety of crops are often rich in above- and below-ground beneficial organisms that naturally control pests, inhibit growth of disease organisms, boost a crop's natural defenses and suppress some weeds. The use of crop diversity, crop rotations, scattered fields, adjacent uncultivated land and a perennial crop component are methods that can be used to reduce pest pressure.

- Encourages beneficial organisms

Planting crops that support natural enemies or directly inhibit insect attack helps to stabilize pest communities. Spatially and temporally diverse plantings ensure that natural enemy populations are provided continuous availability of resources. Beneficial insects, mites and nematodes can also be provided food and habitat by including areas of adjoining, uncultivated land and wild vegetation. Further, using ground covers and surface residues can enhance the abundance and efficiency of predators and parasitoids.

- Spreads economic risk

Increasing farm diversity offers the opportunity to increase profits while decreasing production costs. Adding new crops that fit the climate, geography and management requirements can increase profits by providing the opportunity to exploit niche markets, expand marketing opportunities and offset commodity price swings.

2.3.2 Strategies for increasing biodiversity

Healthy plant is less vulnerable to pest and disease infestation. Therefore, a major aim for the organic farmer is to create conditions which keep a plant healthy. The interaction between living organisms and their environment is crucial for a plant 's health. Plant's health is more at risk in monocultures and on-farm diversification provide a balanced interaction between different plants and pests and predators. This is why a well-managed ecosystem can be a successful way of reducing the level of pest or disease population. Certain crop varieties have more effective mechanisms than others due to the adaptive nature to the environment and therefore have a lower infection risk.

The health condition of a plant depends to a large extent on the fertility of the soil. When nutrition and pH is well balanced, the plant becomes stronger and is therefore less vulnerable to infection. Climatic conditions, such as suitable temperatures and sufficient water supply, are further factors which are crucial for a healthy plant. If one of these conditions is not suitable, the plant can become stressed. Stress weakens the defense mechanisms of plants and makes them easy targets for pests and diseases. One of the most important points for an organic farmer is therefore to grow diverse and healthy plants. This avoids many pest and disease problems. Strategies for increasing biodiversity in organic farming are shown in Figure 2.2.

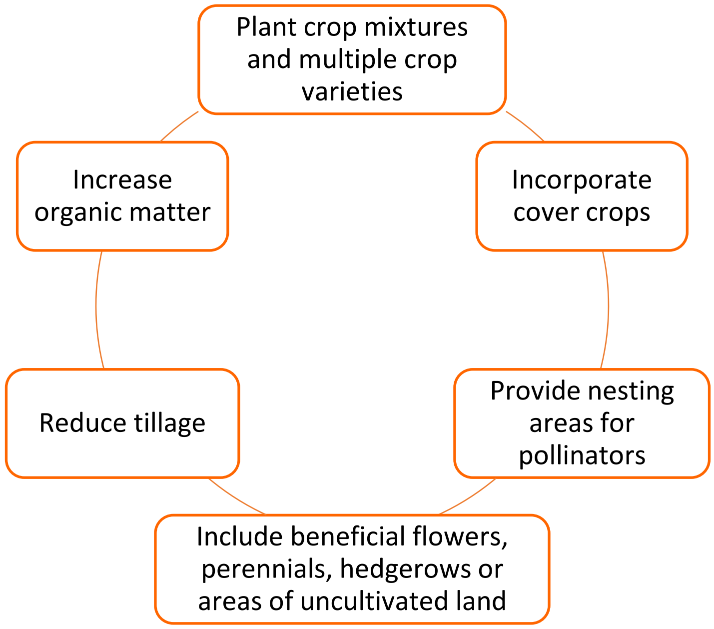


Figure 2.2 Strategies for increasing biodiversity in organic farming

How to Increase On-Farm Biodiversity?

- Ensure diversity of plant species

Increasing within-field biodiversity can be achieved through planting crop mixtures and multiple crop varieties. The establishment of diverse plantings at field margins should also be considered. Planting strips of beneficial flowers, incorporating perennials, establishing hedgerows (a row of trees or shrubs separating fields) and leaving areas of land uncultivated are methods of increasing diversity on non-cropped land.

- Preservation of pollinators and natural enemies

To increase diversity of native pollinators, establish nest blocks and allow access to areas of soil, such as open soil, for nesting. A source of water is also essential. Branches of trees and shrubs, such as those in hedgerows, will also provide nesting sites for pollinators. The organic farmer should try to conserve natural enemies already present in the crop environment and enhance their impact. This can be achieved with the following methods:

a) Minimize the application of natural pesticides (chemical pesticides anyway are not permitted in organic farming);

b) Allow some pests to live in the field which will serve as food or host for natural enemies;

c) Establish a diverse cropping system (e.g. mixed cropping);

d) Include host plants providing food or shelter for natural enemies (e.g. flowers which adult beneficial insects feed on).

There are many possibilities to enhance floral diversity within and along the boundaries of crop fields:

Hedges - Use indigenous shrubs known to attract pest predators and parasitoids by offering nectar, pollen, alternative hosts and/or preys. Most flowering shrub species have this property. However, care should be taken to not use plant species known to be alternative hosts of pests or diseases.

Beetle banks - Strips of grass in the neighborhood of crop fields harbor different natural pest enemy groups like carabids, staphylinid beetles and spiders. In order to lower the risk of weeds and plants known as host plants of crop pests and diseases, one to three native grass species can be sown in strips of 1 to 3 m.

Flower strips - Use indigenous flowering plant species known to attract predators and parasitoids by offering nectar, pollen, alternative hosts and/or preys. Most flowering plant species have this property. However, care should be taken not to use alternative hosts of pests or diseases. Three to five native flowering plant species can be sown in well-prepared seed beds, arranged in strips of 1 to 3 m on the boundary of the crop field. After flowering, seeds can be collected to renew the strip or create new ones.

Companion plants - Natural pest enemies can also be attracted by companion plants within a crop. These companion plant species can be the same as used in the flower strips. A few (1 or 2 per 10 m^2) flowering companion plants within a crop serve as a 'service station' for natural pest enemies.

- Crop rotation

Crop rotation refers to the sequence of crops and cover crops grown in a specific field. Rotation designs should include multiple crop families, manage short- and long-term crop fertility needs, reduce weed pressure, disrupt weed and disease cycles and optimize crop production.

- Intercropping

Two or more crops grown in close proximity can produce beneficial interactions. Intercropping can be achieved by growing crops in alternating rows (row intercropping), growing crops in larger alternating strips (strip intercropping), growing crops together with no distinct row arrangement (mixed intercropping) or by planting a second crop into a standing crop at the reproductive stage (relay intercropping). Special attention should be given to the spatial arrangement, plant density and expected maturity dates of selected crops.

- Cover crops

Cover crops are used to protect the soil from erosion during times when a field is not under production. Crops that are easy to plant, establish and control or kill should be selected. Suitable varieties provide reliable ground cover and have no negative impact on the following crop. It is important to evaluate rooting depth and crop characteristics, such as weed and disease suppression, nitrogen fixation and the attraction of pollinators and natural enemies. Planting dates and climate requirements are also important for consideration, as suitable crops vary by geography and climactic conditions.

- Conservation tillage

Conservation tillage requires minimal soil disturbance, keeping at least 30 percent of the soil covered by crop residue. After harvest, crop residues are left or cover crops are established until the next crop is planted. Several methods of conservation tillage have been established. No-till planting uses specialized equipment, disturbing only a small area where the seed or transplants are set. Strip- or zone-tillage creates a tilled seedbed 5 to 7 inches wide along the plant-rooting-zone, leaving the rest of the field undisturbed. Ridge-tillage creates permanent soil ridges on top of which crops are grown.

- Incorporation of organic matter

Increasing organic matter provides harbors for soil microbes and intensifies soil biological activity, helping to lessen the risk of disease. The breakdown of organic matter by soil microbes returns nutrients to the soil removed during crop production. Animal manures, cover crops, crop residues and organic amendments can be incorporated into the soil to increase organic matter content over time.

Revision questions

1) Biodiversity encompasses:

a) All species of plants present in a certain ecosystem
b) All species of animals present in a certain ecosystem
c) All species of plants, animals, and microorganisms and the ecosystems and ecological processes of which they are parts

2) Organic cropping systems promote a diverse, balanced ecosystem as a practice to enrich the soil and prevent weed, insect pest and disease problems:

a) True
b) False

3) Increasing biodiversity in organic cropping systems

a) Improves soil quality
b) Enhances insect, weed and disease control
c) Encourages beneficial organisms
d) Offers the opportunity to increase profits while decreasing production costs
e) All of the above

4) Strategies for increasing biodiversity in organic farming include:

a) Plant crop mixtures and multiple crop varieties
b) Include beneficial flowers, perennials, hedgerows or areas of uncultivated land
c) Provide nesting areas for pollinators
d) Incorporate cover crops, reduce tillage and increase organic matter
e) all of the above

5) How can the diversity of plant species be improved?

a) Avoiding hedgerows
b) Planting crop mixtures and multiple crop varieties
c) Never leaving areas of land uncultivated
d) Planting strips of beneficial flowers, incorporating perennials

6) **Describe what can be done to preserve the pollinators and natural enemies?**
   a) ____
   b) ____
   c) ____
   d) ____

7) **Biodiversity can be enhanced by using crop rotation because it reduces weed pressure, disrupts weed, insect and disease cycles and optimizes crop production.**
   a) False
   b) True

8) **Intercropping (two or more crops grown in close proximity):**
   a) Enhances beneficial interactions
   b) Can help improve pest management e.g. reduce pest damage
   c) Is not supported by organic farming because it causes economic losses

9) **Explain how the conservation tillage can help conserve biodiversity?**

   ____

10) **Incorporation of organic matter is a strategy for increasing biodiversity in organic farming, because the breakdown of organic matter by soil microbes returns nutrients to the soil removed during crop production, which helps to regain soil richness and health.**
   a) True
   b) False

2.4 Pests monitoring and forecasting

Learning outcomes

- Learn the importance of pest monitoring and forecasting.
- Define most popular and widely used monitoring techniques and explain their use in integrated pest management.

Many producers routinely apply pesticides on a calendar schedule when pest infestations are suspected or when pest populations are already high and difficult to control. The total cost of pest control over the production cycle can be expensive when calendar applications are used. Excessive spraying can render pesticides ineffective by promoting resistance to pesticides; applications can cause phytotoxicity; increasing regulations make spraying more difficult.

In many cases, a certain number of pests and a low level of damage can be tolerated; this concept is fundamental to integrated pest management (IPM). It is difficult to set specific thresholds and guidelines because the significance of the presence of pests or damage depends on many factors, including the tolerance of the farmer.

It is best to start monitoring pest populations before introducing or changing pest control measures. Monitoring is the systematic collection, recording and analysis of observations over time. The most important thing is to learn what trap caches reflect compared to pest damage and crop quality. Then it is necessary to modify control measures based on monitoring information. Farmers who systematically monitor their crops can develop their own thresholds. Many numerical thresholds can be developed for most monitoring methods.

2.4.1 Pest monitoring

2.4.1.1 Insect pest monitoring

To control insect pests, it is necessary to first determine the damage situation and create an optimal control plan, considering the environmental conditions and characteristics. Insect pest monitoring is the first basic step for proper IPM. Insects can be monitored using a variety of monitoring tools such as: pheromone traps, light traps, coloured sticky traps, suction traps, etc. Pest monitoring methods are usually very time consuming and require significant investment in species identification after manual trapping in the field.

Trap catch data serves several purposes: 1. ecological studies; 2. tracking insect migration; 3. new arrivals in agroecosystems; 4. initiating field surveys and sampling; 5. timing of pesticide applications; 6. defining phenology models; 7. predicting generation size; 8. pest control.

Predicting pests is an important part of the strategy of IPM. Early warnings and forecasts based on biophysical methods provide a lead time for managing an impending pest infestation and can thus minimize crop losses, optimize pest control, and reduce the cost of cultivation.

There is also a need to prevent secondary damage and spread through continuous monitoring by supplementing primary control with conscientious control according to planned pest management methods. As monitoring is carried out throughout the vegetation period, it is necessary to focus on a large area in a short period of time, taking into account the time when the damage occurred intensively and the time when control can be carried out.

Insect pests monitoring trough traps

Trap catches can warn of the presence of pests, hot spots, and insect migration and activity, and provide a relative measure of insect density. Comparisons of the number of adult pests trapped on specific sampling dates can indicate whether pest densities in crops are changing or remaining relatively constant over the long term. Evaluation of trap catches can help determine treatment needs, timing of applications, and effectiveness of previous control measures.

Among the various methods and devices used in pest monitoring, the most popular and widely used are sex pheromone traps for selective monitoring of individual flying species, light traps for flying species attracted to light, and coloured sticky traps for species attracted to colour. While adult males are usually caught in sex pheromone traps, adults of both sexes are caught in light traps and coloured sticky traps. Light traps and coloured sticky traps can be used to detect species presence and to study population distribution and movements (migrations in the ecosystem) in a given area. Sticky traps have provided interesting results and can be considered as unbiased recording systems. They do not require a power source and are inexpensive, but their inspection for identification and eventual collection of trapped insects can be difficult and time-consuming, and their handling is relatively cumbersome.

a) Sex pheromone traps

Pheromones are messenger substances used for species-specific communication. Normally, these pheromones are produced by females to attract males. Commercially, they are produced by synthesizing the appropriate components and putting them into dispensers that can be placed in traps of various designs, depending on the production.

Figure 2.3 Trap with pheromone (D. Lemic)

Sex pheromone traps are useful for monitoring pests that evade early detection of economic damage. By using pheromone traps (Figure 2.3), it is possible to monitor the occurrence and abundance of adult pests and predict crop damage in the following year. Once key habitat parameters have been identified, it is possible to predict infestation levels on an annual basis, thereby informing farmers of appropriate control strategies required for this and the following year's crop. For example, larval emergence can be predicted based on the abundance of adults and eggs in the year prior to repeated sowing of a particular crop.

According to good agricultural practice (e.g., Ministry of Agriculture), pest management must be based on population-level forecasts that comply with the principles of IPM. Determining the factors that positively or negatively influence or limit the growth of pest populations facilitates the development of IPM strategies aimed at slowing the spread of individuals and thus mitigating damage to crops at the national and possibly international level.

b) Coloured sticky traps

The coloured trap is the most efficient method of monitoring the crop for insect pests and can often indicate the presence of the insect early enough for other control measures to be taken. Sticky traps are used as one of the effective IPM strategies for monitoring various insect species. They provide a simple method for estimating pest population density, require low cost and low skilled labour, and are helpful in developing an environmentally friendly control strategy. As a result of estimation with sticky traps, there is generally a reduction in pesticide use, which in turn leads to lower input costs, reduced exposure of workers to pesticides, and ultimately lower pesticide-related phytotoxicity and costs, which directly affect the quantity and quality of yields. Sticky traps are economically affordable as they cost less and require less technical work.

Sticky trap pest control uses an adhesive-based trap to monitor, trap, and immobilize pests. These types of traps are typically made of cardboard with a layer of sticky glue or plastic traps with renewable clue layer. The cardboard can also be folded into a tent shape or laid flat. The tent cover protects the glue surface from dust and other materials. Some glue traps also contain some type of scent to attract certain pests.

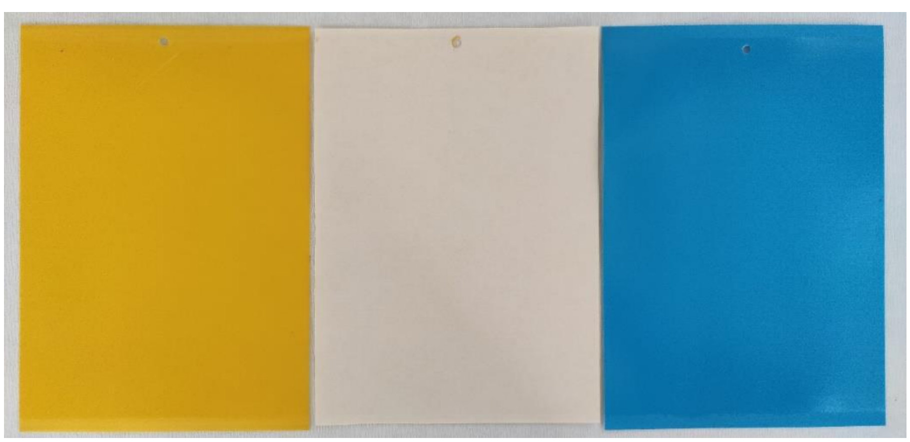


Figure 2.4 Coloured sticky traps (D. Lemic)

Sticky traps attract insect pests with a specific colour spectrum (Figure 2.4). They do not require bait or attractants but can be enhanced with essential oils such as Melissa, Lemon or Cinnamon Oil. Most animals exhibit the species-specific colour preference that an corresponds to a specific range of the visible light spectrum in an individual. Insect colour preference is a rather striking phenomenon that has attracted attention in the basic and applied sciences.

Bright yellow (about 550 to 600 nm wavelength) is highly attractive to many insects. Adult whiteflies, thrips, leafminers, psyllids, shore flies, winged aphids, and parasitoids can be monitored with yellow sticky traps. As an example, the use of yellow sticky traps in seedling production with 1-2 traps/50-100 m^2 can catch a significant number of whiteflies. Blue sticky traps are most attractive to western flower thrips and some other thrips species.

Traps provide a relative measure of insect density; comparing the number of adults trapped between sampling dates can indicate whether pest densities are changing or remaining relatively constant over the long term.

c) Light traps
The use of light to sample night-flying insects is a long-established technique. Light traps are most used to sample moth fauna (e.g., European corn borer *Ostrinia nubilalis*), but they also collect other insects, including adult aquatic insects (e.g., mayflies, dobsonflies, and caddisflies).

Depending on the intended use, there are many methods and variations that utilise an ever-changing technology. Light traps are best for population surveys or determining the geographic distribution of night-flying insects. This is because many species that are caught at night are practically undetectable using other sampling methods. Light traps for native insects potentially reveal a rich diversity of many different insects. It provides information on species diversity across all seasons, landscapes, ecological areas, elevations, and times of night. The light does not attract insects - it confuses them and takes them off their chosen flight path. Some insects fly repeatedly around the light, others simply settle at different distances from the light and fly away after different times. Insects see green, blue, and near ultraviolet (UV) light very well, but yellow and orange light they see poorly and red or infrared light they cannot see. Different types of light sources produce light at different wavelengths (colours) and are therefore differently effective for catching insects. Light traps are most effective for sampling night-flying insects in close proximity - up to 500 m from the light source. A light can be effective over greater distances - up to 1 km or more - if placed slightly elevated. Effectiveness depends on wind direction, as insects fly into the wind, and on wind speed, as many insects settle in strong winds. Flight activity also depends on temperature and humidity, and rain can stop or reduce it. Therefore, care must be taken when using light trap catches for comparative purposes such as monitoring. This requires keeping as many variables as possible the same or as close as possible each time. This is called standardisation.

Figure 2.5 Light trap (H. Virić Gašparić)

There are many types of light traps; they can be powered by 240 V AC or 12 V DC, UV or white light (full spectrum) lamps, and they can collect insects live or act as a killing trap.

Collections from a light trap provide important information about the diversity of nocturnal insects, their respective affinities for different wavelengths of light, and for understanding and predicting how populations function. Such information, when properly documented, can be used by field researchers in multiple ways, such as selecting light traps to attract specific orders of insects.

The light trap's passive sampling, retention of live specimens, and low cost have led to its widespread use for recording insect diversity in terrestrial environments. For example, light traps have been used consistently and widely since the 1940s for standardized mosquito monitoring, as well as for monitoring moths and other species considered pests.

2.4.1.2 Crop Disease Monitoring

Monitoring plants and diseases in their early stages is of paramount importance, as it can prevent damage and allow for early action. In the past, detection and cure of plant diseases was done by the expert in the field. Disease monitoring requires a tremendous amount of work and time. Disease identification and diagnosis can be done directly on the plant. Manual monitoring of diseases does not give the desired result as naked eye observation is unreliable and increases the chances of misdiagnosis. It also requires the attention of an expert, which is time consuming and expensive. Therefore, manual methods are ineffective. Automatic and instantaneous plant disease detection is important to detect the symptoms of diseases at early stages when they appear on the growing leaf of the plant. It is used to segment the leaf, extract characteristics and classify it based on its appearance.

Some approaches focus on establishing a plant disease surveillance network based on the use of mobile phones, while others use satellite imagery. The disease detection aspect of the surveillance module uses computer vision and machine learning to detect plant diseases based on leaf images. However, leaf-based approaches rely on the use of imaging devices in low-resource approaches that use smartphones. This may be limited in areas with no or low smartphone usage.

In observing pathogen and host interactions, various plant diseases and pests would cause a variety of symptoms and plant damage, providing a physical basis for their remote monitoring. It should be noted that not all plant diseases are suitable for remote sensing, as some of them do not have identifiable characteristics. On the other hand, some soil-borne and root diseases that have systemic effects on plant physiology can be detected. Therefore, an essential requirement for the detection and monitoring of plant diseases and pests by remote sensing is the presence of a specific response that can be detected by a specific sensor or sensor system.

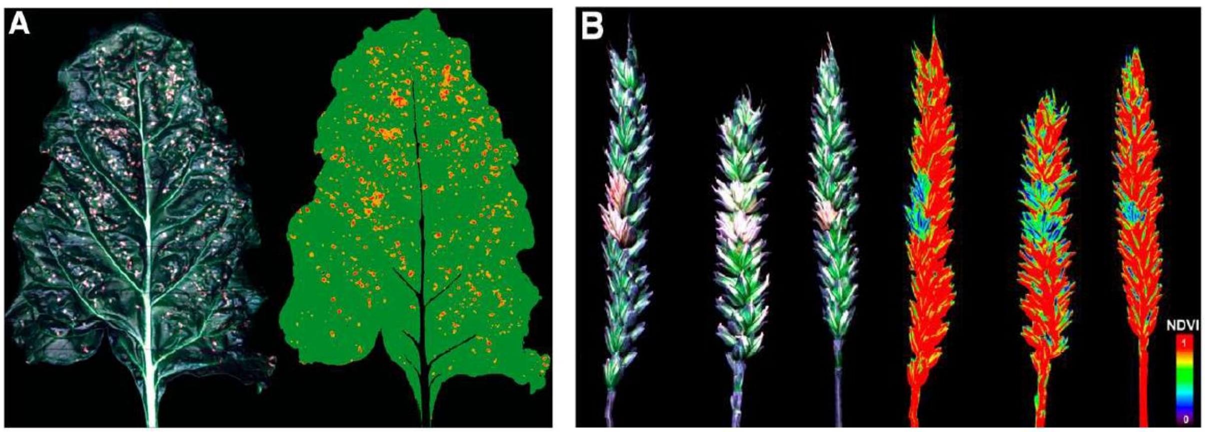


Figure 2.6 Disease detection of fungal plant diseases based on hyperspectral images. A: *Cercospora* leaf spot on sugar beet. B: *Fusarium* head blight on wheat (Mahlein, 2016)

2.4.1.3 Weed Monitoring

Weed monitoring is the first step in any site-specific weed management program. Site-specific weed management (SSWM) is a strategy in which weed control is varied within a field to match variations in location, density, and composition of the weed population. This concept is based on the fact that weed populations are often irregularly distributed within a field.

Most herbicides are only effective against certain weed species. Regular monitoring is used to determine if treatments are working. Weeds often grow in patches, so it may not be necessary to spray postemergent herbicides or till the entire field to control them. Spot treatment can save time and money while achieving good weed control.

The most accurate method of estimating the population of weeds is to count the number of plants in an area of known size in several places. A quadrant, which may be square or circular, should be used to make weed plant counts. The number and location of counts needed to estimate the population will vary depending on the distribution pattern.

Figure 2.7 Sampling and estimating weed density (D. Lemic)

The size of the quadrant depends on the weed density. Small quadrants ($0.1m^2$) are sufficient for weed populations of more than 200 plants per square metre. This would equate to more than 20 plants per quadrant. For lower weed densities, increase the quadrant size (up to 1 m^2) to allow counts between five and 50 plants per quadrant.

At least five quadrant counts should be made in at least four sections within a field, giving 20 counts for the area. The more counts conducted, the more accurate the assessment.

Record plant count for each weed species found. The plant count is an appropriate time to record various aspects of the weeds and the stand. Note whether the plants appear small and crippled or are infested with insects or disease. It is also necessary to make notes about other weeds present. The records should be able to be queried and show changes in weed density and spectrum over time. These records can be an early warning of an emerging problem.

2.4.2 Pest forecasting (prediction)

Pest prediction must consider several intrinsic characteristics of the pests and the determining environmental and host factors. Most pest prediction models consider the phenology of the pest and its host. Accurate prediction of pest infestations before they occur is desirable in pest management programmes so that control measures can be planned with maximum efficiency. Pest dynamics show variations in timing and intensity depending on location and season.

Pests in agroecosystems are undergoing rapid environmental change due to changing cropping systems and a variety of management interventions. As a result, plant pests show a higher degree of instability in population levels. Pests vary in their biology and in their response to their environment. Pests in colder climates generally have discrete generations and dormancy periods in their life cycles, whereas in warmer climates most species show polymodal patterns of occurrence, with multiple generations in a year, due to continuous reproductive opportunities and food availability. On a global scale, seasonal temperatures and precipitation patterns are important factors determining the distribution of organisms.

Globally, an important outcome of understanding population dynamics is to strive for a predictive capability to make appropriate management decisions. Successful predictive techniques are those that are as simple as possible and based on knowledge of the biology and ecology of the pests of concern.

Due to climate regulation, the occurrence usually takes place in a relatively short period of time and is not too difficult to monitor. Pests that survive on alternative hosts can be sampled so that an estimate can be made of their probable pest density on the main crop.

2.4.2.1 Insect prediction models

Insects are unable to regulate their temperature internally, and therefore their development depends on the temperature to which they are exposed. Studies of insect population dynamics often involve modelling growth as a function of ambient temperature.

The most common model for development rate, often called degree-day summation, assumes a linear relationship between development rate and temperature between lower and upper development thresholds. This method works well for optimal temperatures. Temperature-dependent development in insects can also be considered over developmental time. Degree-day models have long been used as part of decision support systems to help farmers predict when to spray or when to control pests.

Ecological life tables are one of the most useful tools in the study of population dynamics of insects with discrete generations. Such tables record a series of sequential measurements that reveal population changes during the life cycle of a species in its natural environment. Long-term data from carefully designed population studies, in which all relevant factors have been accurately measured, are important for constructing population models that are appropriate to biological reality. The goal of life history analysis is to develop a population model that mimics reality. In addition to generating population estimates, this analysis is best done by carefully identifying and measuring the independent factors that cause mortality, such as parasitoids, predators, pathogens, and weather factors. From life table studies, the key factor responsible for increases and decreases in numbers from generation to generation can be identified.

2.4.2.2 Plant disease forecasting

Plant disease forecasting is a management system used to predict the occurrence or change in severity of plant diseases. At the field scale, these systems are used by farmers to make economic decisions about disease control treatments. Often the systems ask the farmer a series of questions about host plant susceptibility and incorporate current and predicted weather conditions to make a recommendation. A recommendation is usually made as to whether disease treatment is necessary.

Prediction systems are based on assumptions about the interactions of the pathogen with the host and the environment. The goal is to accurately predict when the three factors-host, environment, and pathogen-will interact in such a way that a disease may occur and cause economic losses.

Prediction systems can use one of several parameters to calculate disease risk, or a combination of factors. One of the first prediction systems developed for Stewart's wilt (*Pantoea stewartii*) on corn was based on the winter temperature index, since low temperatures would kill the vector of the disease so that there would be no outbreak.

A rational method of predicting disease should be based on the following factors:

(i) Factors (microclimatic) affecting the initial occurrence and subsequent spread of the inoculum.

(ii) Thorough knowledge of the life cycle of the pathogen.

(iii) The way the pathogen spreads

(iv) Rough estimate of the quantities of inoculum expected to be spread via propagules, soil, air, vectors, etc.

(v) Mechanism of host infection

(vi) Knowledge of the susceptibility of the host plant at different growth stages

(vii) Meteorological data (macroclimatic conditions) of the area.

2.4.2.3 Estimating potential weed population density

Potential weed population density can be estimated in several ways. If weeds produce seeds, count the number of seed heads or pods and the number of seeds per pod or seed head on a given sample plot. This gives an estimate of the total number of seeds produced.

A more complex but accurate method is to take soil cores, sieve and wash these samples, and count the seeds in these samples. This technique is often of limited use as a research tool because it is time consuming and depends on seed identification skills.

Irrigate small areas and identify and count germinating weeds. This can be done in the fall but does not always provide a realistic indication of potential weed emergence due to the complex nature of seed dormancy.

Using records from past monitoring provides an assessment of aspects such as weed species, density, seed set and location. It allows monitoring of changes over time.

Revision questions

1) Monitoring is:

a) The systematic collection, recording and analysis of observations over time.
b) An effective and environmentally sensitive approach to pest management.
c) The use of crops and animal products to enhance human life sustainably.

2) To control insect pests, it is necessary to:

a) Determine the damage situation and create an optimal control plan.
b) Choose most effective insecticide and apply in a low pest population.
c) Carry out preventive treatment of pests.

3) List at least three tools for monitoring insects.

a) ______________________________

b) ______________________________

c) _______________________________

4) Using pheromone traps, it is possible to monitor the occurrence and abundance of adult pests and predict crop damage in the following year.

a) True
b) False

5) Essential requirement for the detection and monitoring of plant diseases and pests by remote sensing is the presence of a specific response that can be detected by a specific sensor or sensor system.

a) True
b) False

6. Potential weed population density can be estimated by counting the number of seed heads or pods and the number of seeds per pod or seed head on a given sample plot.

a) True
b) False

7) Accurate prediction of pest infestations before they occur is desirable in pest management programmes:

a) So that control measures can be planned with maximum efficiency.
b) So that control measures can be planned with minimum efficiency.
c) To know how to plan the crop rotation for next year.

8) A rational method of predicting disease should be based on the knowledge of the susceptibility of the host plant at different growth stages.

a) True
b) False

9) The most accurate method of estimating the population of weeds is to count the number of plants in an area of known size in several places. It can be done using:

a) A quadrant, which may be square or circular
b) Pheromone traps
c) Triangle

10) Farmers who systematically monitor their crops can develop their own thresholds.

a) True
b) False

2.5 Direct control measures

Learning outcomes

- Explain the main focus of direct control measures.
- Classify direct control measures.
- Describe which methods each direct control measure involves.

Pest and disease management consists of a range of activities that support each other. Most management practices are long-term activities that aim at preventing pests and diseases from affecting a crop. Management focuses on keeping existing pest populations and diseases low. Control on the other and is a short-term activity and focuses on killing pest and disease. The general approach in organic agriculture to deal with the causes of a problem rather than treating the symptoms also applies for pest and diseases. Therefore, management is of a much higher priority than control. Direct pest control measures control the population of pests present in the fields or in the places where the pest population is maintained and which are the source of infection. In addition to mechanical and physical control measures, direct measures include the use of inorganic plant protection products or products of synthetic or biological origin. If agents of biological origin are applied, it is referred to as biological pest control.

2.5.1 Mechanical control

Mechanical control measures include a number of procedures by which we collect and destroy pests or, with the help of various mechanical barriers, prevent them from reaching crops. Some mechanical pest control measures are carried out when the pests attack the host plant and are aimed at preserving yields, and some measures are carried out when the vegetation is dormant or when the pest does not cause direct damage to plants and is aimed at reducing the population in the future.

Mechanical measures prevent the spread of pests mechanically, and this is achieved by deep plowing of plant residues, cultivation, dusting of stubble, hoeing, handpicking, pruning branches with overwintering forms of pests or pathogens, gathering on small areas or plowing rotten fruit, removing infected leaves, destroyed plants or possible hosts, by digging canals for collecting pests, placing sticky traps on trunks, cleaning seeds and weeds, setting traps for voles and nets to protect against birds and insects, even spraying plants with a water hose to knock off aphids and mites is considered a mechanical practice.

- Destruction of plant debris

Plant debris or residues in which some pests can overwinter must be destroyed by chopping into small pieces and by deep plowing (20-30 cm). Another solution is burning; however, this method is not recommended as burning crop residues eliminates the possibility of humus improvement, and can potentially lead to significant nutrient loss. Likewise, it may affect other organisms living on or in the soil. In greenhouse production, the destruction of plant residues is necessary and may include burning of plant residues.

- Manual or machine collection and direct destruction

Hand destruction or removal of insects and egg masses ensures quick and positive control. This method is especially effective with foliage-feeding insects. Handpicking is also generally useful for the management of caterpillars, leaf rollers, tobacco caterpillar, cabbage butterfly, mustard sawfly, *Epilachna* beetle, white grubs etc. Excluding labor, handpicking is the least expensive of all organic or natural control practices. However, handpicking also has disadvantages in that it must be performed long before insect damage is noticeable and at the key stage of development of the insect. Farmers must actively monitor their crops, watching for the first sign of damage before insect populations get too high. Collecting pests using machinery greatly facilitates this method but it is more expensive.

- Mechanical trapping

Several types of mechanical devices are used for collecting insect pests. Corrugated cardboard banding, applied to the trunks of host trees, works as a trap for many insect larvae as they crawl on the tree in search of a place to pupate and overwinter. Banding is a useful tool that can aid in assessing the level of pests' presence in particular trees as well as in control. Simple vessels or traps filled with water or a mixture of water and vinegar can be used in places accessible to insects. Various traps can be used for cockroaches, wasps, rodents. Adding a bait can help in attracting the pests.

- Mechanical barriers

Mechanical barriers include various types of barriers such as mechanical barriers for snails, game fences, canals for insects that come to the fields by walking, nets that are placed on windows and entrance openings of greenhouses or warehouses, nets or other materials that cover crops or are used to wrap plants.

With the necessary preventive measures, weed density can be reduced, but it will hardly be enough during the critical periods of the crop at the beginning of cultivation. Therefore, mechanical methods remain an important part of weed management.

- Manual and flame weeding

Manual weeding is probably the most important one. As it's very labor intensive, reducing weed density as much as possible in the field will bring less work later on and should therefore be aimed at. There are different tools to dig, cut and uprooting the weeds; hand, ox-drawn and tractor-drawn tools. Using the right tool can increase work efficiency significantly. Weeding should be done before the weeds flower and produce seeds.

Flame weeding is another option: Plants are heated briefly to 100°C and higher. This provokes coagulation of the proteins in the leaves and a bursting of their cell walls. Consequently, the weed dries out and dies. Although it is an effective method, it is quite expensive, as it consumes a large amount of fuel gas and needs machinery. It is not effective against root weeds.

2.5.2 Physical control

Physical plant protection measures include the application of low and high temperature, irradiation, high frequency sounds, light, carbon dioxide, ozone etc., and visual and olfactory baits that cause a reaction of pests to certain stimuli. These measures are used more in insect control than in disease control. The most commonly used are:

- high temperature for thermal soil disinfection. Destruction of harmful microorganisms, pests and weed seeds is achieved by heating the soil to 95 ° C to a depth of 30 cm for 5 minutes;
- solarization or use of solar energy, is a very effective measure for soil disinfection, and is carried out by covering the soil during the summer with a thin, transparent, polyethylene foil for 1-2 months;
- differently colored adhesive boards (sticky traps) attract pests that stick to the adhesive surface. In this way, the attack can be reduced and the number of pest populations can be determined, as well as the beginning of control. Yellow sticky traps that attract aphids and moths, and blue sticky traps that attract thrips are most commonly used in the protected area. In fruit growing, yellow traps are used to attract cherry and olive flies, while white traps attract wasps and red bark beetles;
- light traps can be used to determine the presence and thus reduce the insect population on agricultural land and in warehouses. They are used to catch moths such as armyworms, cutworms, stem borers and other night flying insects. However, light traps have the disadvantage of attracting a wide range of insect species. Most of the attracted insects are not pests. In addition, many insects that are attracted to the area around the light traps (sometimes from considerable distances) do not actually fly into the trap. Instead, they remain nearby, actually increasing the total number of insects in the immediate area;
- reducing the humidity and temperature of stored agricultural products in silos;
- controlled atmosphere in refrigerators for fruit storage. Carbon dioxide is toxic to insect, but its action is low. Eggs and adults of pulse beetle die when exposed to 100% CO_2 at 32°C and relative humidly of 70%. Carbon dioxide under high pressure is found to be effective against stored grain pests. Carbon dioxide and nitrogen treatment have been found effective for grain beetle. A nitrogen atmosphere effectively controls all stages of fruit fly;

- irradiation (microwaves and gamma radiation) are being used against stored grain pests effectively. Infrared radiation can be used dually to the insects or to the stored grain infested with insects. Ionising radiation (X-rays) are sterilizing at lower dosages but lethal at higher dosages.
- sound - low frequency sound waves cause adverse effect on development of insects. Sound produced by male and response of female of a species to the sound can be utilized for their control.

2.5.3 Biotechnical control

Pheromone pest control is often classified into biotechnical control methods along with the application of biotechnical insecticides and some other methods. Pheromones are messenger substances used by insects and other animals to communicate with each other. Insects send these biochemical signals to help attract mates, warn others of predators, or find food. Using specific pheromones, traps can be used to monitor target pests in agriculture areas or to early detect quarantine pests. By constantly monitoring for insects, it may be possible to detect an infestation before it occurs and to determine the need for control. Early detection of pest insects using pheromone traps can also lessen damage to agriculture and other plants as they can be used for massive control of some pests.

2.5.4 Biological control

Biological control is the use of natural enemies and natural products to manage populations of pests and diseases. These are measures that contribute to the conservation of natural enemies, and include the targeted release of natural enemies on agricultural land. There are three types of biological protection: classical (inoculation), augmentative (seasonal) and conservation. The classical method is used to control foreign pests that invaded new countries. Augmentative protection refers to all forms of biological protection in which natural enemies are commercially produced and conservation protection refers to the applying all technics and tactics that preserve indigenous predators and parasitoids.

Biological plant protection products are usually called biopesticides. Biopesticides can be mass-produced and used as products for classical pest control. Biopesticides are most often divided into macrobiological agents (predators, parasitoids, nematodes) and microbiological agents (bacteria, fungi, viruses, etc.), natural pesticides and derivatives of some organisms.

Macrobiological agents

They include predatory and parasitic macroorganisms. Predators comprise insects (true bugs, coccinellids, chrysopids), predatory mites, spiders, insect pathogenic nematodes, birds and mammals. Of the parasitoids, for example, wasps, caterpillar flies and nematodes are used.

If populations of natural enemies present in the field are too small to sufficiently control pests, they can be reared in a laboratory or rearing unit. The reared natural enemies are released in the crop to boost field populations and keep pest populations down. There are two approaches to biological control through the release of natural enemies:

a) Preventive release of the natural enemies at the beginning of each season. This is used when the natural enemies could not persist from one cropping season to another due to unfavorable climate or the absence of the pest. Populations of the natural enemy then establish and grow during the season.

b) Releasing natural enemies when pest populations start to cause damage to crops. Pathogens are usually used in that way, because they cannot persist and spread in the crop environment without the presence of a host ("pest"). They are also often inexpensive to produce.

Microbiological agents

They include microorganisms that cause diseases of harmful organisms, and these can be bacteria, fungi, viruses, mycoplasmas and microsporidia, which come on the market as formulated as preparations similar to chemical preparations for plant protection.

The soil-borne fungus *Fusarium oxysporum* is very effective in reducing the witch weed *(Striga hermonthica* and *S. asiatica)* in different cereal crops, leading to yield increases in scientific trials. Other *Fusarium* species are very effective, too *(Fusarium nygamai, F. oxysporum* and *F. solani)*. Rhizobacteria capable of suppressing germination of witch weed (*Striga* spp.) seeds or actually destroying the seeds are particularly promising biological control agents since they can be easily and cheaply formulated into seed inoculants. *Pseudomonas fluorescens putida* isolates significantly inhibited germination of *Striga hermonthica* seeds. However, currently no biocontrol product is available.

Natural pesticides

Some plants contain components that are toxic to insects. When extracted from the plants and applied on infested crops, these components are called botanical pesticides or botanicals. The use of plant extracts to control pests is not new. Rotenone (*Derris sp*.), nicotine (tobacco), and pyrethrins (*Chrysanthemum sp*.) have been used widely both in small-scale subsistence farming as well as in commercial agriculture.

Most botanical pesticides are contact, respiratory, or stomach poisons. Therefore, they are not very selective, but target a broad range of insects. This means that even beneficial organisms can be affected. Yet the toxicity of botanical pesticides is usually not very high and their negative effects on beneficial organisms can be significantly reduced by selective application. Furthermore, botanical pesticides are generally highly bio-degradable, so that they become inactive within hours or a few days. This reduces again the negative impact on beneficial organisms and they are relatively environmentally safe compared to chemical pesticides.

The preparation and use of botanicals requires some know-how, but not much material and infrastructures. It's a common practice under many traditional agricultural systems. Some commonly used botanicals are:

Neem: Neem derived from the neem tree (*Azadirachta indica*) of arid tropical regions, contains several insecticidal compounds. The main active ingredient is azadirachtin, which both deters and kills many species of caterpillars, thrips and whitefly. Both seeds and leaves can be used to prepare the neem solution. Neem seeds contain a higher amount of neem oil, but leaves are available all year. A neem solution loses its effectiveness within about 8 hours after preparation, and when exposed to direct sunlight. It is most effective to apply neem in the evening, directly after preparation, under humid conditions or when the plants and insects are damp.

Pyrethrum: Pyrethrum (*Tanacetum cinerariifolium*) is a daisy-like *Chrysanthemum*. Pyrethrins are insecticidal compounds extracted from the dried pyrethrum flower. The flower heads are processed into a powder to make a dust. This dust can be used directly or infused into water to make a spray. Pyrethrins cause immediate paralysis to most insects. Low doses do not kill but have a “knock down” effect. Stronger doses kill. Pyrethrins break down very quickly in sunlight so they should be stored in darkness. Both highly alkaline and highly acid conditions speed up degradation so pyrethrins should not be mixed with lime or soap solutions. Liquid formulations are stable in storage but powders may lose up to 20% of their effectiveness in one year.

There are many other extracts of plants known to have insecticidal effects like tobacco (*Nicotiana tabacum*), yellow root (*Xanthorhiza simplicissima*), fish bean (*Tephrosia vogelii*), violet tree (*Securidaca longepedunculata*), and nasturtium (*Nasturtium tropaeolum*) which are traditionally used to control pests in Africa. However, one shall be very careful since some of those plants have very negative effect on humans or other non-target organisms and are actually banned to be used for crop protection. Anise, chillies, chives, garlic, coriander, nasturtium, spearmint and marigold are plants known to have a repellent effect on different pest insects (aphids, moths, root flies, etc.) and can be grown as intercrop or at the border of crop fields.

Pesticides of natural origin for disease control include:

Sulphur is mostly used against plant diseases like powdery mildew, downy mildew and other diseases. The key to its efficacy is that it prevents spore germination. For this reason, it must be applied prior to disease development for effective results. Sulphur can be applied as a dust or in liquid form. It is not compatible with other pesticides. Lime-sulphur is formed when lime is added to sulphur to help it penetrate plant tissue. It is more effective than elemental sulphur at lower concentrations. However, the odor of rotten eggs usually discourages its use over extensive fields.

Bordeaux mixture (Copper sulphate and lime) has been successfully used for over 150 years, on fruits, vegetables and ornamentals. Unlike sulphur, Bordeaux mixture is both fungicidal and bactericidal. As such, it can be effectively used against diseases such as leaf spots caused by bacteria or fungi, powdery mildew, downy mildew and various anthracnose pathogens. The ability of Bordeaux mixture to persist through rains and to adhere to plants is one reason it has been so effective. Bordeaux mixture contains copper sulphate, which is acidic, and neutralized by lime (calcium hydroxide), which is alkaline.

Acidic clays have a fungicidal effect due to aluminum oxide or aluminum sulphate as active agents. They are used as an alternative to copper products but, are often less efficient.

Milk has also been used against blights, mildew, mosaic viruses and other fungal and viral diseases. Spraying every 10 days with a mixture of 1 L of milk to 10 to 15 L of water is effective.

Baking soda has been used to control mildew and rust diseases on plants. Spray with a mixture of 100 g of baking or washing soda with 50 g of soft soap. Dilute with 2 L of water. Spray only once and leave as long gaps as possible (several months). Do not use during hot weather and test the mixture on a few leaves because of possible phytotoxic effects.

2.5.5 Plant protection products and active substances allowed in organic agriculture

European Union organic farming rules cover agricultural products, including aquaculture and yeast (834/2007 and 2018/848 EU regulation). They encompass every stage of the production process, from seeds to the final processed food. This means that there are specific provisions covering a large variety of products, such as:

- seeds and propagating material such as cuttings, rhizome etc. from which plants or crops are grown;
- living products or products which do not need further processing;
- feed;
- products with multiple ingredients or processed agricultural products for use as food.

EU regulations on organic production exclude products from fishing and hunting of wild animals but include harvest of wild plants when certain natural habitat conditions are respected. There are specific rules for wine and aquaculture.

One of the objectives in organic production is to reduce the use of external inputs. Any substance used in organic agriculture to fight pests or plant diseases must be pre-approved by the European Commission.

Additionally, specific principles guide the approval of external inputs such as fertilizers, pesticides, and food additives so that only substances and compounds listed as approved in specific legislation can be used in organic productions.

Processed food shall be produced mainly from agricultural ingredients only (added water and cooking salt are not taken into account). They may also contain:

- preparations of micro-organisms and enzymes, mineral trace elements, additives, processing aids and flavorings, vitamins, as well as amino acids and other micronutrients added to foodstuffs for specific nutritional purposes can be used but only when authorized under organic rules;

- substances and techniques which reconstitute properties that are lost in processing or storage that correct any negligence in the processing or that otherwise may be misleading on the true nature or the products shall not be used;

- non-organic agricultural ingredients can only be used if they are authorized within the annexes to the legislation or have been provisionally authorized by an EU country.

And above all, any substance listed for use in organic agriculture must be compliant with horizontal EU rules and then be thoroughly assessed and approved by the European Commission for use in organics.

Revision questions

1) **Control of pests focuses on keeping existing pest populations and diseases low, while management is a short-term activity and focuses on killing pest and disease.**
   a) True
   b) False

2) **Mechanical control includes:**
   a) The application of low and high temperature, irradiation, high frequency sounds, light, carbon dioxide, ozone, visual and olfactory baits.
   b) The destruction of plant debris, manual or machine collection and direct destruction, mechanical trapping and using barriers.
   c) All of the above.

3) **Destruction of plant debris or residues is important because:**
   a) When burned it improves humus production and increases nutrients.
   b) It eliminates the material in which some pests can overwinter.

4) **Manual or machine collection and direct destruction must be done:**
   a) Before insect damage is noticeable and at the key stage of development of the insect.
   b) When damages are noticeable and pest populations are high.

5) **Mechanical trapping includes:**
   a) Use of visual and olfactory baits.
   b) Corrugated cardboard banding, vessels or traps filled with water or a mixture of water and vinegar.
   c) Use of pheromones.

6) **Mechanical barriers include:**
   a) Mechanical barriers for snails, game fences, canals for insects that come to the fields by walking.
   b) Nets placed on windows and entrance openings of greenhouses or warehouses, nets or other materials that cover crops or are used to wrap plants.
   c) All of the above.

7) **List at least five physical control measures:**
   a) ________________________________
   b) ________________________________
   c) ________________________________
   d) ________________________________
   e) ________________________________

8) **Using specific pheromone traps is an important biotechnical control measure because:**
   a) By constantly monitoring for insects, it may be possible to detect an infestation before it occurs and to determine the need for control.

b) Early detection of pest insects using pheromone traps can also lessen damage to agriculture and other plants.
c) Pheromone traps can be used for massive control of some pests.
d) All of the above.

9) Biological control measures use:

a) Only microbiological agents (bacteria, fungi, viruses, etc.).
b) Only macrobiological agents (predators, parasitoids).
c) Only natural pesticides and derivatives of some organisms.
d) All of the above.

10) Natural pesticides that kill insects are derived from:

a) Bacteria
b) Plants
c) Inorganic material

3 METHODS AND TOOLS TO MANAGE PESTS

Managing pest populations is extremely important in any crop production. Pests can cause different types of damage, which we basically divide into direct and indirect damage.

Direct damage includes:

(a) yield loss, which occurs because the plants have died completely (in the case of seed damage at germination or root), because their leaf mass is damaged (due to the pests feeding on the leaves) or because they have lost their vitality (which occurs due to the pests feeding on the plants by sucking on them), making assimilation more difficult; all of which result in lower yields.

(b) Reduction in product quality, which includes qualitative changes in the composition of plant products (e.g. aphid infestation on carrots leads to poor taste of carrots)

Indirect damage includes:

(a) Transmission of plant pathogens - in some cases pest damage opens the way for pathogen infection, and in some cases (aphid) pests actively transmit pathogens (viruses).

(b) Decreased market value of the product due to contamination by pests or their secretions (in the case of caterpillars, the presence of caterpillars and / or their droppings, the presence of honeydew when infesting aphids, moths, etc.)

(c) Reduced assimilation due to the appearance of smut fungi covering the leaves and fruit on which honeydew has remained

To prevent the damage described above and to avoid creating conditions for uncontrolled growth of pest populations, which may lead to increased damage in future years, pests must be actively controlled. The basic components of active pest control are shown in Figure 3.1.

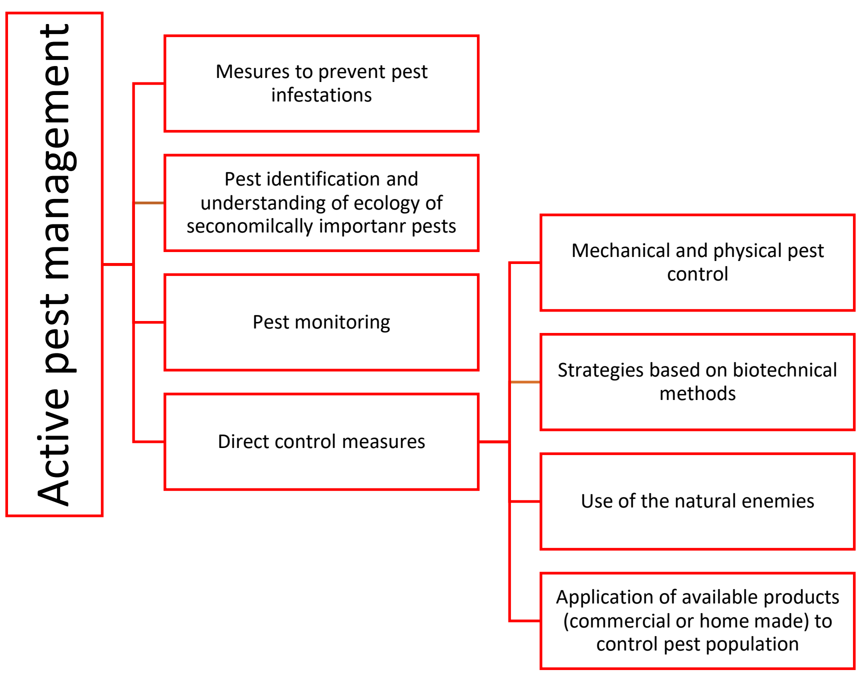


Figure 3. 1 Basic elements of the active pest control

3.1 Measures to prevent pest infestations

Learning outcomes

- Describe the agro-technical practices that contribute to prevention of pest outbreaks.
- Implement the appropriate agro-technical practice that contributes to the prevention of pest outbreaks.

Measures to prevent pest infestations, such as ensuring good growing conditions for plants to improve their adaptability and resistance to pests, and measures to improve the natural mechanisms of ecosystem self-regulation by promoting the development of natural enemies are described in detail in Chapter 2.

In organic farming, active pest management must be carried out. This means that organic farming is organized in such a way that the maintenance process of biological pest control is carried out during the production of each crop. The conservation biological control is not focused on a specific, single pest species. It represents a holistic approach to production and involves the implementation of various procedures aimed at the conservation of natural enemies of pest species, which has a positive impact on biodiversity.

Adherence to good agricultural practice measures generally has a positive impact on natural enemies. Of the good agricultural practice measures, compliance with crop rotation is the most important. In addition, particular emphasis is placed on ensuring minimum land cover, which ensures good conditions for the development of natural enemies. The maintenance of landscape features also has a positive effect on natural enemies, i.e. the maintenance of hedgerows, which provide important refuge area for natural enemies. The protection of permanent pastures is also important for maintaining the population of natural enemies. On the other hand, proper management of crop residues can also reduce pest infestations. In addition to these measures, there are several practices that further ensure and strengthen the natural mechanisms of self-regulation.

One important measure is attracting insectivorous birds to crops, as they can significantly reduce pest numbers. For their support avenues of trees can be planted along fields and birdhouses can be placed in plantations. To attract birds of prey that hunt species of larger insects, harmful birds (e.g. *Sturnus vulgaris*), mice, rats, etc. T-shaped stakes can be placed in or next to crops.

Another important measure is the maintenance of linear or areal structures or measures called maintenance of ecological infrastructure. The uncultivated and unseeded edges along crops favor the development of natural flora and fauna, maintain the balance and increase the number of natural enemies. It is proved that the activity zone of ants and ground beetles is 50 m from the place of residence. Weasels and turtles are active within a radius of 150 m and hedgehogs within a radius of 250 m. According to findings from France, 2-3 times more animal species are found in orchards surrounded by hedges, which has a positive effect on self-regulating mechanisms.

Revision questions

1) Choose the correct statement.

a) We always use pesticides in active pest control.

b) When implementing active pest control, we maintain the process of biological control.

2) The conservation biological control has positive impact on biodiversity

a) True

b) False

3) Connect the good agricultural practice measures with the impact each of them has on natural enemies

a) Crop rotation	A) Ensuring the habitat for natural enemies
b) Ensuring minimum land cover	B) Destroying the pest during their specific life stage
c) the maintenance of hedgerows	C) Ensuring the refuge area for natural enemies
d) Management of crop residues	D) Increasing biodiversity
e) Preserving permanent pastures	E) Breaking the life cycle of the pest

4) List three practices that can attract insectivorous birds into the plantation

a) ________________________

b) ________________________

c) ________________________

5) Choose correct statement/s- Maintaining ecological infrastructure is a measure that favor:

a) Number of insect pests

b) Crop yield

c) The development of natural flora and fauna

d) Maintain the balance and increase the number of natural enemies.

3.2 Pest identification and understanding ecology of economically important species

Learning outcomes

- Describe the life cycle of the insects.
- Classify the pests into different groups based on their morphology and damages.
- Identify the pest based on their morphological features and the symptoms of the damage.

Identifying pests and understanding their life cycle and ecology (the influence of climate and other factors on their development) allows producers to take the right steps and plan mitigation strategies and, if necessary, direct control. Species of insects and mites that feed exclusively on plant food and that we find on crops are conditionally classified into three categories according to their harmfulness:

Economically important pests are species that, if we do not control them, can multiply to population levels that exceed decision thresholds and can cause economically important damage.

Secondary pests are species that are common but whose population rarely exceeds the level at which economic damage can be expected. These are usually species that are regulated by their natural enemies, so their overpopulation is usually caused by the use of some broad-spectrum insecticides that have a negative impact on their natural enemies. In this case, these pests can become problematic.

Incidental pests are pests that occur very rarely and can cause major damage once in several years, usually when extremely favorable environmental conditions prevail.

When we find an insect on a plant, we usually find only one stage of its development. It means that by this investigation we determine only a small part of its entire life cycle. Pest control is based on a tactic where we search for the "weakest link", i.e. the developmental stage that we can most easily influence. In the life cycle of pest, we distinguish the following stages:

(a) Insect eggs are often a weak link, being stationary and unable to defend themselves. They are often attacked by predators and parasitoids, but direct pest control rarely focuses on eggs.

(b) Insect larvae that undergo incomplete metamorphosis - they resemble adult insects in appearance, lack developed wings so do not fly, and are often stationary, attached to the plant on which they feed. They feed in the same way as adults and their damage is usually greater as they are much more numerous. Because they move less (or not at all), they are often a suitable target for both parasitoids and predators. Larvae are also the most common target of control programs.

(c) Larvae of insects that undergo complete metamorphosis - they look completely different from adult insects and often feed differently than adults. In fact, very often the larvae are the ones that damage plants. These larvae are sometimes difficult to identify. To identify the species, sometimes it is necessary to grow them to an adult insect. As these larvae are also poorly mobile, they are good targets for parasitoids and predators, and control measures are mainly directed against them.

(d) Pupae - insects that undergo complete metamorphosis pass through the pupal stage. Pupal stage is stationary and during this stage insect do not take food. But significant changes take place in the pupa that lead to the development of an adult insect. Pupae cannot be actively defended against parasitoids and predators and are not a frequent target of control programs (since metabolism with the environment is minimized). Very often, the pupa is a stage where the insect spends a diapause (dormant or resting) period. Diapause occurs under conditions of low or high temperatures, depending on the species.

(e) Adult insects - since some of them do not cause direct damage (they do not feed on plants) and they are usually very mobile, we do not usually control them (except in exceptional cases). The use of pheromones to attract adult insects to control them is also an exception.

When we find a particular type of insect on plants, it is important to know how to determine its role in the ecosystem - what and how it feeds, and whether it is harmful, useful, or indifferent from the standpoint of cultivated culture. The role of each species in the ecosystem can be as follows:

(a) Herbivorous species - feed on plants, so all pests are herbivores. But not all herbivorous species are necessarily pests, because some species feed on weeds.

(b) Predators - feed on prey, usually other insect species (harmful and useful).

(c) Parasitoids - lay their eggs in or on various developmental stages of other insect species (harmful or beneficial). Parasitoid larvae develop in or on a host that is not directly killed by the parasitoid, but after the parasitoid completes its development, the host dies.

(d) Saprophaga - insects that feed on dead organic material of plant or animal origin. In agro-ecosystem they are useful because they help in decomposition of organic material. In commercial crops, where little organic matter is returned to the soil, they are often absent.

Accurate identification of pests is important because it allows us to make decisions about possible control measures:

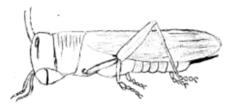
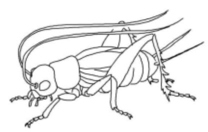
1. estimate the level of population - or pest infestation - and predict the likelihood of damage and the need for control measures.

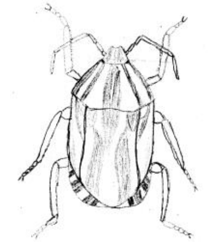
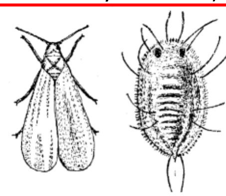
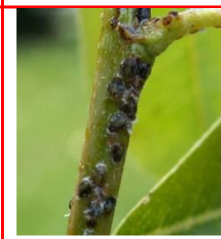
2. if the population is low, determine the monitoring method.

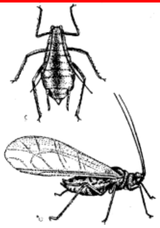
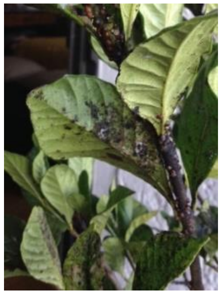
Because agricultural crops are attacked by a wide variety of different pests, accurately identifying them down to species level is often complex and requires highly specific knowledge. However, any practitioner must be able to identify the pest at least to the family or genus level, and this identification can then be used to surmise (depending on the host plant) exactly what species it is. After a preliminary identification of the pest, which includes an examination of the pest we found on the plant (if it was on it) or on a tool we used to hunt the pests (trappers, yellow plates), the damage is determined. All this, together with the knowledge of the most common species that occur on the cultivated crop, can allow us to accurately identify pests.

For the approximate identification of the main groups of pests, we suggest using the drawings, descriptions and photographs in Table 3.1.

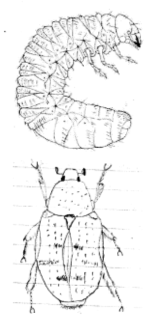
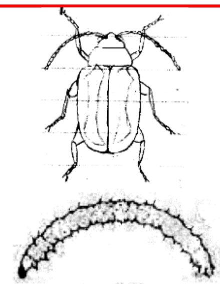
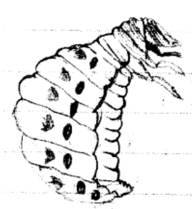
Table 3.1 Overview of the basic characteristics of the most important groups of pest species

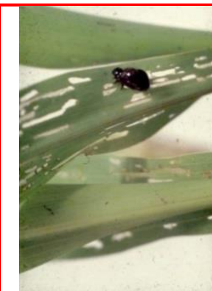
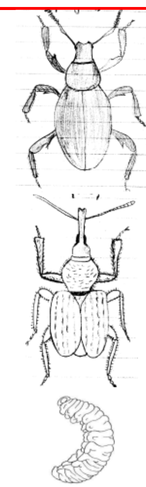
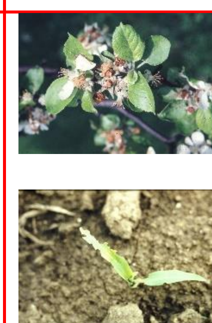
Group of the pest (family, suborder, order)	Morphological traits		Description and character of the damage		Some economically important species
	Description of the damaging developmental stage	Picture/photo	Description	Picture/photo	
Grasshoppers	Grasshoppers are insects of larger size. They move by jumping with the aid of hind legs, which are longer and more developed. At the end of the back they have the ovipositor. The larvae resemble the adults, except that they do not have wings.	 **Figure 3.2** Grasshopper (after Schmidt, drawn by R. Bažok)	Damage is done by larvae and adults. Damage is seen as irregular bites on all aboveground plant parts (leaves, fruits). Damage is more common on vegetable and field crops	 **Figure 3.3** Grasshopper damage (R. Bažok)	*Dociostaurus marocanus, Anacridium aegyptium*
Mole cricket and crickets	Similar to grasshoppers but their wings are laid horizontally above their bodies.	 **Figure 3.4** Cricket (after Schmidt, drawn by R. Bažok)	Larvae and adults feed on plant parts. Mole crickets feed on the underground parts of the plant, resulting in plant decay. Some species of crickets lay eggs in the shoots, causing additional damage.	 **Figure 3.5** Molecricket damage (©David Jones, University of Georgia, Bugwood.org)	*Gryllotalpa gryllotalpa, Oecanthus pellucens*
Thrips	Tiny insects with two pairs of wings overgrown with tassels.	 **Figure 3.6** Thrips (after Schmidt, drawn by R. Bažok)	Adults and larvae suck on plants, most often on leaves or flowers. The consequence of the diet is the loss of chlorophyll at the site of sucking - white spots appear on the leaf.	 **Figure 3.7** Thrips damage (R. Bažok)	*Frankliniella occidentalis, Thrips tabaci*

True bugs	Flat insects with a specific unpleasant smell. Larvae are like adults but do not have fully developed wings.	 **Figure 3.8** True bug (after Schmidt, drawn by R. Bažok)	The damage is done by adults and larvae by sucking on leaves and fruits (seeds). The result is deformed ears and stunted grains with poor quality and specific smell.	 **Figure 3.9** *Eurygaster spp. damage on* wheat (R. Bažok)	*Eurydema oleracea, Eurydema ventrale, Eurygaster spp.*
Whiteflies	Tiny insects, very much alike moths but white in color. Adults are flying low above the plants. The larvae are located on the back side of the leaves, they are very small, attached to the leaf.	 **Figure 3.10** Whitefly (after Wyniger, drawn by R. Bažok)	Damage is done by both stages (adult and larva) but the damage from the larvae is much greater. The larvae suck on the back of the leaf. White spots are seen on the face (loss of chlorophyll). Later leaves are drying. The larvae secrete honeydew.	 **Figure 3.11** Damage by Whitefly (R. Bažok)	*Trialeurodes vaporariorum, Bemisia tabaci*
Psyllids	Gentle, tiny insects with a short and wide head and large prominent eyes. There are a small number of veins on the transparent wings. The wings have specific position above the body (like roof over the house). The larvae also have prominent large eyes. They have no wings.	 **Figure 3.12** *Psylla* spp. (after Schmidt, drawn by R. Bažok)	The damage is done by both stages but the damage from the larvae is much greater. The larvae suck on the buds, shoots and leaves, cause the leaves to curl and the attacked plant organs are covered with honeydew.	 **Figure 3.13** Colonies of Psyllids on plant (R. Bažok)	*Cacopsylla pyri, Psylla pirisuga*

Leafhoppers	Some species are extremely large, others much smaller (up to 1 cm). When at rest, the wings are folded over the body like a roof. They are characterised by a large head and a prominent neck shield. They move around by jumping and flying. Larvae and adults have large, protruding eyes. Larvae resemble adults but do not have wings.	 **Figure 3.14** Leafhopper (after Schmidt, drawn by R. Bažok)	Although both stages do damage, the larvae are more harmful. The damage is manifested by sucking on plant organs. Often the plant organs are deformed, covered with honeydew, colonised by smut fungi and there is reduced assimilation. Some species are transmitting different diseases (phytoplasma, bacteria...)	 **Figure 3.15** Grapevine leaves damaged by *Empoasca vitis* (R. Bažok)	*Metcalfa pruinosa, Empoasca vitis, Scaphoideus titanus, Philaenus spumarius*
Aphids	Tiny insects, which exist in winged and unwinged forms. Larvae and wingless females have no wings; they dwell in dense colonies on plants. The winged forms have two pairs of transparent wings.	 **Figure 3.16** Aphids (after Wyniger, drawn by R. Bažok)	Damage is caused by all developmental stages that suck on plants (mainly leaves and buds). Sucking causes leaf curling and deformation of the affected plant organs. Aphid colonies can be seen on the back of the infested leaves. They spread viruses.	 **Figure 3.17** Aphid damage on sugar beet plant (R. Bažok)	*Myzus persicae, Aphis fabae, Eriosoma lanigerum*
Scale insects	Harmful developmental stages are larvae, which vary greatly in shape (depending on the species). The larvae are usually attached to plant organs, usually their dorsal side of the body is hardened or covered with waxy secretions.	 **Figure 3.18** Scale insect (after Wyniger, drawn by R. Bažok)	The larvae suck on all parts of the plant, being most abundant on twigs and branches. When the population is high, they attack the leaves and fruits. Infested plants weaken, lose leaves prematurely, and often the infested organs are covered with honeydew, on which sooty fungi colonise, so that assimilation is reduced.	 **Figure 3.19** Scale insects and	*Icerya purchasi, Quadraspidiotus perniciosus, Lecanium corni*

				damage (R. Bažok)	
Sawflies	The damage is caused by larvae, which resemble butterfly caterpillars: they have 3 pairs of legs on the front of the body and 6-8 pairs of legs on the abdomen.	 **Figure 3.20** Sawfly larva (after Schmidt, drawn by R. Bažok)	Larvae feed on leaves by biting them into irregular shapes. In some species (apple, pear, and plum wasps) the caterpillars burrow into the freshly germinated fruit, by which they gnaw the seed and the fruit falls from the tree.	 **Figure 3.21** Oilseed rape damaged by *Athalia rosae* (R. Bažok)	*Hoplocampa flava, Hoplocampa testudinea, Athalia rosae, Janus compressus*
Wireworms	The damage is caused by larvae. The larvae resemble a piece of wire, are copper-brown in color, have a dark, firmly chitinized head and three pairs of legs on the thoracic segments. The first developing stadia of the larvae are whitish. They grow up to 25 or 30 mm in size (depending on the species).	  **Figure 3.22** Wireworms (a) drawing (after Schmidt, drawn by R. Bažok, b) photo (R. Bažok)	The larvae feed on germinating seeds and the roots of germinated plants. The result of the infestation is a reduced plant population and a high number of underdeveloped plants. Damage to potatoes before sprouting shows up as holes drilled in the tubers.	  **Figure 3.23** Oilseed rape field (a) and potato tuber (b) damaged by wireworms (R. Bažok)	*Agriotes* spp.

Cockchafers	Damage is caused by adults and larvae (white grubs). Larvae are found in the soil. Larvae of May beetles grow up to a few centimeters in size. They are milky white in color, have a sinuous shape, a dark, firmly chitinized head and three pairs of legs on the chest. Adults are large insects (more than 1 cm), the body is often painted with shiny metallic colors. They have fan-shaped antennae.	 **Figure 3.24** Larva and adult of cockchafer (after Schmidt, drawn by R. Bažok)	The adults feed on leaves or flowers, which they destroy by biting the pistil and anthers. The larvae feed on the roots of the plants, causing decay, wilting, or slow growth of the plants. The result is a sparse crop - the damage is usually visible on a localized area in the field.	 **Figure 3.25** Maize field damaged by cockchafer larvae (R. Bažok)	*Melolontha melolontha, Cetonia aurata*
Flea beetles	Adult insects are very small (up to 5 mm), dark body color with metallic sheen, stripes are often seen on the body. They move by jumping. Larvae are usually found in the soil, where they feed on roots, or in plants, where they feed on stems or leaf veins. They are whitish in color, have a densely chitinized, darker head, three pairs of thoracic legs, and often have sparsely distributed hairs or bristles on the body.	 **Figure 3.26** Adult and larva of flea beetle (after Schmidt, drawn by R. Bažok)	The damage is usually done by the adults, which make small, regularly shaped holes in the leaves of infested plants. The holes enlarge as the leaves grow. Initially, the upper or lower epidermis remains undamaged. In monocotyledonous plants, the damage is always seen in the form of streaks between the veins. The larvae feed in the stems or petioles and form galleries.	 **Figure 3.27** Damage caused by adults of flea beetle feeding plant leaves (R. Bažok)	*Phyllotreta spp., Chaetocnema tibialis, Psylliodes chrysocephala, Epitrix spp*.
Chrysomelids	Adult beetles are vividly colored insects. The body is oval and elongate. The larvae have a densely chitinous, darker colored head and three pairs of legs on the thoracic segments. There are often bumps, warts or		Adults and larvae feed on leaves, gnawing and causing defoliation of plants. Some larvae are feeding on roots. Feeding symptoms on leaves occur in the form of irregular corking. Due to the larger		*Leptinotarsa decemlineata, Oulema melanopus, Phytodecta fornicata,*

	bristles on the body and the limbs.	**Figure 3.28** Larva of chrysomelid beetle (after Schmidt, drawn by R. Bažok)	number and greater feeding capacity, larvae can cause total defoliation.	 **Figure 3.29** Damage caused by adults of Colorado potato beetle (a) and Cereal leaf beetle (b) (R. Bažok)	*Diabrotica virgifera virgifera*
Weevils	Adults are insects whose heads are elongated into a rostrum (varying in length and width), at the tip of which is a mouthpart for biting and chewing. They are usually somewhat larger in body size, and some species are painted with shiny metallic colors. The larvae are white, slightly curved, have a densely chitinous, darker colored head, and no legs on the body. The larvae are usually found in stems, fruits or in the soil.	 **Figure 3.30** Adults and larva of weevils (after Schmidt, drawn by R. Bažok)	In some cases, the damage is caused by larvae gnawing on flower or leaf buds or mining in the stem. Flower buds wither. Adult feeding takes place on leaves, and damage can be seen in the crescent-shaped incisions on leaf margins. In one day they can destroy a few whole young plants.	 **Figure 3.31** Damage caused by weevils attacking flower buds (a) and leaves (b) (R. Bažok)	*Anthonomus pomorum, Anthonomus pyri, Byctiscus betulae, Bothynoderes punctiventris, Ceutorhynchus napi*

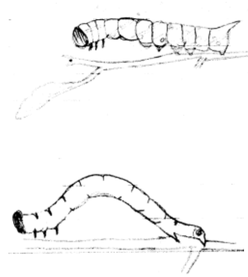
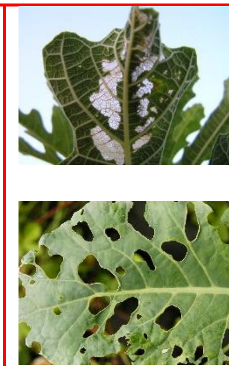
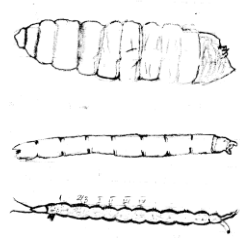
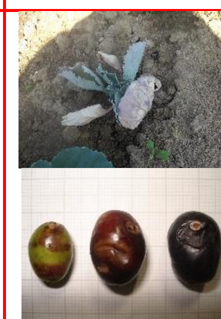
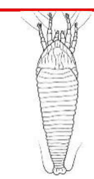
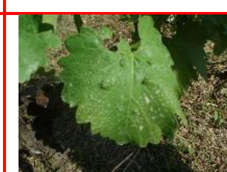
Caterpillars	Butterfly larvae are called caterpillars. Their appearance varies from those whose bodies are covered with thick (even poisonous) hairs to those whose bodies are naked. A common feature is that we find a densely chitinized (usually darker colored) head on the body and always three pairs of legs on the chest. In the caterpillars the legs are also present on the segments of the abdomen, but their number never exceeds 5 pairs (2-5).	 **Figure 3.32** Caterpillars (after Schmidt, drawn by R. Bažok)	The damage is caused by caterpillars, which usually feed on plant tissue (leaves, fruits, etc.). If the stings are irregularly shaped on the surface, the leaf veins initially remain undamaged. Some species burrow into infested plant organs (fruits, leaves, cabbages). In some cases, the infested organs are covered with threads and form the thread-covered nests, which usually contain several caterpillars.	 **Figure 3.33** Damage caused by caterpillars on leaves (R. Bažok)	*Leaf miners, Mamestra brassicae, Cydia pomonella, Agrotis segetum, Autographa gamma*
Larvae of the flies	The larvae of insects belonging to the order Diptera are pale, almost transparent. They have no legs on the body. They have no distinct head. Exceptions are e.g. sciarid flies with a dark sclerotized head capsula.	 **Figure 3.34** Different larvae of flies (after Schmidt, drawn by R. Bažok)	The damage is caused by larvae living in the plant tissue (leaf of the fruit, stem or root) on which they feed. The damage depends on the species, the species that infest the fruits cause fruit drop and the quality of the infested fruits is reduced. In the case of vegetable flies, the infested plants rot, the development of the plants is delayed and the infested organs are deformed.	 **Figure 3.35** Damage caused by larva of flies on plants (a) and fruit (b) (R. Bažok)	*Phorbia brassicae, Delia antiqua, Bactrocera oleae, Ceratitis capitata, Rhagoletis cerasi*
Eriophyid mites	Eriophyid mites have a narrow, elongated body brushed over the surface. They have two pairs of legs. They are small (less than 1 mm).		Nymphs and adults suck on the back of leaves, where they live in cobwebs. Eriophyid mites can be categorized according to the type of damage they cause		*Colomerus vitis, Phyllocoptes vitis*

		Figure 3.36 Eriophyid mite (after Wyniger, drawn by R. Bažok)	to plants, being (1) those that form galls (gall-formers) and (2) those that inhibit the growth of new plants.	**Figure 3.37** Grape leaf attacked by Eriophyid mite (R. Bažok)	
Spider mites	Adults have an oval body shape. They are red in color. They have 4 pairs of legs. The body is covered with sparse short hairs.	 **Figure 3.38** Spider mite (after Wyniger, drawn by R. Bažok)	Nymphs and adults suck on the back of the leaf where they live in cobweb. The effect of sucking can be seen on the face of the leaves - on the leaves you can see small white dots that increase, the yellow leaves dry out and fall off.	 **Figure 3.39** Spider mite damage on leaves (R. Bažok)	*Tetranychus urticae, Panonychus ulmi*

Revision questions

1) List the developmental stages of insects that undergo the complete metamorphosis

a) ___________________

b) ___________________

c) ___________________

d) ___________________

2) The insects that do not undergo complete metamorphosis lacks ________________

3) The pest stage that is mainly causing the biggest damage and that is usually controlled is

____

4) Connect the group of insects with their feeding characteristics

1. Parasitoids	a) Feed on prey
2. Predators	b) Feed on dead organic material of plant or animal origin
3. Herbivores	c) Lay their eggs in or on various developmental stages of other insect species
4. Saprophaga	a) Feed on plants

5) Mark the group of insects that suck on the plants

- Grasshoppers
- Scale insects
- Chrysomelids
- Psyllids
- Mole cricket and crickets
- Weevils
- Whiteflies
- Flea beetles
- Sawflies

6) Mark the group of insects that are chewing on the different part of plant as larvae and/or adults

- Wireworms
- Thrips
- Aphids
- Cockchafers
- Eriophyd mites
- True bugs
- Caterpillars
- Spider mites
- Leafhoppers

7) List two groups of insects that are attacking seeds and roots?

a) _______________________

b) _______________________

8) Match the insect group with the description of their shape

1.Aphids	a) Tiny insects with two pairs of wings overgrown with tassels.
2.Weevils	b) Tiny insects, which exist in winged and unwinged forms. Larvae and wingless females dwell in dense colonies on plants. The winged forms have two pairs of transparent wings.
3.Thrips	c) Their appearance varies from those whose bodies are covered with thick (even poisonous) hairs to those whose bodies are naked. A common feature is that we find a densely chitinized (usually darker colored) head on the body and always three pairs of legs on the chest. The legs are also present

	on the segments of the abdomen, but their number never exceeds 5 pairs (2-5).
4. Caterpillars (Lepidoptera)	d) Adult insects are very small (up to 5 mm), dark body color with metallic sheen, stripes are often seen on the body. They move by jumping. Larvae are usually found in the soil, where they feed on roots, or in plants, where they feed on stems or leaf veins.
5. Grasshoppers	e) Adults are insects whose heads are elongated into a rostrum, at the tip of which is a mouthpart for biting and chewing. They are usually somewhat larger in body size, and some species are painted with shiny metallic colors. The larvae are white, slightly curved, have a densely chitinous, darker colored head, and no legs on the body.
6. Flea Beetles	f) Insects of larger size. They move by jumping with the aid of hind legs, which are longer and more developed. At the end of the back they have the ovipositor.

9) Match the insect group with the description of damage

1. Wireworms	a) Nymphs and adults suck on the back of leaves, where they live in cobwebs. They can be categorized according to the type of damage they cause to plants, being (1) those that form galls (gall-formers) and (2) those that inhibit the growth of new plants.
2. Scale insects	b) The larvae feed on germinating seeds and the roots of germinated plants. The result of the infestation is a reduced plant population and a high number of underdeveloped plants.
3. Sawflies	c) The larvae suck on all parts of the plant, being most abundant on twigs and branches. Infested plants weaken, lose leaves prematurely, and often the infested organs are covered with honeydew, on which sooty fungi colonise, so that assimilation is reduced.
4. Chrysomelids	d) Although both stages do damage, the larvae are more harmful. The damage is manifested by sucking on plant organs. Often the plant organs are deformed, covered with honeydew, colonised by smut fungi and there is reduced assimilation.
5. Leafhoppers	e) Larvae feed on leaves by biting them into irregular shapes. In some species (apple, pear, and plum wasps) the caterpillars burrow into the freshly germinated fruit, by which they gnaw the seed and the fruit falls from the tree.
6. Eriophyd mites	f) Adults and larvae feed on leaves, gnawing and causing defoliation of plants. Some larvae are feeding on roots. Feeding symptoms on leaves occur in the form of irregular bark growths.

10) Match the insect group with pests that represent it

1. True bugs	a) *Bactrocera oleae, Rhagoletis cerasi, Ceratitis capitata*
2. Spider mites	b) *Cacopsylla pyri, Psylla pirisuga*
3. Cockchafers	c) *Eurydema oleracea, Eurydema ventrale, Eurygaster spp.*
4. Whiteflies	d) *Melolontha melolontha, Cetonia aurata*
5. Psyllids	e) *Tetranychus urticae, Panonychus ulmi*
6. Flies	f) *Trialeurodes vaporariorum, Bemisia tabaci*

3.3 Pest monitoring methods

Learning outcomes

- Understand and distinguish Economic and Action threshold level.
- Understand the differences among different pest monitoring methods.
- Choose and implement the monitoring of the most common pests, decide on actions that need to be taken in order to preserve yield and prevent economic damage.

Protection against pests in organic farming is not possible without regular monitoring of the occurrence and determination of the level of the population of pests and natural enemies, as well as the determination of damage to plants. The data collected are the basis for determining the decision threshold and deciding whether to use direct pest control measures.

The economic threshold level (ETL) is the point at which the economic damage caused by harming a particular pest population equals the cost of controlling the same population (which includes the cost of environmental damage). The ETL takes into account the amount of damage prevented, the cost of the action and the environmental damage. Since in organic farming we use methods and means that have minimal (or no) impact on the environment, the environmental damage is minimal.

The action threshold is the level of pest infestation, or the constellation of factors on which the occurrence of a pest depends, at which the expected value of prevented damage is equal to the sum of the application cost and the value of environmental damage. The action threshold represents the level of infestation at which suppression is approached. Proper assessment of the action threshold also requires information on the population of natural enemies, the presence of which may reduce the need for direct control. Data on action thresholds for most economically important pests in integrated agricultural production are well known and are based on studies of the harmfulness of certain species under certain production conditions, calculation of yield and price of agricultural products from integrated farming, and economic calculation of the cost of classical means of plant protection (which are cheaper, but for which the environmental damage is higher). Since the expected yields and prices of organic products vary and the prices of plant protection products are higher in organic farming and the environmental damage, they cause is much lower, the action thresholds for organic farming can vary considerably. In most cases they are not known, so decisions are often made based on the producer's experience.

Successful pest management in organic farming is not possible without regular and systematic monitoring of the pest population and crop damage, as well as beneficial insect monitoring. These ultimately allow assessment and decision making depending on the stage of development of the crop, the general condition of the crop, the presence and level of populations of natural enemies, and the level of pest population and damage present and/or expected.

In addition to regular monitoring, for successful insect monitoring, it is important to monitor climatic conditions. For some pests and natural enemies, temperatures at which insect development begins have been determined, and developmental models have been created based on summing effective air or soil temperatures (depending on where the particular stage of the insect develops). Effective temperatures represent the difference between the average daily temperature and the thermal threshold of development and are summed over a period of time until their sum reaches what is known as the. Thermal constant, i.e. the number of thermal units that have been shown to be necessary for a species (or developmental stage) to complete its development.

The most common methods of pest monitoring are shown in Figure 3.40. They differ depending on whether we are inspecting crops or looking for insects. When inspecting crops one can determine the damage caused by insects in addition to the insects, while when collecting insects, one can use a method that attracts insects in addition to direct inspection.

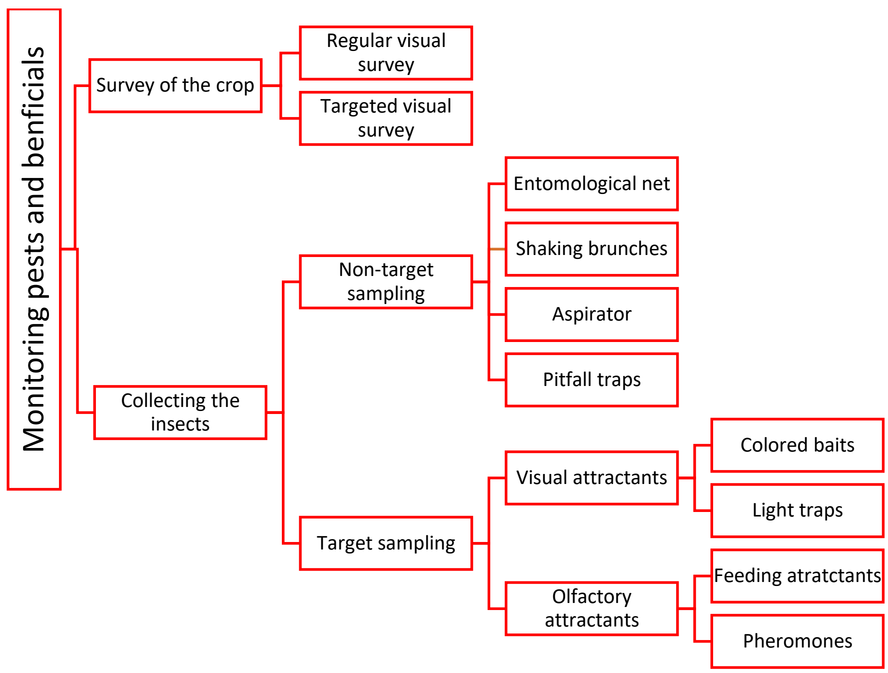


Figure 3.40 Schematic overview of the available pest monitoring methods

Some monitoring methods are carried out according to certain prescribed protocols for crop and pests. Table 3.2. shows how each method is carried out.

Table 3.2 Monitoring methods and their implementation

Monitoring method		Implementation
Survey of the crop	Regular visual survey	➢ At specified intervals, a certain number of plants are inspected, the presence and number of pests and natural enemies are determined, and damage is assessed using various scales. ➢ If necessary, samples are taken and the species found are determined in the laboratory. ➢ Records of each survey shall include the following: 1. date, time of survey, weather conditions 2. assessment of general condition of crops/plantations 3. number of pests by species 4. damage assessment and type of damage 5. number of beneficial insects by species

			6. presence of parasitic pest individuals 7. stage of development of crops/plantations
	Targeted visual survey		➢ It is carried out at certain stages of development of the crop according to the protocol for each individual pest. The exact timing of the survey can be further determined by monitoring of insects, such as by pheromones or yellow panels. ➢ Targeted surveys are often conducted by taking a specific number of samples (e.g. branches of the exact length for perennial species, a specific number of flower buds or leaves).
Collecting the insects	Non-targeted sampling	Entomological net	➢ For species that reside on above-ground organs, an entomological net is used on low crops (arable, vegetable crops) to make a certain number of catch sweeps over the plants, walking diagonally across the field. ➢ Catches from the net are determined by species, the number of individuals of each pest and beneficial species determined in the sample is recorded. ➢ Catches from nets are determined by species in the laboratory using a magnifying glass (depending on the skill of the person determining) and the number of individuals is recorded;
		Shaking the branches	➢ It is performed on fruit trees. The branches are struck with a rubber stick, and the falling insects are collected in a fixed entomological net. The protocols prescribe the number of branches to be shaken and the number of strikes for each branch. ➢ Catches from the net are identified to species in the laboratory using magnifying glasses (depending on the skill of the person determining). The number of individuals of each harmful and useful species determined in the sample is recorded
		Aspirator	➢ Depending on the type of aspirator, it is possible to use it on all types of crops. The aspirator sucks in all insects that are on certain parts of plants or whole plants that are aspirated. ➢ The catches from the aspirator are determined to the species in the laboratory using a magnifying glass ((depending on the skill of the person determining). The number of individuals of each pest and beneficial species identified in the sample is noted.
		Pitfall traps	➢ Pitfall traps are containers of liquid (usually water to which common salt is added) buried in the ground so that the top of the container is at ground level. Insects that walk on the soil surface fall into the traps, which must be emptied regularly. ➢ Catches from the traps are identified to species in the laboratory using a magnifying glass (depending on the skill of the person determining). The number of individuals of each harmful and useful species determined in the sample is recorded.

	Targeted sampling	Visual attractants	Colored baits	➢ It is performed for species that fly and that attract certain colors. The most commonly used colored sticky boards are blue, yellow, or white. ➢ In some cases, hunting pots are used, painted on the inside and filled with water in which the insects drown. ➢ The color of the sticky or colored bait adapts to the species whose presence we want to detect, blue tends to attract thrips, yellow effectively attracts aphids, various types of flies, moths, crickets... white attracts wasps (which lay their eggs on white flowers). ➢ Colored sticky boards have standard dimensions and are placed so that the bottom edge of the board is just above the canopy - as plants grow, the board must be moved. ➢ Several species of insects (and in some cases beneficial insects) are caught on the colored boards, so when checking, the species found and the number of each pest must be determined. ➢ Colored baits placed in large numbers can also be used to control some pests.
			Light traps	➢ Performed for species that fly and are attracted to light. ➢ The most commonly used lamps that draw their power from solar sources. ➢ Light traps catch several species of insects (in some cases useful species too), so when inspecting the caught insects, it is necessary to determine the species found and their number.
		Olfactory attractants	Feeding attractants	➢ It is performed for species that are attracted to a particular type of food. ➢ Food attractants used are plants and parts of plants, food (honey, sugar), products of animal origin (e.g. fish) or special synthesized products (e.g. hydrolyzed protein, buminal). ➢ The attractants are placed in different types of traps. ➢ The attractants are usually species-specific so that individuals of the species we monitor, whose numbers we determine during inspection, can be easily found. When the attractants are placed in large numbers, they can also be used to control some pests (e.g. olive flies, wasps, hornets, ants...).

			Pheromones	➢ Pheromones are produced by insects themselves. ➢ There are several types of pheromones, but for pest monitoring we use aggregation and sex pheromones. Aggregation pheromons are secreted by social insects (ants, bees) and some other insects (palm weevils, beet weevils). Normally, sex pheromones are secreted by females to attract males of the same species. ➢ The pheromones are synthetically produced and formulated for monitoring purposes in the form of capsules that are placed in traps of various shapes. ➢ The design of the traps is adapted to the behavior of the pest species. ➢ Due to their high specificity, insects trapped with pheromones do not need to be specifically identified. ➢ Pheromones determine the time limits for the appearance of a particular pest species, and for some pests (e.g. codling moth, grape berry moth, etc.), population size and control needs can be determined. ➢ Pheromone capsules and / or traps with pheromone baits placed in large numbers can also be used to control some pests using the confusion method or the mass trapping method (see Chapter 3.4.2.).

Revision questions

1) Choose the statement/s that match the Economic threshold level

a) It represents the level of infestation at which suppression is approached.
b) It is the point at which the economic damage caused by harming a particular pest population equals the cost of controlling the same population (which includes the cost of environmental damage).
c) It takes into account the amount of damage prevented, the cost of the action and the environmental damage.

2) Choose the statement/s that matches the Action threshold level

a) Represents the level of infestation at which suppression is approached.
b) The information on the population of natural enemies is needed to decide on the action taken.
c) Data on action threshold level in organic farming exist for almost all pests.

3) Choose the statement/s that matches the regular visual survey

a) It is carried out at certain stages of development of the crop according to the protocol for each individual pest.
b) It is carried out at specified intervals, a certain number of plants are inspected, the presence and number of pests and natural enemies are determined, and damage is assessed using various scales.
c) It is often conducted by taking a specific number of samples (e.g. branches of the exact length for perennial species, a specific number of flower buds or leaves).

4) Circle the tool/s that can be used for non-targeted sampling in orchards to collect insects on the trees

a) Pitfall traps
b) Shaking the branches
c) Entomological net
d) Aspirator

5) Please choose the correct statement

a) The use of aspirator is possible on all type of the crops
b) The use of aspirator is possible on field crops only

6) Pitfall traps are ________________________ buried in the ___________ so the top of ____________ is at ________________. ___________________ that walk on the ___________________ fall into the ____________.

7) Please list the two types of visual attractants

a) _____________________

b) _____________________

8) Choose the statement/s that matches the targeted sampling by visual attractants

a) It is performed for species that are attracted by food.
b) It is performed for insects that are attracted by color or light.
c) It is performed for insects that are attracted by color only.
d) It is performed for insects that are attracted by light only.

9) The species-specific attractants are:

a) Light traps
b) Feeding attractants
c) Colored traps
d) Pheromones

10) The traps that catch beneficial insects too are:

a) Pheromones
b) Pitfall traps
c) Light traps
d) Feeding attractants

3.4 Direct pest control methods in organic farming

Learning outcomes

- Explain the advantages and disadvantages of different methods and products for insect pest control.
- Choose the appropriate method and product for pest control in specific conditions of agricultural production.
- Select and recommend the appropriate methods and products to be applied in order to keep pest population below the economic threshold.

3.4.1. Mechanical and physical pest control methods

Mechanical pest control measures include various methods of collecting or destroying insects in the crop or the use of certain mechanical barriers. Some mechanical pest control measures are implemented when the pests infest the host plant and aim to maintain yields, while other measures are implemented when vegetation is dormant or when the pest is not causing direct damage to the crop and aim to reduce the pest population in the future. Examples of some mechanical control measures are given in Table 3.3. and the possible implementation of a particular measure for other crops or pests is described.

Table 3.3 Some examples of mechanical pest control measures

Method	Target pest	How to implement it	Additional comments and possible implementation
Destroying crop residues	*Ostrinia nubilalis*	It is applied after harvest. Corn in which caterpillars overwinter is crushed into pieces shorter than 1 cm using specially designed equipment.	The destruction of plant remains may still be accomplished by chopping, burning, or deep plowing. This measure is acceptable for several other pests. In greenhouse production, destruction of plant residues is necessary. Leaf miners that pupate in the leaf are suppressed by collecting and burning fallen leaves.
Collecting and destroying the insects	*Leptinotarsa decemlineata*	At the time of emergence of the adult beetles, they are collected and mechanically destroyed (clearly visible on the plants). Leaves on which eggs are laid are also collected. Collection should be carried out at least twice a week at the time of emergence of overwintering adult beetles.	Manual collection can be done for pests with larger body sizes (e.g., weevils on grapevines), for pests that are held together (e.g., caterpillar cocoons on branches), or when the egg clutches of the pest are collected. In some cases, the pests are collected with the parts of the plant (e.g. leaves, twigs) that they infest. Mechanical collection is carried out with aspirators and in this case, in addition to the pests, their natural

			enemies are also collected - these should be returned to nature after collection. The obligatory measure after collecting is the destruction of the collected pests.
Collecting the pests by using different tools	*Cydia pomonella*, wasps, horns, rodentia, crockroaches	Mechanical trapping of pests is carried out with the aid of various aids, which may be hunting belts of corrugated cardboard, hunting vessels filled with a mixture of water, vinegar, etc., or specially constructed traps.	Hunting belts of corrugated cardboard placed around the trunk in early fall to catch overwintering codling moth caterpillars. They are also suitable for other caterpillar species that overwinter on the trunk. Hunting pots or traps are placed in areas accessible to insects and some form of bait can be placed in them to attract the target organism. See Table 3.4. Suitable for a wide range of pests.
Mechanical barriers	Slugs, *Bothynoderes punctiventris*, wild animals, aphids, rodents	Various types of barriers, such as mechanical barriers for slugs, fences for wildlife, barriers (digging channels) to prevent migrating insects from infesting the field (weevils), nets attached to windows and entrances of greenhouses or warehouses, nets or other materials used to cover crops, wrap plants, etc.	Suitable for a large number of pests. It is necessary to choose the best type of barrier according to the type of pest and its way of life and the characteristics of the plants.

Physical control methods involve the use of physical means to control pests. These include the use of temperature (low or high), humidity, carbon dioxide, vacuuming, and the use of optical and olfactory baits, gamma rays, ozone, etc. High and low temperatures are most commonly used for pest control in protected areas (e.g. steam sterilization of floors) or in warehouses during food storage (e.g. freezing beans to control pea weevil). A brief overview of the most common physical methods and possible applications is given in Table 3.4.

Table 3.4 Examples of the use of physical pest control methods

Method	Target pest	Description	Wider implementation
Soil sterilization by steam	Pests, diseases, and weeds in protected areas in the soil (nematodes, fly larvae,	Hot steam is introduced through perforated pipes into empty greenhouses or sheltered areas. It is produced in a specially constructed apparatus. Under the influence of the steam, the soil temperature rises to such an extent that survival of organisms in the soil is no longer	The method is applicable to all protected areas and to almost all harmful organisms present in the soil at the time the method is carried out.

	spores of various fungi, weed seeds)	possible. In carrying out the procedure, it is important to ensure a certain period of time during which the temperature is elevated, i.e. the organisms must be exposed to the target temperature for a certain period of time. The lower the target temperature, the longer the exposure can be. It is recommended to heat the soil to 95 ° C for 5 minutes.	
Solarization	Nematodes in vegetables and ornamental plants	During the summer months, when there is no cultivation on certain areas, the soil is covered with a transparent plastic foil (PE or PVC) 0.015-0.05 mm thick. The soil remains covered for 1-2 months. Before covering the soil should be moistened. Soil temperatures at a depth of 10 cm under the foil are raised by 10-20 ° C in relation to the uncovered soil. This is enough to destroy organisms (nematodes, fungi, weed seeds) in the soil.	Applicable to all groups of harmful organisms in conditions where it is possible to leave the plots unsown during the summer months.
Vacuum and Carbon dioxide	Stored product pests	The method is based on removing the air from the warehouses where grain products are stored, creating a vacuum and causing the pests to die under such conditions. Another option is the introduction of carbon dioxide into the storage room, which displaces the air and the pests die due to the lack of oxygen. The implementation of these methods is possible in warehouses that are designed to be completely sealed.	Applicable to all groups of harmful organisms in storage areas.
Ozon	Stored product pests	Introduction of ozone produced for this purpose in devices (ozonators) in warehouses. To achieve full success it is necessary to achieve a certain concentration of ozone in a certain period of time depending on the type of insect.	Research on different ways of using ozone is underway.
Sterilization of males by gamma rays	*Ceratitis capitata, Dacus oleae*	This method is also referred to as SIT technology. Gamma rays are used to sterilize mass bred male fruit flies and then release them into plantations where they compete with fertile males for females to copulate with. After a female copulates with a sterile male,	Suitable for other types of fruit flies (e.g. olive fruit fly) and is also used worldwide for insects that attack humans (mosquitoes, cannibal flies, etc.)

		she does not produce eggs, so the released sterilized males reduce the number of eggs laid and the number of larvae that cause damage. Sterile males are usually released over a geographically larger area (area-wide management) hence	
Mass trapping using colored sticky traps	Aphids, white flies	A large number of yellow plates are placed on the edges of greenhouses or protected areas. The plates are placed so that the lower edge of the plate is flush with the top of the crop. The aim is to catch a larger number of aphids as they fly into the building. The yellow plates must be replaced regularly to ensure the capacity of the adhesive surface.	Besides aphids, the method is also suitable for moths, thrips, fruit flies, vegetable flies, etc. The color of the sticky board adapts to the type of pest.
Mass trapping using aggregation pheromones	*Bothynoderes punctiventris*	A larger number of traps containing the aggregation pheromone is set up in early spring in fields where the beetle has overwintered. Adults come out of the ground, come to the traps where they are caught, and do not go into the fields sown with sugar beets.	Suitable method for sugar beet weevil and for palm tap
Confusion by sexual pheromones	Grapevine moths	Pheromone capsules (without traps) are placed in large numbers in plantations. The pheromone capsules release a high concentration of female pheromones, confusing the males and making it impossible for them to find the females. Therefore, they do not mate. Unfertilized females do not lay eggs, so caterpillar infestation is reduced.	Also suitable for codling moth, South American tomato moth and some other species that produce pheromones.

3.4.2 Biotechnical methods-based strategies

Biotechnical methods include the control of pests with pheromones, the release of sterile insects and the use of insecticides with biotechnical action. Biotechnical insecticides influence the metabolism of insects (e.g. molting inhibitors) resulting in insect death. Biotechnical insecticides primarily do not have a harmful effect on insects, but disrupt processes in their metabolism, resulting in insect death. Because biotechnical insecticides (although considered more environmentally friendly than conventional chemical insecticides) are not all approved for use in organic agriculture, in this chapter we will focus on strategies for applying pheromones and releasing sterile males for pest control.

There are two ways to use pheromones for pest control: Mass trapping and confusion. Both methods are described in Table 3.4. Both methods, as well as the method of releasing sterile insects, are excellent when an area-wide control strategy (hereafter AW) is used to control pests. In contrast to individual control measures that we implement with the goal of immediate damage reduction in a specific area, the long-term goal of the AW program is to reduce pest infestations in each area below the number that can cause damage. The purpose of this environmentally friendly method is to reduce the population of pests below the decision threshold. The control of a particular pest species is not only done on the crop that suffers economic damage, as in the individual approach (Figure 3.41 A), but on all crops that the pest can feed on (Figure 3.41 B).

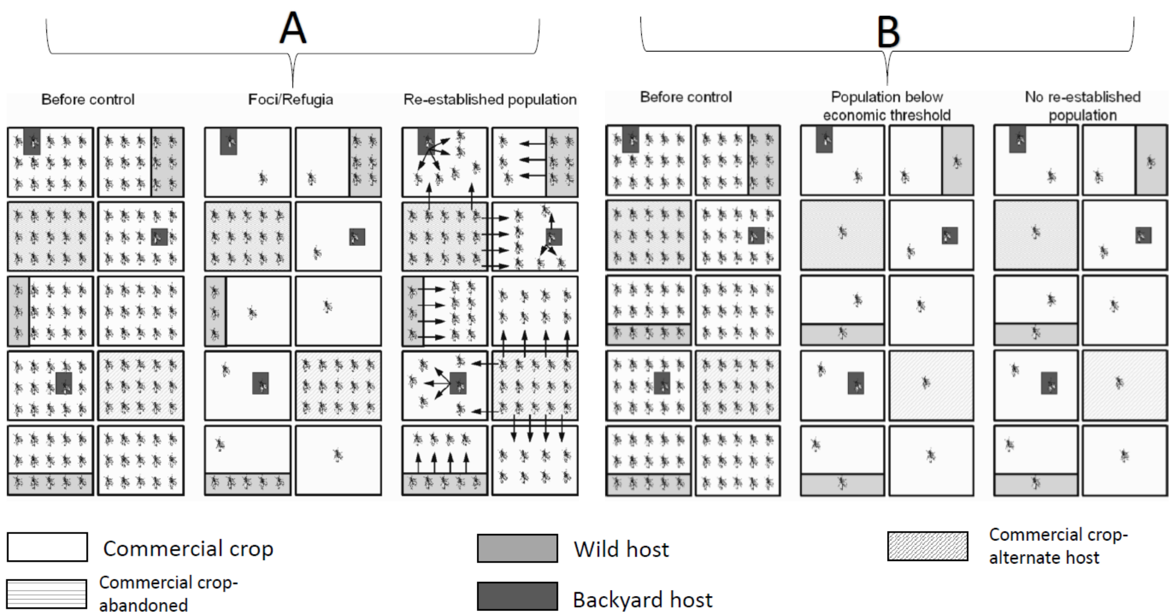


Figure 3.41 Graphical representation of the control concept on individual fields (A) and on large areas (B). (After Hendrichs et al., 2007). 3.41.A: Pest population declines below the decision threshold on fields of commercial importance and is not controlled on neglected crops, alternative hosts, backyard hosts, and wild hosts. As a result of control, significant areas remain uncontrolled by the remaining pests, which are then the source of their restored population. 3.41.B: The pest population declines below the decision threshold on all areas, including neglected crops, alternative hosts, backyard hosts, and wild hosts. The result of control is the absence of significant areas to hold the remaining pest individuals that escaped control and would be the source of the restored pest population.

The specificity of this strategy is that it must be organized and implemented by all owners of agricultural land in a given area.

3.4.3 Use of natural enemies

The use of natural enemies (predators and parasitoids) for pest control is one of the ways of biological control. The most used method of biological control is the augmentation method, which aims to increase the population of natural enemies that exist in a given field or to introduce species that are widely distributed in a given area. This method is implemented in several ways:

1. cultivation of the natural enemy in the laboratory and its release into the farm

2. collecting a natural enemy in another environment and bringing it to the farm where we want to carry out biological control

3. purchasing a natural enemy from an authorized supplier/manufacturer of the formulated products called biopesticides

The following requirements are necessary for the successful use of natural enemies:

- ✓ An accurate identification of the pest;
- ✓ An accurate and timely assessment of the threat;
- ✓ The selection of the optimum natural enemy for the specific conditions; the determination of the optimum time for the first application;
- ✓ Knowledge of the optimum required ratio between the number of natural enemies and the number of pests;
- ✓ Knowledge of the manufacturer of the chosen enemy who can guarantee the quality and make the delivery quickly;
- ✓ Properly prepared storage of the natural enemies from receipt to application;
- ✓ Existing/previous measures in the crop into which the natural enemy is introduced (nets at ports of entry, application of other pesticides, etc.);

There are a large number of natural enemies that can be used in organic farming. Table 3.5. shows the main species available on the market with their basic characteristics and scope of application (target pests for which they can be used).

Table 3.5 Overview of the most important species of the most commonly used natural enemies available on the market

Type of the natural enemy (systematic group)	Species	Packaging	Target pests	Application tips
Predatory mites	*Neoseiulus cucumeris, Amblyseius swirskii*	Adult mites mixed with inert substance in a bottle or in smaller packets prepared for hanging on plants.	Phytophagous mites (*Tetranychus urticae, Panonychus ulmi* etc.)	Scatter the mites evenly in the culture on the leaves (depending on the culture 5 - 100 mites/m²) or hang the sachets on the plants. Mites tolerate temperatures up to 40 ° C, but work optimally at temperatures between 25-30 ° C and humidity 40-90%.
	Phytoseiulus persimilis			
	Macrocheles robustulus	Adult mites mixed with inert substance (vermiculite).	Pests in soil (thrips nymphs, sciarid flies etc.)	Release on the soil
	Amblydromalus limonicus	Nymphs and adult mites mixed with inert substance.	Thrips, whiteflies	Scatter the mites evenly in the culture on the leaves (depending on the culture 5 - 100 mites/m²) or hang the sachets on the plants. Mites tolerate temperatures up to 40 ° C, but work optimally at temperatures between 25-30 ° C and humidity 40-90%.
Predatory true bugs	*Orius insidosus, O. laevigatus*	Nymphs and adults mixed with woodchips and buckwheat.	Thrips (various species)	Scattering of bugs in groups of 75-100 on plant leaves for preventive control.
	Macrolophus pygmaeus, M. caliginosus	Nymphs and adults mixed with wood chips and/or buckwheat.	Thrips, whiteflies, aphids, leaf miner larvae, *Tuta absoluta* eggs.	Shake from the bottle onto the leaves or into a storage box that hangs on the plants. It works best at temperatures below 20 ° C.
Coccinellids (predators)	*Adalia bipunctata, Cryptolaemus montrouzieri, Delphastus catalinae*	Depending on the species, larvae and adults mixed with wood chips and/or buckwheat.	Depending on the species: aphids, mealybugs, whiteflies….	Open bottles or packets, place in dispensers that are placed near infected plants.
Lacewings (predators)	*Chrysoperla* spp.	Larvae mixed with buckwheat.	Aphids, other pests	Open bottles or packets, place in dispensers that are placed near infected plants.

Predatory Diptera	*Aphidoletes aphidimyza*	Fly pupae in a bottle mixed with organic material.	Aphids	Leave the open bottle on the ground or hang it between the plants - flies that come out of the pupa will fly out and lay eggs next to aphid colonies.
Parasitoid wasps	*Aphelinus abdominalis*	Parasitic wasps mummies on the card or in bottles mixed with inert material (buckwheat, wood-chips etc.).	Aphids	Wasps are less mobile, so it is important to distribute the mummies evenly around the infected plants.
	Aphidius ervi, A. matricariae, A. colemani		Aphids	Distribute the mummies evenly around the infected plants. *A. matricariae* does not act above 28 ° C and *A. colemani* and *A. ervi* above 30 ° C.
	Anagyrus vladimiri		Scale insects	Distribute the mummies evenly around the infected plants. They are most active around 25 ° C and the activity zone is from 13 to 38 ° C.
	Encarsia formosa		*Trialeurodes vaporariorum, Bemisia tabaci*	Hang cards with mummies on plants. Temperatures above 17 ° C are required to achieve efficiency.
	Eretmocerus eremicus		*Trialeurodes vaporariorum, Bemisia tabaci*	Also suitable for use in higher temperature conditions.
	Dacnusa sibirica	Adults	Larvae of leaf miner flies	The wasp lays an egg in the miner larva, the wasp larva develops in the mineral larva.
	Diglyphus isaea			The wasp paralyzes the miner larva and lays eggs on it, the wasp larva develops in the mine and feeds on the miner larva.
Entomopathogenic nematodes	*Steinernema feltiae, S. carpocapsae, Heterorhabditis bacteriophora* …	Nematode (larvae) mixed with inert carrier material.	Lepidoptera: *Tuta absoluta*, Noctuids larvae, *Spodoptera* spp., cotton bollworm, corn earworm (*Helicoverpa* sp.), *Chrysodeixis chalcites*, *Agrotis* sp., *Autographa gamma*, *Duponchelia fovealis, Cydalima*	Depending on the target pest, they are poured onto the soil or applied by spraying the trunk and soil around the trunk. Nematodes are susceptible to ultraviolet light (UV): do not use them in direct sunlight; the moisture content of the soil must be kept high for several days after application. When possible, irrigate the crop before and right after application.

			perspectalis, Crambus hortuellus, Chrysoteuchia topiaria, Cydia pomonella, *Cydia molesta, Cydia funebrana, Adoxophyes orana*, and *Synanthedon myopaeformis*. Coleoptera: *Leptinotarsa decemlineata, Capnodis tenebrionis, Crioceris asparagi*. Diptera: *Scatella* sp., *Tipula* sp. Other orders: *Nesidiocoris tenuis, Corythucha ciliata, Gryllotalpa gryllotalpa, Neoscapteriscus* sp.	For foliar application, spray when relative humidity will exceed 75% for several hours post treatment; an adjuvant and/or an anti-desiccant/humectant additive can be beneficial.

3.4.4 Products for direct pest control allowed in organic production

Two types of products can be used for direct pest control in organic farming. These are homemade products and ready formulated products found in the market.

Homemade products

Homemade products are usually the preparation of various plant-based products called botanical or herbal products that can be used for direct pest control (in this case we are talking about botanical insecticides) or to enhance plant resistance. Botanical insecticides are made from extracts of toxic and non-toxic plants. Extraction of non-toxic, mostly medicinal and aromatic herbs such as nettle, onion, chamomile, wormwood, rosemary, etc., yields extracts that are non-toxic and can be sprayed at any stage of plant development. Many of these extracts have not been adequately studied, so their mechanism of action is unknown. They are mainly extracts that have no direct insecticidal effect on pests, but are characterized only by an indirect effect, such as the ability to repel insect pests or to strengthen the resistance of the plant. Some of the major preparations obtained using non-toxic herbs are Horsetail tea, Wormwood, Elderberry, Nettle. In addition to extracts from non-toxic plants, extracts from toxic plants can also be prepared on the farm, but because of the potential danger in their preparation, their preparation is more often carried out in factories. The preparation of herbal insecticides at home is reasonable if the following conditions are met:

- the people involved in the production must not be exposed to the risk of poisoning;
- production must not pose a danger to the environment;
- research has established that the products obtained are safe for the consumer;
- the raw material for the preparation of the extracts is readily available;
- the preparation is not expensive;
- there are no equally acceptable and effective preparations on the market
- the efficacy has been proven by research;

Plants used to make herbal insecticides can be used fresh or dried. The best time to pick them is just before flowering and during the sunny period. Then they must be dried in a clean, ventilated and shaded place. The procedure for making insecticides from plants may vary. Many authors explain the different instructions, and in general all methods can be divided into cold and hot water extraction methods or alcohol extraction. Extraction is a method of separating essential from less important constituents of a medicinal plant. Herbs are most commonly used as preparations in the form of herbal tea, herbal soups, and herbal extracts.

Herbal tea is made by pouring boiling water over fresh or dried herbs and letting such a mixture steep, covered, for 10-15 minutes. This is followed by the straining process.

Vegetable soup is made when the prescribed amount of herbs is soaked in water for 24 hours, preferably in rainwater. Then the soup is brought to a boil and simmer on low heat for about half an hour. The soup should be cooled and strained after cooling.

Herbal extracts are made from fresh or dried herbs or parts of plants. Extraction involves pouring a solvent over dry or fresh plant parts. Although water is not the best solvent for extracting all compounds from plant parts, it is most acceptable for use when the process is done at home. Besides water, alcohol (ethanol) can also be used as a solvent in home preparation, while the use of methanol, chloroform, acetone, etc. is not recommended, as these are compounds considered hazardous substances.

Industrial products

Industrial products used for pest control in organic farming can be based on different active ingredients. The use of industrial plant protection products in organic production is regulated by Regulation 2018/848 of the European Parliament and the Council. According to the regulation, the use of certain plant protection products is allowed when the application of all methods described above does not provide sufficient protection. Only plant protection products authorised under Regulation (EC) No. 2021/1165 may be used after they have been evaluated and found to be in compliance with the objectives and principles of organic farming. Only the active substances listed in Annex I Regulation (EC) 2021/1165 may be contained in plant protection products used in organic production. Some of the authorised products belong to the so-called basic substances, others are authorised as products with a specific effect. Basic substances are active substances, not predominantly used as plant protection products but which may be of value for plant protection and for which the economic interest in applying for approval may be limited. Insecticides are mostly plant-based products (plant insecticides), living microorganisms (bacteria, viruses or fungi) and their by-products, and substances or compounds of organic or inorganic origin. An overview of the most important active substances for protection against insect pests, mites and snails that are permitted in organic production (EU Pesticide Database) is shown in Table 3.6.

Table 3.6 Active substances permitted for use against harmful insects, mites and snails in organic farming

Category	Active ingredient	Mode of action	Applicability	Important information
Basic substances	Beer	Feeding attractant	Slugs and snails	Iti s use as a bait for slugs and snails only.
	Fructose	It stimulates the defense mechanisms of plants.	Lepidoptera larvae in orchards, American grapevine leafhopper (*Scaphoideus titanus*)	A solution in cold water should be prepared immediately before use.
	L-cysteine	Preventive	Ants from genus *Atta* and *Acromyrmex*	L-cysteine should be used in a mixture with wheat flour or similar, food in a concentration of not more than 8%.
	Sucrose	It stimulates the defense mechanisms of plants.	Lepidoptera larvae in orchards, American grapevine leafhopper (*Scaphoideus titanus*), European	A solution in cold water should be prepared immediately before use.

			Corn Borer (*Ostrinia nubilalis*)	
	Talk (E553B)	Creates a barrierpreventing pest Feeding.	*Cacopsylla pyri, Cacopsylla fulguralis, Drosophila suzukii, Panonychus ulmi, Bactrocera oleae*	The aqueous solution shall be prepared immediately before use and must be stirred at all times.
	Nettle extract	Industrial products obtained by different extraction processes (depending on the manufacturer).	Numerous pest species as are: aphids (*Myzus persicae, Macrosiphum rosae, Eriosoma lanigerum, Cryptomyzus ribis, Callaphis juglandis, Myzus cerasi, Aphis fabae* etc.), cabbage flea beetle (*Phyllotreta nemorum)*, diamondback moth (*Plutella xylostella*)	Application by spraying or as mulch on the ground.
Substances of organic origin	Parafin oil	Due to its viscosity, it creates a coating on the body of harmful insects and closes the air vents (stigma) of harmful insects and mites.	Insecticide, acaricide	They are used for winter spraying or for spraying in vegetation.
	Plant oils	They show toxic and / or repellent effects. Due to their viscosity, some can act similarly to parafin and mineral oils.	Insecticide, acaricide	They can be essential, in which case they are a mixture of volatile and lipophilic compounds.
	Hydrolyzed proteins	Attractants, only in authorized applications in combination with	Different product for different pest species	Used for mass trapping.

		other appropriate products.		
	Mineral oil	Due to its viscosity, it creates a coating on the body of harmful insects and closes the air vents (stigma) of harmful insects and mites.	Insecticide, acaricide	They are used for winter spraying or for spraying in vegetation.
	Pelargonium acid and other acids from C_7 to C_{20}	It acts on all groups of pest organisms.	Soft-bodied insects (aphids, whiteflyes, mites)	Applied by spraying
Substances of inorganic origin	Diamonium phosphate	It is used as bait for the method of mass trapping in orchards.	*Ceratitis capitata, Rhagoletis cerasi, Bactrocera oleae*	Applied diluted in baits
	Sulfur	Although originally a fungicide it is known to have an acaricidal activity.	Mites on different plant species: orchards, vinegrapes et.	Sulfur has a negative effect on beneficial predatory mites and this should be taken into account when making a decision on control.
	Diatomaceous earth	It works mechanically because coarse particles damage the cuticle of insects that lose moisture from the body and dehydrate.	The most common use against pests in warehouses	It is applied by spraying, less often as a powder.
	Ferric phosphate (iron (III) orthophosphate	It has an abrasive effect on the mucous membrane of snails.	Limacide	It is used against harmful snails in the form of baits
Microorganisms-viruses	*Adoxophies orana* granulovirus	It causes a lethal effect on caterpillars after feeding.	*Adoxophyes orana*	Spray in the evening, adjust the dose to the height of the canopy. Application in orchards
	Cydia pomonella granulovirus		*Cydia pomonella*	
	Helicoverpa armigera nucleopolyedrovirus		*Helicoverpa armigera*	It is used on vegetables.

Microorganisms- fungus	*Isaria fumosorosea* strain Apopka 97	A fungus that can be found in soils around the world.	*Trialeurodes vaporariorum*	The pest is most susceptible to infection in the N1 and N4 stages of the nymph. The infection cycle is rapid and symptoms of infection are visible within 24-48 hours after the conidia get in contact with the insect.
	Akanthomyces muscarius strain Ve6, earlier *Lecanicillium muscarium*	A fungus that can be found all over the world in nature, in soils and in other organisms.	*Trialeurodes vaporariorum, Thrips sp.*	Effective by direct contact and under the right environmental conditions kills larvae after 7-10 days. After spraying, spores germinate and grow, creating hyphae that penetrate the body cavity, where they multiply, destroying tissues. The fungus then grows through the cuticle of the insect and creates spores on the outside of the carcass, which can spread the infection to other whiteflies and thrips.
	Beauveria bassiana	Spore fungi formulated as a powder (for use in storage) or as water-soluble granules to be applied by spraying.	Storage pests: (*Oryzaephilus surinamensis, Sitophilus granarius, Cryptolestes ferrugineus)* and pests in glashouses *Frankliniella occidentalis, Thrips tabaci, Trialeurodes vaporariorum, Bemisia tabaci, Bemisia argentifolii*	When spraying, the volume of water should be adjusted to the developmental stage of the crop.

	Metarhizium anisopliae var. *anisopliae*	Spore fungi formulated as granules for application in soil.	*Phyllopertha horticola, Otiorhynchus sulcatus, Daktulosphaira vitifoliae, Amphimallon solstitialis*	The granules need to be mechanically incorporated into the soil.
Microorganisms- bacteria	*Bacillus thuringiensis* sbsp. *aizawai*	Bacterial spores and crystals formulated in a spray preparation.	Defoliator caterpillars in pepper	Gastric poison, it acts only after the caterpillars (or CPB larva) take it into the digestive system together with the leaves.
	Bacillus thuringiensis sbsp. *kurstaki*		Wider application on other crops but always to control butterfly caterpillars.	
	Bacillus thuringiensis sbsp. *tenebrionis*		Colorado potato beetle larvae	
Derivates of microorganisms- naturalites	Spinosad	Spinosyns are biologically active substances obtained by fermentation from the bacterium *Saccharopolyspora spinosa*. Spinosad is a mixture of spinosyn A and spinosyn D.	Very wide range of action - used to control potato beetles, harmful caterpillars, thrips and moths on vegetable crops and fruit trees.	Permitted in organic production, but the justification of its application must be supported by data on the intensity of pest attacks.
Botanical insecticides	Azadirachtin	Extract obtained from Indian neem tree (*Azadirachta indica*).	Colorado potato beetle and many other pests	It acts as a growth regulator and also has a repellent effect.
	Pyrethrin	Pyrethrin is the common name for six active compounds: pyrethrin I, pyrethrin II, cinerin I, cinerin II, cinerin III, jasmolin I and jasmolin II isolated from the plant *Chrysanthemun cinerariifolium.*	Wide range of action. Controls many pests.	Pyrethrin acts almost immediately after contact. It works in smaller doses. Although a biological agent, it should be used sparingly and care should be taken not to come into contact with beneficial insects, such as ladybugs and honey bees. Pyrethrin degrades rapidly and is

				not retained in the environment. Caution, it decomposes poorly in water and binds very tightly to soil and organic matter.
Sexual pheromones	Lavandulyl senecioate	Naturally occurring arthropod pheromone with a non-toxic mode of action. A very targeted activity concerning one species is assumed.	Specific effect on the pest species, *Planococcus ficus*.	Manual application in passive dispensers for mating disruption
	Other sexual pheromones	Intended to attract males of certain species - there are a large number of registered pheromones.	*Cydia pomonella, Adoxophyes orana, Pandemis heparana, Agrotis spp. Polychrosis botrana* and others	They are used for confusion of males (see 3.4.1.)
Aggregation pheromones		They attract both sexes of insects and are suitable for mass trapping	*Bothynoderes punctiventris etc.*	They apply to mass trapping (see 3.4.1) and in some cases in area wide management programs.

Revision questions

1) Match the listed mechanical and physical control methods with pest species that can control

1. Mechanical barriers	a) Stored pests
2. Solarization	b) European corn borer
3. Ozon	c) nematodes
4. Destroying crop residues	d) Slugs

2) Choose the statement/s that matches confusion by sexual pheromones

a) A large number of traps containing pheromones is set up in the field.
b) Pheromone capsules (without traps) are used.
c) The pheromones are attracting females into traps.

d) The pheromone capsules release high concentration of pheromones that is confusing males.
e) Males are able to find females and they successfully mate.

3) Choose the statement/s that matches sterile insect technique by gamma rays

a) Laboratory reared colonies of pests are exposed to gamma rays.
b) Sterilized females are released in orchards.
c) Sterilized males mate females (natural population).
d) Females don't lay eggs.
e) SIT is usually used for area –wide programs.

4) Choose the statement/s that matches biotechnical methods based strategies

a) Biotechnical insecticides primarily have a harmful effect on pests.
b) Biotechnical insecticides disrupt the processes in pest metabolism resulting in insect death.
c) There are three ways of the use of pheromones for pest control (area-wide, mass trapping, confusion).

5) Choose the correct statement

a) The use of natural enemies (predators and parasitoids) for pest control is the only way of biological control.
b) Augmentation method aims to increase the population of natural enemies that exist in a given field or to introduce species that are widely distributed in a given area.
c) Only few species of natural enemies can be used for biological control.

6) Please list the three groups of natural enemies

a) ______________________

b) ______________________

c) ______________________

7) Entomopathogenic nematodes can be used for control of following pests (please mark the correct answer/s).

a) Aphids
b) *Cydia pomonella*
c) Thrips
d) *Leptinotarsa decemlineata*

8) Choose the statement/s that explain when the preparation of herbal insecticides at home is reasonable:

a) the risk of poisoning during the production (for people and environment) must be minimized;
b) there are equally acceptable and effective preparations on the market;
c) the preparation is not expensive;
d) the efficacy has been proven by research;

9) Group the listed active ingredients into appropriate category in the table

Active ingredients:

a) Ferric phopsphate	e) Azadirachtin	i) L-cysteine	m) sucrose
b) Plant oils	f) *Beauveria bassiana*	j) Pyrethrin	n) Diatomaceous earth
c) Nettle extract	g) Sulphur	k) *Bacillus thuringiensis*	o) *Cydia pomonella* granulovirus
d) *Akanthomyces muscarius*	h) Parafin oil	l) Beer	p) Talk (E553B)

Category	Active ingredient
Basic substances	
Botanical insecticides	
Microorganisms- bacteria, viruses, fungi	
Substances of organic origin	
Substances of inorganic origin	

4 METHODS AND TOOLS TO MANAGE DISEASES

Plant diseases can have either abiotic or biotic causes. While abiotic diseases are caused by environmental influences such as air or soil pollution, the cause of biotic diseases, which are dealt with in this module, lies within pathogens (Greek pathos = suffering, disease). Pathogens are divided into the groups of fungi, bacteria including phytoplasmas (cell wall-free bacteria) and viruses.

Diseases caused by fungi are called mycoses (Greek myces = fungus). They are controlled by fungicides (Latin fungus = fungus). Diseases caused by bacteria or phytoplasmas are called bacterioses or phytoplasmoses. They are controlled with bactericides.

Diseases caused by viruses are called viroses. They are controlled with viricides or their vectors (insects, mites, nematodes, fungi) are controlled with suitable products.

In principle, preventive measures for disease avoidance, such as the right choice of location and variety and crop rotation, are the first priority. This can delay or reduce pathogen infection and, ideally, prevent it. In addition, the robustness of the crop can be supported with plant strengthening products by increasing its defenses.

If a disease is suspected, for example in infested areas or in weather conditions that promote diseases, early detection, monitoring and identification of the pathogen are prerequisites for targeted control.

To ensure control success, the right product or product mixture must be used at the right time.

In addition, hygiene measures and forward-looking health management are essential for the following years or the following crop in agriculture.

Way of life of phytopathogenic fungi, bacteria and viruses

In fungi, germinating spores and mycelia (fungal tangles) can colonize and feed on both living and dead host cells. In doing so, the fungus either directly invades epidermal cells or uses the infection route via natural plant openings such as stomata (respiration holes), lenticels (cork warts), hydratodes (water-secreting glands), and wounds. Fruiting bodies with spores formed on the plant surface will usually be spread by wind or rain.

Bacteria enter plants through injuries and wounds. This includes bites or stings from vectors. Bacteria multiply and spread passively throughout the plant within the host tissue or with the sap flow.

Viruses are transmitted mechanically by grafting, injury, and vectors (insects, mites, nematodes, fungi). They enter the cell upon contact with the cell wall and multiply there. Spread within the plant occurs with the sap flow towards the growth zones (shoot tip, root), where uptake by vectors occurs.

4.1 Prevention methods for plant protection against diseases in organic agriculture

Learning outcomes

- Describe cultural engeneering measures to prevent disease outbreak.
- Implement the appropriate agro technical practice that helps to prevent the outbreak of diseases.
- Predict the effect of implementing various agro technical methods on disease progression under specific agro climatic conditions.

4.1.1 Choice of location

To ensure the containment of fungal diseases, the choice of microclimate and geology is essential. Rapid drying ensures that infection pressure from fungal diseases is kept to a minimum. Wind-open locations are therefore a prerequisite for good air circulation. This is supported by an eastward orientation of sloping sites (vineyards) and an optimization of planting and foliage density of the crop.

The creation of entry points for fungal diseases (viticulture: *Oidium*, *Peronospora*) through frost cracking is a special issue. Especially due to climate change in recent years, frost locations are becoming the main problem in fruit and wine growing. Flat sites and depressions should be avoided because of the formation of cold lakes. Slopes are less susceptible to frost because the cold can run off. However, shaded sites and north-facing slopes are also gaining in importance. They have an advantage in late frosts due to later bud break. Frost damage can additionally be minimized by using oil products for delayed bud break.

Strict adherence to crop rotation is a prerequisite for disease prevention. When cultivating predominantly non-susceptible species or varieties, diseases with a restricted host range can be "starved out". They can only survive as long as at least parts of their host plant are present in the crop. This is usually 1-2 years.

However, special attention is given to non-host-specific pathogens and to disease species that persist in the soil for a long time. Crop breaks of up to 20 years are necessary for persistent diseases, such as *Phytophthora cactorum* var. *rubia* in raspberries and blackberries. In this extreme case, it is recommended to switch from soil to substrate culture, where infected plants can be easily removed from the culture. In the case of infestation with particularly infectious diseases, e.g. in soft fruit (*Phytophthora*) and in cereals (stone blight), long cultivation breaks of 10 years are the rule. In arable farming, sufficient cultivation intervals must be observed, especially for potatoes and legumes, because of soil-borne diseases (4-5 years for potatoes, 5 years for pea and lentil; 3 years for field bean). In addition, in legume cultivation, sufficient intervals to forage legumes or green cover (alfalfa, red clover, sainfoin) must be considered. In orchards, extreme postplanting due to growth depression due to soil fatigue is taking place nowadays. The reason is not sufficiently understood. It is probably a multitude of pathogens. Steaming the cultivated area can remedy this situation!

Soil structure and soil type also have a direct influence on fungal disease infestation. The risk of fungal diseases is particularly high in moist, heavy soils. Cultivation techniques such as ridging or bedding can help by increasing the distance from the crop to the soil, thus promoting warming and drying. Root-borne diseases such as *Verticillium*, *Rhizoctonia* and *Fusarium* occur more frequently in compacted soils. Looser soils are therefore particularly important in horticulture and arable farming. This can be achieved primarily by green manuring. Active loosening is achieved with deep-rooting species (clover, alfalfa, yellow mustard, Phacelia). In viticulture and orchards, perennial greening before cultivation is useful. It is important to note that alfalfa should be avoided in Orchards because of disease transmission of *Verticillium* and *Phytophthora*.

Not all diseases have the same growth requirements. For arable and vegetable crops, drought helps well with fungal pressure, but poor water availability negatively affects the crop for bacterial diseases. Loss of turgor can cause wilting to occur more quickly in damaged crops. Avoid intermediate hosts in the immediate vicinity of the crop! Forest edges and windbreak hedgerows pose a higher risk of infection for pathogens without host specificity. For host-specific pathogens, the intermediate host can be specifically avoided e.g.: Juniper for European pear rust.

4.1.2 Choice of variety

In principle, the choice of variety is always dependent on the variety requirements. Extremely important with regard to disease resistance of a variety is the resistance of a plant to biotic and abiotic factors (e.g.: frost hardiness in apricot) in order to keep the susceptibility to pathogens as low as possible. There are more or less pathogen resistant varieties of all cultivated species. In organic farming, less disease-susceptible, traditional (if possible native) varieties are preferred. In some cases, however, the flavor and yield of the variety are more important than existing resistance. A certain degree of yield loss due to diseases, among other things, is accepted.

The robustness of the plant is defined - in addition to its resistance to abiotic factors - by its ability to repel diseases. The thickness of the epidermis and the wax layer (cuticle) on top of it, as well as strengthening deposits (silicic acid) in the cell walls, play a decisive role here. Thicker-skinned cultivars have an advantage over thin-skinned ones.

While powdery mildew resistance is a priority for all crops, especially in organic farming, additional attention is paid to fungal diseases such as *Oidium* and *Peronospora* in wine. In organic fruit and wine growing, more and more areas are being planted with new fungus-resistant (PIWI) varieties. In fruit crops, resistant varieties against scab, *Marssonia*, canker and storage rot (*Gloeosporium*) are available. Resistant fruit varieties are available against fire blight (apple), curl disease (peach), Scharka virus (plum), and generally disease-resistant raspberry varieties.

In arable crops, the focus in resistance breeding is on leaf diseases in cereals, late blight in potato, leaf diseases and bubonic blight in corn, and *Sclerotina, Phomopsis*, basket rot in sunflower. *Rhizoctonia*-resistant sugar beet varieties are available for *Rhizoctonia*-infested sites.

In horticulture, late blight-resistant varieties in tomatoes and cucumber mosaic-resistant varieties in cucumbers have been bred.

Furthermore, disease pressure from certain pathogens can be circumvented by varieties with suitable planting and harvest dates. For example, early wine varieties are somewhat less likely to be infected late with *Botrytis*. The likelihood of rain and risk of injury is reduced because the grapes are already harvested in summer.

4.1.3 Choice of rootstocks (especially against soil-borne pathogens)

Grafting, i.e. grafting a susceptible scion of the desired cultivar, onto a resistant or a robust rootstock (e.g. wild form), increases the resistance of the cultivar. The choice of rootstock balances soil type (lime intolerance of the scion, pH requirements), water demand, vigor and stability, and controls budbreak (early/late). In orchards and vineyards in particular, less vigorous varieties are desirable because they provide better aeration and thus lower susceptibility to fungi even with less foliage work.

In fruit growing, standard rootstocks are available against various diseases:

- M9 and Genovese in pome fruit against fire blight.
- Docera 6, a hypersensitive rootstock in stone fruit. In plum, enhanced resistance to scab is achieved in combination with scab-resistant varieties.

In addition, in orchards, intermediate grafting is possible with trunk formers to 60-70 cm height. In currant, tall stems are grafted onto *Ribes aurorum* to obtain upright, stable stems that promote faster drying of leaves and fruit.

The former standard rootstock St. Julian GF6 552, since organic farming and ESFY (European Stone Fruit Yellows) is occurring, is no longer used because it develops stem shoots. This is a disadvantage in the transmission of ESFY by leaf suckers, which suck especially on stem shoots.

If the scion is susceptible to soil-borne pathogens and grows poorly, the use of an insusceptible rootstock variety is recommended (tomato on potato rootstock; cucumber and melon on pumpkin rootstock against *Fusarium*, *Verticillium*).

4.1.4 Educational systems/measures and soil care

Plant and row spacing are specified depending on the crop and are usually designed to optimize yield. The microclimatic conditions within a crop can be influenced with training systems such as leaf wall management. Soil activation with compost or green manure has a positive effect on the crop. Supplementary irrigation must always be used in a crop-optimized manner.

Foliage management in orchards and vineyards creates a loose plant structure with good ventilation and exposure. While winter pruning establishes the basic shape of permanent crops, summer pruning or thinning reduces leaf mass and stingy shoots. Together, these measures contribute to good aeration and exposure and allow for rapid drying, which minimizes fungal diseases. In principle, the rule is as much leaf mass as necessary, as little leaf mass as possible.

In addition, diseases can be prevented by varying the height of the trunk: for example, the higher the foliage wall starts in the vineyard, the less the splash effect, in which spores of *Peronospora* are catapulted by rain from the ground to the lowest layer of foliage. It is also essential to remove stingy shoots on the trunk to prevent *Peronospora* from "shimmying up" to the foliage zone of the cultivar.

In berry fruits, tail systems are preferable to shrub systems.

Soil activation can be accomplished with compost, green manuring, or greening with nitrogen-fixing plants. Generally, greening stands in water competition with the crop, but at the same time provides a continuous source of nutrients to optimize plant growth. This leads to an increase in resistance to fungal or bacterial pathogens. A plant overfed by mineral fertilizers - especially nitrogen - is very quickly attacked and damaged by fungi (e.g. *Botrytis* sp.). Optimally nourished plants, on the other hand, can actively defend themselves against pests and thus resist infestation for longer. Herbaceous plantings with water-saving plants are preferable in planting. Care should be taken not to let the greening become too high because of the microclimatic moisture development and the associated risk of fungal attack. Mowing, rolling or undercutting with "Greenmanager" are possibilities to keep the green cover short. In addition, the greening prevents the spread of pathogens with the soil erosion by wind through its action as an erosion prevention. Supplementary irrigation must necessarily be interrupted during rainfall.

4.1.5 Fertilisation leaf/soil

Soil or foliar fertilisation of the crop is used to compensate for nutrient deficiencies or imbalances. It can either be applied with in the form of purchased products or stored in the soil as part of the rotation of a previous crop, such as legumes (nitrogen). Excessive or incorrect fertilizer applications can weaken plant health. Nitrogen promotes rapid growth. At the same time, the soft cell walls of the new shoots facilitate the penetration of pathogens.

4.1.6 Plant strengthening

Plant strengthening promotes the robustness of the plant and disease prevention. It may stimulate root growth and support nutrient supply, thus increase stress resistance to environmental factors and promoting healthy plant growth. The use of plant strengthening agents is always preventive. Strengthened plants have strengthened cell walls and epidermis, which prevent or reduce the penetration of pathogens.

For example, the horsetail extract Equisetum plus makes infections by fungal pathogens such as Oidium more difficult when used regularly, due to the deposition of silicic acid in the cell walls. Plant strengtheners can also activate the plant's own defenses and thus protect against possible infection by microbial pathogens. After their application, there is an increase of phytoalexins (plant defense substances) and so-called ROS defense proteins (reactive oxygen species H2O2; destruction of pathogens invading the plant) in the green parts of the plant. They are responsible for the crop's resistance to disease attack.

Generally, plant and nutrient extracts as well as microorganisms for seed treatment are used for plant strengthening. Algae extracts possess a high number of micronutrients and increase the tolerance of plant protection products. Extracts from the following algae species are used for plant strengthening:

- *Ascophyllum nodosum* (SuperFifty®, AlgoVital Plus®)

- *Laminaria* (Resistance®)

4.1.7 Encouraging natural enemies and avoid intermediate hosts

In principle, increasing biodiversity in the ecosystem through, for example, flower strips or species-rich revegetation supports the attraction of beneficial insects. These beneficial parasitiods or predators can reduce vectors of pathogens such as aphids or cicadas and thus reduce the likelihood of transmission of viral and bacterial diseases. On the other hand, care should be taken to avoid intermediate hosts of pathogens (e.g.: juniper for pear lattice rust).

Revision questions

1) Mark five categories of prevention methods against diseases

a) Crop rotation
b) Spidermites
c) Variety
d) Plant strengthening
e) Fertilization
f) Nutrient deficency
g) Sunburn
h) Soil care

2) Important conditions for disease-inhibiting locations are (mark the right options)

a) Good air circulation
b) Flat sites and depressions
c) Loose soil
d) Late frost
e) Crop rotation

3) Resistant fruit varieties in orchards are available against (Choose the right options)

a) Fire blight
b) Curl disease
c) Oidium
d) Scharka virus
e) Peronospora

4) Looser soils can be achieved by (Choose the right options)

a) Green manuring
b) Perennial greening
c) Deep rooting greening
d) Steaming
e) Burning infected plant material

5) What is the splash effect in vineyards (mark the right option/s)

a) Spores of fungi are catapulted by rain from the ground to the lowest layer of foliage.
b) Spray droplets from fungicide applications bounce off the leaf.
c) Fungus infected grapes burst open during harvest and the splashing fruit juice spreads spores.

6) Options to reduce the splash effect of Peronospora infections in vineyards (mark the right option/s)

a) Greater trunk height
b) Remove shots on the trunk
c) Defoliation of the fruit zone

7) Name the ways of action of plant strengtheners (Choose the right option/s)

a) Activate the plants own defences.
b) Stimulate root growth.
c) Reduce stress resistance.
d) Increase of phytoalexins.
e) Curative.

8) Name the advantages of shaded sites and north-facing sloops (Choose the right option/s)

a) Late budbreak has an advantage in late harvesting.
b) Late frost is advantageous for fruit development.
c) Late budbreak has an advantage in late frosts.

9) Name the phrase/s that matches the topic "educational systems" (Choose the right option/s)

a) Resistant variety
b) Foliar management
c) Trunk height
d) Grafting
e) Row spacing

10) The choice of rootstock balances: (Choose the right options)

a) Soil type
b) Water demand
c) Disease susceptibility
d) Flavor development
e) Budbreak
f) Vigor and stability

4.2 Monitoring and prognosis models for diseases

Learning outcomes

- Classify diseases based on their morphology and damage pattern.
- Identify diseases based on their morphological characteristics and symptoms of damage.
- Coordinate and organize the monitoring of diseases, identify them and decide on measures to be taken to maintain yield and prevent economic damage under certain conditions of agricultural production.

4.2.1 Monitoring of diseases

Monitoring refers to the surveillance of processes in agricultural crops to obtain data and knowledge on diseases. Disease is assessed visually for obvious symptoms and by infestation frequency (percent of plants infested), and infestation severity (percent of plant tissue infested). The distribution pattern in the field stand is also important. There is also the possibility of an infestation survey for early detection of disease without visible symptoms. Here, random sampling is analyzed in the laboratory for pathogen genetic material using PCR testing.

Monitoring is carried out personally. Here, many years of experience on the farm and the right timing of the control play an essential role. In disease-sensitive periods or when the weather is conducive to disease, it is even advisable to carry out checks several times a day. Alternatively, consultants assist in crop inspection.

In addition, public warning services document first occurrence, infestation intensity and damage thresholds for the main cultivation areas of a crop variety in a country or region. Additional information on disease occurrence can be obtained from official advisory services.

Warning services are based on forecasting models. They are adapted to the respective climate zones and have been established for many years. Their values are based on the interaction of weather data, growth stages, infestation pressure in the region or previous year's infestation and variety susceptibility. Weather stations distributed across the country measure precipitation, humidity, air pressure, sunshine hours and wind. Based on these weather data, constantly updated and easily understandable models are created by the Plant Protection Warning Service for viticulture, orcharding, arable farming and horticulture and processed in graphs.
For example, -
In viticulture, *Peronospora* and Oidium pressure are calculated from the parameter's humidity and atmospheric pressure.
In orchards, there are very good forecasting models for the bacterial disease fire blight (precipitation, blossom stage) and the fungal disease scab (all climatic parameters, previous year's infestation, variety). For many other diseases, a risk can be well estimated: the fungal curl disease has its germination window in the bud stage and must be controlled at this time. Bacterioses such as *Pseudomonas* occur after frost (microcracks) or after leaf fall (wounds).
For arable crops prediction models particularly for cereal diseases such as rust fungus, powdery mildew, and *Septoria*, among others, are available. Pre-harvest monitoring and early warning systems for mycotoxins in cereals and maize enable crop quality to be assured through timely herbicide application. For powdery mildew diseases other than in cereals, good empirical data on the temperature-humidity combination are available. For potato, recommendations for optimal late blight (*Phytophthora*) control can be calculated.
In addition, for certain diseases, computer programs have been developed for farmers that use weather data to show scenarios for infestation development. Crop- and country-specific technical literature is also available.

4.2.2 Typical symptoms caused by bacteria, fungi, viruses

The signs of diseases are called symptoms.
Symptoms can be local - occurring on individual plant parts - or can affect the entire plant (systemic). Local symptoms include physiological changes in plant structure such as leaf spots and proliferation. Systemic changes manifest as discoloration (e.g., yellowing) or growth changes (compression, broom growth).
Symptoms may be primary or secondary regarding their mode of action. Primary symptoms are directly due to the interaction of the pathogen with plant tissue (proliferation). Secondary symptoms are a result of the pathogen's activity. Parts of the plant or the entire plant are affected. An example is wilting of the entire plant due to obstruction of the conduits in the roots by soil-borne fungi in horticulture (*Verticillium*, *Fusarium*).
Symptoms can be microscopic or macroscopic. While microscopic changes are identified by specialists under the microscope, macroscopic symptoms are readily identifiable during visual crop inspection (Table 4.1.).

Table 4.1 Typical macroscopic symptoms caused by bacteria, fungi, viruses (rough symptom classification)

Pathogen group overview			
Symptoms	Pathogen / Scientific name of the disease	Transfermode of the disease/ Note	Examples
Local: fungal lawns, fruiting bodies and pustules, leaf spots, discoloration. Systemic: wilt, dieback	Fungi Mycosis	by wind and water (splashing) Pay attention to warning services!	Powdery mildew, downy mildew, *Fusarium*, *Botrytis* Viticulture: Oidium, Esca, *Peronospora* Orchards: pear rust, monilia, scab Arable crops: *Phytophthora, Septoria*, Rust Horticulture: *Rhizoctonia, Verticillium, Phytium, Alternaria*
Local: Leaf spots, galls, ulcers, tumors, slimy oozing. Systemic: Wilt, dieback	Bacteria and phytoplasmas Bacteriosis Phytoplasmosis	by wind, water, vectors and contaminated work equipment. Observe forecast models and climate data	Viticulture: bacterial leaf spot, mildew, Orchards: fire blight, pear decay, curl disease Arable crops: *Erwinia, Streptomyces*, Stolbur, stone blight, bacterial blight, tuber blight Horticulture: Clavibacter bacterial wilt
Local: chlorotic spots, rings, necroses Systemic: dwarfism, stunted growth,	Virus Virosis	by vectors (aphid, cicada, beetles, fringed aphids, nematodes), contaminated plant material (rootstock, pollen, seeds, tubers), and contaminated implements,	Viticulture: grapevine fanleaf virus (GFLV) Orchards: apple mosaic virus (ApMV), sharka virus, broomrape, bark canker

yellowing, wilting, death			Arable crops: Potato leafroll virus (PLRV), Pea necrotic yellow dwarf virus (PNYDV) Horticulture: Tomato spotted wilt virus (TSWV), Cucurbit aphid-borne yellows virus (CABYV)

Pay attention to warning services!

Table 4.2 Symptom description of the most important/frequent pathogens in viticulture

<table>
<tr><th colspan="2">Early symptoms</th><th colspan="2">Late stage and other associated symptoms</th><th>Pathogen</th></tr>
<tr><td>Rough symptom classification and example picture showing typical symptoms</td><td>Description</td><td>Rough symptom classification</td><td>Description</td><td></td></tr>
<tr><td rowspan="3">Leaf spots

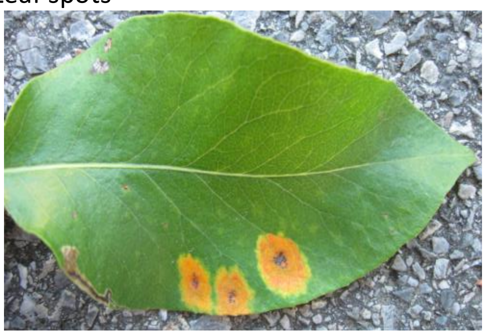
Figure 4.1 Example leaf spots (© biohelp)</td><td>Bright spots on top of leaves that appear dark when backlit</td><td rowspan="2">Fungal lawn</td><td>Whitish gray fungal lawn on underside of leaves</td><td>Fungus:
Downy mildew (Peronosporales):
Peronospora</td></tr>
<tr><td>Brown spots on leaf, flower or fruit</td><td>Superficial gray coating; spreading to the whole plant</td><td>Fungus:
Gray mold rot:
Botrytis</td></tr>
<tr><td>Chronic:
Irregular yellow spots between leaf veins</td><td>Death</td><td>Leaf necrosis

Acute:
Death of the plant</td><td>Fungus:
Esca (fungi complex)</td></tr>
<tr><td>powdery cover

Figure 4.2 Example powdery cover (© biohelp)</td><td>Whitish-gray fungal lawn on lower leaf surface. Later like powdery white lawn "powdery mildew" on the upper side of the leaf.</td><td>Fungal lawn</td><td>Infestation of the previous year: Oidium figures on 2-year-old wood (extensor-shot).
First symptoms of infestation on pointer shoots (= infected stingy shoots),
Infestation of the grape: fungal edge on ridges (stems) spreads from there over the berries, seed breakage as a consequence.</td><td>Fungus:
Powdery mildew:
Oidium (*Erysiphe necator*)</td></tr>
</table>

Discoloration and growth deformation  **Figure 4.3** Example discoloration and growth deformation (© A. Eppler, Justus-Liebig Universität, Bugwood.org)	delayed budding in spring, partial or complete yellow discoloration of the leaf blade, various leaf deformations, shortened internodes and zigzag growth.		Weak growth, scimitar, broom growth; changes and abnormal branching of the vine wood, small berries and increased trickling.	Virus: Grapevine fanleaf virus + Arabis mosaic virus
	The oldest leaves curl downward, at the same time the leaf blades begin to turn yellow (white wine varieties) or dark red (red wine varieties) from the edges.		In the final stage, only the main veins with their fringes remain green; symptom continuation along the shoots. Growth depression; increased trickling of the shoots.	Virus: Grapevine leafroll virus GLRaV 1+3
	Light coloration of leaf veins in young leaves.		Mosaic-like patterns on older leaves, curvature.	Virus: Marbling of the vine (Grapevine fleck virus GFkV)
	Growth deformation: crippled shoots, shortened internodes, deformed, chlorotic leaf spots.		Reduction quality and quantity of the yield.	Virus: Ruländer disease (Grapevine Pinot gris virus)
	Stem and branch changes			Virus: Wood rot, corky bark disease (Grapevine virus A + B)

Table 4.3 Symptom description of the most important/frequent pathogens in orchards

Early symptoms		Late stage and other associated symptoms		Pathogen	Culture
Rough symptom classification and example picture showing typical symptoms	Description	Rough symptom classification	Description		
Leaf spots  **Figure 4.4** Example leaf spots (© biohelp)	Bright spots on the top of the leaf	Fungal lawn	White fungal lawn mostly on top of leaves - can be easily wiped off; spread to all parts of plant; stunted growth, brown discoloration and drying of leaves/plant.	Fungus: Powdery mildew (Erysiphiaceae)	orchards
	Bright spots on top of leaves that appear dark when backlit.	Fungal lawn	Whitish gray fungal lawn on underside of leaves.	Fungus: Downy mildew (Peronosporales) - species group!	orchards
	Brown spots on leaf, flower or fruit.	Fungal lawn	Superficial gray coating; spreading to the whole plant.	Fungus: Gray mold rot (*Botrytis cinerea*)	orchards (strawberry)
	Rust colored spots	Pustules	Pustules on leaves, breaking open pustule-shaped spore deposits; death of plant parts.	Fungus: Rust fungi (Pucciniales)	Apple, pear, plum
	dull olive green, later brown or humped blackish spots on leaves	Necroses	Coalescence of spots, necrosis, leaf fall, cracked corked fruit skin.	Fungus: Scab (Venturiaceae) Apple scab (*Venturia inaequalis*)	apple

	Small, angular, watery spots bordered by the leaf veins, appearing translucent in backlight and black in incident light.	Mucus secretion and death	Symptom spread to whole leaf, leaf dieback, mucus discharge.	Bacterium: Strawberry leaf spot disease (*Xanthomonas fragariae*)	strawberry
	Shot-like, translucent symptoms with yellowish border.	Lesions	Grooved, sunken, black-red lesions on bark of trunk and branches.	Bacterium: Bacterial fire (*Pseudomonas syringae* pv. *morsprunorum*)	Stone fruit (plum, cherry)
Discoloration and growth deformation  **Figure 4.5** Example discoloration and growth deformation (© biohelp)	Curling and blistering of young leaves with partial red discoloration.		Severe curling of leaves, chlorosis; reduction of fruit.	Fungus: Curl disease (*Taphrina deformans*)	Peach, Nectarine
	brown/black coloration and wilting from the petiole, bending of the shoot tips.	Mucus secretion and death	Leakage of bacterial slime, death of the plant between a few weeks (young plants) and a few years.	Bacterium: Fire blight (*Erwinia amylovora*)	Pome fruit
	Premature sprouting, chlorotic leaf rolling.		Early leaf drop, Necrosis of phloem, Abnormal fruit development and early fruit drop.	Phytoplasma: European Stone Fruit Yellows (ESFY, Candidatus phytoplasma prunorum)	Stone fruit
	Early shoots with red leaf tips, stipules enlarged		Autumn color already in summer, broom-like branching of one-year-old shoots "witches broom".	Phytoplasma: Apple shoot blight (Candidatus phytoplasma timesi)	apple

	spots, ring spots (leaf, fruit, core), broom growth			Virus: E.g.: Cherry: 100e viruses, Raspberry 280 viruses	orchards
Wilt  **Figure 4.6** Example wilt (© biohelp)	Shoot tip dieback		Gum flow; fruits turn brown, dry up and show white fruit bodies.	Fungus: Monilia (*Monilinia* spp.)	orchards
	Withered leaves	death	Death of the entire plant.	Fungus; soilborne: Verticillium wilt (*V. dahliae*)	Raspberry, Strawberry, cherry

Table 4.4 Symptom description of the most important/common pathogens in arable crops

Early symptoms		**Late stage and other associated symptoms**		**Pathogen**	**Culture**
Rough symptom classification and example picture showing typical symptoms	Description	Rough symptom classification	Description		
Leaf spots  **Figure 4.7** Example leaf spots (© Penn State Department of Plant Pathology & Environmental Microbiology Archives, Penn State University, Bugwood.org)	Bright spots on the top of the leaf	Fungal lawn	White fungal lawn mostly on top of leaves - can be easily wiped off; spread to all parts of plant; stunted growth, brown discoloration and drying of leaves/plant.	Fungus: Powdery mildew (Erysiphiaceae)	Arable farming
	Brown irregular spots on leaves	Fungal lawn	Brown spots on stems and fruits; White-gray fungal lawn on underside of leaves; Rotting or withering of leaves, rotting of fruits and tubers.	Fungus: Downy mildew: Late blight; late blight (*Phytophthora infestans*)	Tomato, potato
	Brown spots on leaf, flower or fruit	Fungal lawn	Superficial gray coating; spreading to the whole plant.	Botrytis, gray mould (*Botrytis cineraria, B. fuckeliana*)	Arable farming
	Rust colored spots and pustules on leaves	Pustules	Breaking open pustule-shaped spore deposits; death of plant parts.	Fungus: Rust fungi (Pucciniales)	Cereal, asparagus, bean, pea, leek

 **Figure 4.8** Example leaf spots (© biohelp)	oval, yellow-green, chlorotic spots on the lower leaves	Necroses	Gray-green streaky necrosis, leaf drought, black fruiting bodies on upper and lower leaf surfaces.	Fungus: Septoria leaf drought (*Septoria tritici*)	Cereals
Wilt  **Figure 4.9** Example wilt (© Howard F. Schwartz, Colorado State University, Bugwood.org)	Fading and/or wilting of leaves or fruit clusters.	spore covering	Grape Spike and orange coloration of lemmas due to spore coatings in cereals; yield reduction.	Fungus; soilborne: Spike fusariosis and stem and cob rot (Nectriaceae) - narrower species group of *Fusarium* wilt.	Cereals, corn
	Withered leaves	death	Death of the entire plant.	Fungus; soilborne: Verticillium wilt (*V. dahliae, V. longisporum* on cabbage)	Sugar beet, hops, sunflower, Peas, beans, cabbage
	Withered leaves	death	Death of the entire plant.	Fungus; soilborne:	Onion, cabbage,

				Fusarium wilt (Nectriaceae)	spinach, cucumber, pea, bean
	Necrosis and strangulation of seedlings, wilting symptoms.	death	Overturning of seedlings, death of above- and below-ground plant parts.	Fungus; soilborne: *Rhizoctonia* falling sickness, stem rot (*R. solani*, *R.* sp.), beet rot (*R. solani* AG 2-2)	Arable farming
Discoloration and growth deformation  **Figure 4.10** Example discoloration and growth deformation (© Howard F. Schwartz, Colorado State University, Bugwood.org)	white stem base (whitelessness), curling of the top leaves		Air nodules, nodule deformation, Dry core.	Fungus; soilborne: *Rhizoctonia* (R. solani AG 3)	Potato
	chocolate-brown necroses on the leaves (drought spots, spray spots)	Necroses	Coalescence of necroses, destruction of leaf mass, partial stains on stems.	Fungus; soilborne: *Alternaria*, drought spot disease and spray spot disease (*Alternaria* sp.)	Cereals, potato
Growth deformation  **Figure 4.11** Example growth deformation (© Central Science Laboratory, Harpenden , British Crown, Bugwood.org)	Cauliflower-like cell growths on the tuber	Spore covering	Black spore powder from growths; yield loss, crop failure.	Bacterium: Potato canker (*Synchytrium endobioticum*)	Potato

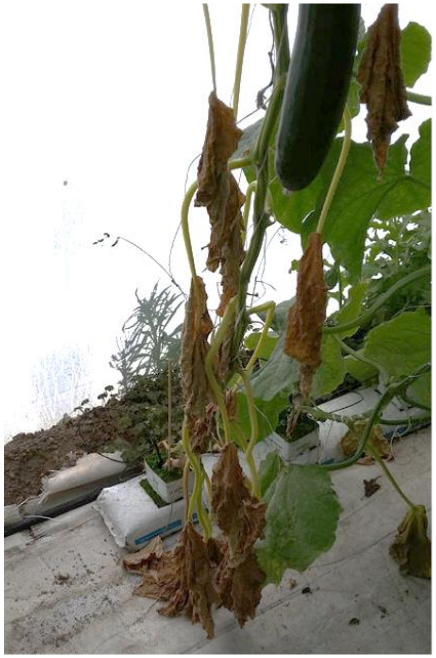
Smell  **Figure 4.12** Example smell (© Howard F. Schwartz, Colorado State University, Bugwood.org)	Fishy odor in wheat and barley	Spore covering	Instead of spikes, black-brown spore deposits are formed.	Fungus: Stone blight (*Tilletia* spp.), flying blight (*Ustilago* spp.)	Cereals
Rot  **Figure 4.13** Example rot (© Howard F. Schwartz, Colorado State University, Bugwood.org)	Muddy, slimy rot on tuber, turnip or stem, unpleasant odor	death	Complete rotting of the tuber in storage.	Bacterium: Bacterial, tuber wet rot, soft rot, blackleg of potato (*Pectobacterium carotovorum*)	Potato, carrot, cabbage, celery

Discoloration and growth deformation  **Figure 4.14** Example discoloration and growth deformation (© biohelp)	Leaf yellowing, dwarfism, leaf deformation and curled leaves.	Necroses	Necrosis, dieback	Virus: Nanoviren; Pea necrotic yellow dwarf virus (PNYDV)	Native legumes. alfalfa and soybean not affected!
	Discoloration, necrotic spots on leaf and stem.		Flesh discolored such brown.	Stem blotch disease/iron spot (potato), turnip blotch (beet; tobacco rattle virus TRV)	Potato

Table 4.5 Symptom description of the most important/common pathogens in horticulture

Early symptoms		Late stage and other associated symptoms		Pathogen	Culture
Rough symptom classification and example picture showing typical symptoms	Description	Rough symptom classification	Description		
Leaf spots  **Figure 4.15** Example leaf spots (© biohelp)	Bright spots on the top of the leaf	Fungal lawn	White fungal lawn mostly on top of leaves - can be easily wiped off; spread to all parts of plant; stunted growth, brown discoloration and drying of leaves/plant.	Fungus: Powdery mildew (Erysiphiaceae)	Horticulture
	Bright spots on top of leaves that appear dark when backlit	Fungal lawn	Whitish gray fungal lawn on underside of leaves.	Fungus: Downy mildew (Peronosporales) - species group!	Horticulture
	Brown irregular spots on leaves	Fungal lawn	Brown spots on stems and fruits; White-gray fungal lawn on underside of leaves; Rotting or withering of leaves, rotting of fruits.	Fungus: Late blight (*Phytophthora infestans*) - type of downy mildew!	Tomatoe

 **Figure 4.16** Example leaf spots (© biohelp)	Brown spots on leaf, flower or fruit	Fungal lawn	Superficial gray coating; spreading to the whole plant.	Fungus: Gray mold rot (*Botrytis cinerea*)	Strawberry, Cucumber
	Yellowish, blurred brightenings on the upper side of the leaf	Fungal lawn	Patches of gray-brown to olive-green mycelial coating on the underside of leaves.	Fungus: Velvet spot (*Cladosporium fulvum* syn. *Passalora fulva*)	Tomatoe
	slight lightening of the veins, faintly visible concentric rings on the leaf, stem and fruit. Depending on the variety, the color and shape of the spots differ	growth deformation	Fruit deformation	Virus: Tomato spotted wilt virus (TSWV)	Tomato, bell pepper
Discoloration and growth deformation 	Older leaves become chlorotic, leaf thickening and brittle leaves.		Entire plant may become chlorotic, Reduced fruit set, Fruit shedding.	Virus: Cucurbit aphid-borne yellows virus (CABYV)	Horticulture

Figure 4.17 Example discoloration and growth deformation (© biohelp)					
Wilt  **Figure 4.18** Example wilt (© biohelp)	Withered leaves	Death	Death of the entire plant.	Fungus; soilborne: *Verticillium* wilt (*V. dahliae*)	Cucumber, tomato
	Withered leaves	Death	Death of the entire plant.	Fungus; soilborne: *Fusarium* wilt (Nectriaceae)	Cucumber, tomato
	Discoloration and strangulation of seedlings and young plants at the root neck.	Death	Death of the entire plant.	Fungus; soilborne: *Pythium* root rot (*Pythium* sp.)	Horticulture
	Necrosis and strangulation of seedlings, wilting symptoms.	Death	Overturning of seedlings, death of above- and below-ground plant parts.	Fungus; soilborne: *Rhizoctonia* falling sickness stem rot (*R. solani, R*. sp.)	Horticulture
	Leaf parts wilting	Death	Dieback of plant parts, bird's eye spots on fruits.	Bacterium: Bacterial wilt (*Clavibacter michiganensis*)	Tomato, bell pepper

Revision questions

1. Typical macroscopic visible symptoms of fungal attack. (Choose the right option/s)

a) Leaf spots
b) Powdery cover
c) Cancer
d) Rusty pustules
e) Slimy oozing

2. Typical macroscopic visible symptoms of bacterial attack. (Choose the right option/s)

f) Slimy oozing
g) Powdery cover
h) Cancer
i) Leaf spots
j) Leaf wilt

3. Typical macroscopic visible symptoms of viral attack. (Choose the right option/s)

a) Stunned growth
b) Rusty pustules
c) Chlorosis
d) Ring spots
e) Wilt

4. Name the transfer modes of diseases excluding those that can be prevented with hygienic measures and healthy plant material. (Make an "x" in the cell to mark the mode)

Disease	Transfermode		
	Wind	Water	Vector
mycosis			
bacteriosis			
virosis			

5. When monitoring diseases in the field you have to assess: (Choose the right options)

a) Percent of plants infested
b) Percent of plant tissue infested
c) Pistribution pattern in the field
d) Pathogen genetic material

6. Choose appropriate terms concerning early detection of diseases (Choose the right option/s)

a) Symptoms not visible
b) Random sampling
c) Laboratory analysis
d) PCR test
e) Branch cage
f) Microscope

7. **The forecast model for the fungal disease scab in orchards is based on the following parameters: (Choose the right option/s)**

   a) Climatic parameters
   b) Previous year infestation
   c) Variety
   d) Crop rotation
   e) Blossom stage

8. **Chose the right symptom categories in regard to the mode of action of pathogens.**

   a) Local
   b) Primary
   c) Macroscopic
   d) Systemic
   e) Secondary

9. **Typical local symptoms of pathogen action are: (Choose the right options)**

   a) Leaf spots
   b) Discoloration
   c) Pustules
   d) Compression
   e) Proliferation

10. **Typical macroscopic symptoms of pathogen action are: (Choose the right options)**

   a) Necrotic leaf spots
   b) Germinating spores
   c) Wilt
   d) Compression
   e) Hyphae

4.3 Direct control measures

Learning outcomes

- Present advantages and disadvantages of various methods and products for disease control.
- Chose appropriate methods and products for disease control under specific conditions of agricultural production.
- Select and recommend appropriate methods and products to keep the spread of the disease below the economic threshold.

4.3.1 Plant protection products including microorganisms

In principle, all fungicidal, bacteriocidal and viricidal products are used preventively in organic farming and are contact agents. The only exception is applications in the form of curative stop sprays on germinating fungal spores. Particularly important are the correct spray timing, as well as the formulation of the active ingredients, good distribution of the spray broth, and good adhesion with good rainfastness.

The optimal spray timing is determined with the help of monitoring and warning service messages. Sprays are made at the prescribed minimum intervals. In case of heavy new growth or after wash-off due to rainfall, the spray coating must be renewed.

The formulation of the active ingredient plays an essential role in the effectiveness of the crop protection product. For example, copper formulated as copper hydroxide shows the fastest action with good long-term efficacy and plant tolerance. Other copper formulations have a slower effect with very good long-term efficacy or plant compatibility. Here, individual decisions must be made according to need and crop. To achieve good distribution, it is important to choose the right nozzle setting. For example, in viticulture and orchards, the lowest nozzle must be directed upward to ensure complete wetting of the underside of the leaves. Applied in this way, a copper application against *Peronospora* in viticulture also protects against spore transfer by splashing (spores are catapulted from the ground to the lowest leaf layer during rain). Additives such as wetting agents and stickers ensure good distribution and adhesion (e.g. alcohol ethoxylate/Wetcit®). In addition, these additives increase the spray droplets enormously. Thanks to the optimized spray coating, the spraying intervals can be extended and thus crop protection agents can be reduced.

To improve the crop tolerance of aggressive crop protection agents, such as copper products, plant strengthening agents in the form of algae extracts (*Ascophyllum nodosum*; AlgoVital®Plus) are available, for example. They reduce the risk of burning and russeting.

To protect the seed, seed treatment is applied against emergence diseases. It can be applied dry, wet, or in the form of a suspension.

To maintain foliage health in permanent crops, sprays are also useful after harvest: e.g. 1-3 treatments with copper and sulfur for early varieties in fruit growing.

By groups of active ingredients fungicides, bactericides and viricides can be divided into the following groups:
I organic/ biological products
I.I. living microorganism strains of fungi, bacteria, and viruses
I.II. components of dead microorganisms: yeast fungi
II. inorganic products: copper, sulfur, sulfuric lime, potassium hydrogen carbonate

Organic/biological fungicides, bactericides and viricides

Living microorganisms can prevent pathogen infestations in the form of plant protection products. Fungi as well as bacteria and viruses fall under this category.

Living microorganisms as plant protection products may either have a direct killing effect, an antagonistic effect, a resistant inducing effect or their secondary metabolites have antibiotic properties.

Live fungi as plant protection agents

For example, the hypoparasitic fungus *Ampelomyces quisqualis* (AQ 10® WG) protects strawberry, cucurbit, and nightshade plants against powdery mildew. The also hyperparasitic fungus *Coniothyrium minitans* (Contans® WG) is used in arable and vegetable crops against white stem disease and stem rot (*Sclerotinia sclerotiorum, Sclerotinia* sp.). The antagonistic fungus *Gliocladium catenulatum* (Prestop®) is a product available for protected vegetable production for limited protection against soil-borne pathogens such as *Fusarium*, *Pythium* and *Rhizoctonia*. The yeast-like fungus *Aureobasidium pullulans* (Blossom Protect™, Botector®) is used in orchards. It colonizes the stigma and nectaries of the blossom and thus protects against fire blight infection. In fruit, wine and vegetable growing, *A. pullulans* is also used against gray rot (*Botrytis*) and fungal storage rot (Monilia*, Botrytis*). The fungus *Trichoderma atroviride* (Vintec®) acts as an antagonist in wound treatment in viticulture to prevent the penetration of ESCA pathogens. *Trichoderma asperellum* provides conditional protection against *Sclerotinia* and *Fusarium* in arable crops.

Live bacteria as a plant protection agent

The bacterium *Pseudomonas chlororaphis* (Cedomon, Cerall) is available against cereal diseases (*Tilletia, Fusarium, Septoria*). Another member of the genus *Pseudomonas* (Proradix®) reduces *Rhizoctonia solani* infestation in potatoes. The bacterium *Bacillus amyloliquefaciens* (Serenade® ASO) reduces fungal and bacterial diseases in fruit, vegetables, and arable crops (fungi: *Botrytis, Alternaria, Sclerotinia,* Monilia, powdery mildew; soil-borne fungi: *Phytophthora, Rhizoctonia*, bacteria: Fire blight, *Pseudomonas, Xanthomonas, Clavibacter*).

Live viruses as plant protection agents

Against viral diseases, there is the possibility of an inoculation strategy to reduce infestation with a weak viral variant to protect against the more potent form that is dangerous to the crop. This method is available, for example, for Pepinomosaic virus (PepMV) in horticulture (V10, PMV®-01).

Components of dead microorganisms

As components of dead microorganisms, the active ingredient Cerevisan (Romeo®) consists of cell walls of the yeast *Saccharomyces cerevisiae*. These are composed of lipids, proteins and polysaccharides and show limited efficacy against fungal diseases (powdery and downy mildew, gray mold) in vegetable crops and strawberries.

Inorganic fungicides, bactericides and viricides

Within the category of inorganic pesticides, copper and sulfur products are among the oldest fungicides.
In the case of copper - in contrast to the compounds used in the past (sulfates, oxychlorides) - the modern copper formulations (hydroxides: Cuprozin® progress, Funguran® progress) achieves better efficacy with significantly lower pure copper quantities. Copper products have a very broad spectrum of activity as fungicide and bactericide (e.g.: Viticulture: *Peronospora*, Orchards: Monilia, Horticulture: *Phytophthora*, Arable: downy mildew, *Cercospora* leaf spot disease). Only against powdery mildew fungi they are ineffective. The application is always preventive and exclusively on dry foliage. Complete wetting of the plant parts to be protected (upper and lower leaf surfaces) is a precondition for good efficacy of the pure contact fungicide.

Net Sulfur (Netzschwefel Stullen, Kumulus®, Thiovit Jet®) has a good effect against powdery mildew fungi as well as a side effect on many fungal diseases (scab, shot, ...), but no effect against Monilia. Net sulfur acts as a contact fungicide and via the vapor phase by releasing sulfur dioxide. The best effect is achieved at temperatures between 15 and 28°C. Below 12°C, net sulfur is ineffective; above 28°C, there is a risk of sunburn or leaf scorch. The dose must therefore be adjusted to the weather. Net sulfur can be sprayed on dry and wet foliage, depending on the mixing partner. A wetting agent additive is recommended (Helioterpen® Film) when applied to dry foliage, Cocana® when applied to wet foliage). In viticulture it is used for Oidium budburst spraying.

Lime Sulfur (Curatio®) is a very broad-acting and powerful broad-spectrum fungicide and bactericide. After application, hydrogen sulfide is released, which is responsible for the good efficacy on the one hand, and for the strong odor (rotten eggs) for a few hours after application on the other. By far the best effect is achieved by application into the ongoing infection on wet foliage (immediately after rain, on the germinating fungal spores) (= stop spraying). Preventive spraying on dry foliage is possible, but much less effective, as the hydrogen sulfide has evaporated by the time the infection occurs. The preventive foliar effect is comparable to that of simple net sulfur. Advantageously, with sulfuric lime there is a possibility to react to unforeseen infection events retroactively (for a limited time! Depending on temperature and disease 12-36 h). Even after very long or heavy rainfall, which washed off an existing fungicide coating, infection can be prevented with sulfuric lime.

With bicarbonate (=potassium hydrogen carbonate) the ph-value on the plant surface is raised. Fungi need it slightly acidic and therefore feel less comfortable. Bicarbonate has a dehydrating effect and ionic action on the cell walls of the fungal hyphae (mycelium). The cell walls of the germinating spores burst open and dry out. This purely physico-chemical mechanism of action cannot lead to resistance and the dosage can be safely adjusted to a beneficial use if necessary. Products available are VitiSan® (viticulture: highly effective against Oidium) and Kumar® (incl. formulation adjuvants, good rainfastness, poor plant tolerance). VitiSan® has the additional advantage of free choice of formulation adjuvants. It can be applied on wet foliage. In principle, for all fruit crops, copper and sulfur should be applied in the pre-flowering period until "red buds" and bicarbonate from flowering onwards.
Bicarbonate is applied in orchards against Monilia in stone fruit, *Botrytis* in soft fruit (Kumar®) and rain spot; In Horticulture against powdery mildew and velvet spot.
Copper, sulfur and bicarbonates and most foliar fertilizers are miscible.

Table 4.6 Mixtures and application alternatives

Crop and disease	Copper	Net sulfur	Lime sulfur	Bicarbonate	Organic PPP
Viticulture					
Oidium		x		x	
Orchards					
Scab (apple)	x	x	x	x	
Powdery mildew (apple)		x	x	x	
Marssonia (apple)	x		x		
Rain spots (apple)		x	x	x	
Fire blight (apple, pear, ...)	x		x (only etching effect)		Blossom protect™
Monilia	x	x	x	x	Prestop®, Serenade® ASO
Cherry leaf spot (cherry)	x	x	x	x	
Leaf curl disease (peach, nectarine)	x	x			
Shothole disease	x	x	x	x	
Arable farming					
Powdery mildew (sugar beet, onion)		x		x	
Horticulture					

Botrytis				x	Prestop®
Pythium	x				Prestop®

4.3.2 Physical methods for disease control

As a physical method, trunk/white coating against frost cracks is used in fruit growing to prevent entry points for diseases.

4.3.3 Mechanical methods for disease control

Mechanical methods available in principle are desinfection, pruning, foliage management and protection systems. The prerequisite is that the planting material is disease-free and the working tools for grafting, pruning, or planting are disinfected and clean.

Desinfection can prevent or minimize further spread of infection in soil as well as seed and plants. Seeds can be desinfected with a hot water treatment. In horticulture and arable farming, the risk from soil-borne fungi (e.g.: *Verticillium* sp.) is particularly high. In addition to a long crop rotation, steaming and scorching are used. In addition, for example, in onions to control downy mildew, the flaming device is set higher to burn the fungal spores directly on the plant by heat development.

In addition to increasing the yield, fungal diseases are minimized by targeted pruning and foliage management. Pruning is done only in dry weather. Pruning activities in rainy weather should be avoided because of optimal conditions for pathogens to penetrate the fresh wounds!
In viticulture, foliage management involves defoliation of the grape zone already during flowering. Foliage removal is carried out by means of leaf suckers and/or leaf shooters, which suck or shoot the leaves out of the grape zone (thus there is no danger for blossoms or young grapes!). Pay attention to the weather! Low humidity!). This, in addition to acclimatization of the vine to UV radiation, enables faster drying of the remaining leaves through good aeration. Infection with fungal diseases such as Peronospora and Oidium is thus minimized (*Peronospora* needs a water film for infection; Oidium needs moist and warm conditions for infection). Pruning of the shoot tips should be done as late as possible, otherwise a lot of new stingy shoots will form and the risk of the grape zone becoming overgrown is increased. Early summiting also gives too early an impulse for fruit to be formed. The result is dense berry growth (desirable: loose berry) and fruit bursting. As soon as berries stick together and especially when it rains shortly before harvest, there is a danger of *Botrytis*. In orchards, targeted summer pruning reduces the foliage mass and promotes aeration. In arable farming, flailing and harrowing are used to remove diseased plant parts or to strengthen the resistance of certain plant parts. For example, the foliage of potatoes is killed by harrowing about three weeks before harvesting to prevent the pathogen that causes late blight (*Phytophthora infestans*) from spreading from the infected potato foliage to the tubers. In addition, in potatoes, harrowing thickens the skin of the tubers, making them more resistant to pathogens. In cereals, harrowing removes diseased, old leaves.

Protection systems

Protective netting, in addition to animal damage, keeps vineyards and orchards safe from weather events such as hail and heavy rain. Injuries from hail would provide pathogens (e.g. *Botrytis*, *Pseudomonas*) with optimal infection sites. Mitigated rainfall reduces the risk of splashing (e.g. *Botrytis*).
In horticulture, shading compensates for temperature fluctuations and suppresses powdery mildew. Soil cover in the form of foil or straw prevents the transfer of pathogens from soil to crop. In strawberry

cultivation, the classic straw covering at the beginning of flowering prevents the fruit from becoming dirty and prevents fungal attack by *Botrytis cinerea* gray rot.

4.3.4 Hygienic measures

Hygiene measures aim to prevent the introduction of a disease into the crop or to minimize and - in the best case - eradicate it. This can be achieved by targeted pruning, which removes old and diseased plant parts, as well as by crop residue hygiene or by preventing the spread of diseases and vectors.

To prevent the introduction of a disease, healthy and certified planting and sowing material is of utmost importance. Especially with strawberries, young plant quality is extremely important and the introduction of diseases such as *Phytophthora cactori* var. *fragaria* should be avoided at all costs. But it is also important to keep disease-introducing vectors, such as insects, away from the crop. In viticulture, the spread of grapevine cicada and *Phylloxera* by humans from vineyard to vineyard (infectious from L5) must be avoided to prevent secondary infections by bacteria, fungi and viruses.

Preventing the spread of disease: If parts of a crop or the entire crop are affected by a disease, pruning of diseased plant parts, grubbing and disposal or burning of individual plants or the entire crop and/or appropriate crop residue and fallen leaf management will help. Special attention should be paid to notifiable quarantine diseases.
In viticulture, for example, plants affected by flavescence doree (golden yellowing) must be grubbed up to prevent transmission by grapevine cicada to other plants. Grapevines showing the disease complex Esca must also be either grubbed or tried to be cured by special grapevine surgery techniques under development. In orchards, complete harvesting is important. Pruning must always be done into the healthy wood. Injuries must be avoided, as they are entry points for diseases. Diseased material is removed after pruning and from the plant and burned if necessary. Plants affected by quarantine diseases such as fire blight must be grubbed. Fruit mummies must also be removed and burned to prevent sources of infection for the following year. In addition, foliage removal should be encouraged by tilling, incorporating, spraying with vinasse, and sweeping foliage out of tramlines to suppress virus diseases. While fungal spores, for example, can survive in the substrate for up to 15 years, viruses can only survive in the plant material or host. In arable crops, individual plants must be removed if they are infested with soil-borne fungi such as *Phytophthora* or *Verticillium*. In corn, incorporating stubble into the soil reduces the risk of *Fusarium* stem and tuber rot. In *Rhizoctonia*-infested areas, corn should be avoided in the sugarbeet rotation or corn crop residue should be well chopped and incorporated, as the fungus uses organic matter to survive in the soil. The promotion of good old straw rot should generally be stimulated by multiple flat tillage passes.
In addition, special attention should be paid to keeping equipment clean. If there is a risk of disease spread, it is necessary to clean the equipment or the tractor at the washing station (kärchern, hot water treatment). In horticulture, for example, tomato and bell pepper crops must be uprooted and burned if the notifiable bacterial wilt *Clavibacter* occurs. In general, crop residues must be removed or worked deep into the soil.

Revision questions

1) **In principle, all fungicidal, bacteriocidal and viricidal products are used ________________in organic farming and are ___________ agents. The only exception is applications in the form of ___________ stop sprays on _______________ fungal spores.**

2) **What options do you have to improve the crop tolerance of aggressive crop protection agents, such as copper products and to reduce the risk of burning and russeting (Choose the right option/s)**

   a) Adding plant strengthening agents in the form of algae extracts
   b) Half the concentration of the spray broth
   c) Application of the copper products during rainfall

3) **Living microorganism can prevent infestations in the form of plant protection products. The yeast-like fungus *Aureobasidium pullulans* is used in orchards against fire blight infection. Name the mode of protection. (Choose the right option)**

   a) It colonizes the leaf buds and young leaves.
   b) It colonizes the stigma and nectaries of the blossom.
   c) It colonizes the root tips of the secondary roots.

4) **Possibilities of biological plant protection against viral diseases (Choose the right option)**

   a) Defoliation of the infected part of the plant to reduce virus pressure.
   b) Inoculate a weak variant of the virus to protect the plant against the more potent and dangerous form.
   c) Weekly desinfection of the crop to avoid infection with the virus.

5) **Examples of inorganic fungicides, bactericides and viricides (Choose the right option)**

   a) Copper
   b) Net sulfur
   c) Lime sulfur
   d) Bicarbonate
   e) Strobilurins
   f) Lime
   g) Magnesium

6) **Mechanical methods of disease control (Choose the right options)**

   a) Desinfection
   b) Spraying plant proection products
   c) Pruning
   d) Foliage management
   e) White coating
   f) Hail protection net

7) **Hygienic measures to prevent the introduction of diseases into the crop (Choose the right option/s)**

   a) Vaccinated farmer
   b) Targeted pruning
   c) Healthy and certified planting material
   d) Control of insect vectors
   e) Removal and burning of fruit mummies
   f) Netting

g) Clean equipment

8) Mark active biological ingredient/s against bacterial diseases

a) Bacillus amyloliquefaciens
b) Cell walls of the yeast *Saccharomyces cerevisiae*
c) Lime Sulfur
d) Aureobasidium pullulans
e) Copper
f) Pepinomosaic virus (PepMV V10)

9) A plant virus can survive in (Choose the right option/s)

a) Plant material
b) Vector insect
c) Substrate

10) How can protective netting serve as mechanical control of diseases (Choose the right option/s)

a) Minimize hail injury that provide infection sites for pathogens.
b) Protection against the inflow of fungal spores.
c) Mitigated rainfall reduces the risk of splashing.
d) Minimize animal damage that provide infection sites for pathogens.

5 METHODS AND TOOLS TO MANAGE WEEDS

5.1. Theoretical background

Learning outcomes

- Explain the principle and main objectives of weed management in organic farming.
- Choose the appropriate combination of the preventive/cultural/curative practices for ensurement of effective weed management.
- Select and recommend a system-based, long term weed control strategy.

5.1.1 Principles of weed management in organic farming

One of the most important criteria for organic farming is to control weeds without the use of herbicides. To this end, all other elements of integrated weed control (agrotechnical, physical, mechanical, biological) and the elements of cultivation technology are protected against weeds by using as many elements as possible. The role of local climatic and soil conditions in the development of weeds is increasing compared to conventional farming. Thus, we have to consider with a unique weed flora in each organic farm. The most important principle of ecological weed control is not the destruction of weeds, but to promote the development and competitiveness of the crop with certain elements of cultivation technology at the expense of the weed by utilization of natural resources. The main goal of weed management strategies is to make the crop production system unfavorable to weeds, thus the harmful effect of weeds surviving can be minimized. For implementing effective results, a system-based, long-term weed control strategy is required to develop.

Weed control in organic farming cannot be performed successfully by a single method. Harmony of weed control and agricultural production must be found which does not constitute a step backwards, but represents a better, more advanced technology. Although maintaining weeds within an agricultural system is both harmful and beneficial, the aim of ecological farming is not to eradicate completely the weeds. As in all areas of plant protection, prevention is the most effective in weed control. This includes the use of weed-free, metal-sealed seed; well-treated, weed- and weed-free organic manure and compost; inhibiting the spread of weeds by keeping tillage, plant care and harvesting machines clean.

5.1.2 Knowledge on and importance of positive and negative interaction between crop and weed (background knowledge for further procedures)

The ecological role of weeds can be approached by a different point of view. The most known harmful effects of weeds are to compete with crops for nutrients, water, light and space, to reduce the quality of crops, to increase production costs. However, weeds have some benefits as well. A balanced weed population can provide a favorable microclimate and the roots of the weeds can help to increase the microbiological activity and improve the structure of the soil. Weeds can promote biodiversity. Weeds are a source of nutrients for many insects. Although some of these insects are pests, others can be predators or parasitoids that can contribute to biological plant protection. Complete eradication of weeds can also mean that insects have no choice but to feed on the crop. Weeds can also be considered as indicator plants as they show the disadvantages and benefits of soil (applied nutrient replenishment and tillage).

Weed management objectives

The growth of the world's population requires higher food production, which can be achieved by increasing yields and applying a sustainable approach through responsible use of land and water and increasing food diversity. One of the objectives of integrated weed management is to maintain the weed population below the economic threshold by reducing the focus on eradication strategies and promoting a containment strategy for the potential increase in weed diversity. The ecological role of weeds can be approached by a different point of view. In conventional agricultural practices, weeds are declared as undesirable intruders that reduce crop yields and compete for limited sources. In this perspective, weeds force the usage of large amounts of human effort and technology to prevent even greater crop losses. On the other hand, weeds can be evaluated as beneficial component of agroecosystem that provide services complementing those obtained from crops in the following ways: (i) providing habitat for natural enemies of pests; (ii) reduction of soil erosion; (iii) provision of important sources of animal feed and human medicine; (iv) offering of habitat for game birds and other desirable wildlife species.

From the point of view of plant protection, integrated weed management has three main objectives:

a. Weed density shall be reduced to tolerable levels. Experimental studies describe a rectangular hyperbole for the relationship between crop yield loss and weed density (Figure 5.1). According to this mathematical curve, total elimination of weeds from crops is questionable. The same time, eradication efforts can be expensive and can result in harmful environmental damage and deprives living organisms including humans of ecological services. It is also indicated that this relationship is strongly influenced by various abiotical factors, such as weather and soil conditions. Thus, weed management is desirable rather than eradication.

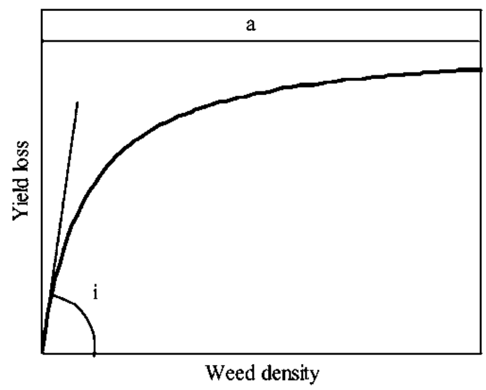


Figure 5.1 Rectangular hyperbola (from Cousens, 1985a) that links the relative yield loss to the density of a weed species. Parameter "I" and "a" represents the initial slope of the curve and the maximum yield loss found with a very high weed density, respectively.

b. Reduction of the damage amount that a given density of weeds inflicts. Crop yield damage caused by weeds can be reduced not only by reducing weed density, but also by minimising the resource consumption, growth, and competitiveness of individual surviving weeds. This can be approached by delaying or accelerating the appearance of weeds compared to the appearance of plants, by increasing the proportion of resources available by plants and damaging weeds with mechanical or biological agents. Accelerate the growth of the weed to control it mechanically or thermally in one step before the crop breaks through.

c. Shift of weed community composition toward less aggressive, easier-to-manage species. Weed species act differently in their relationship with the crops. They differ in the degree of damage and of difficulty they impose on crop management and harvesting procedures. According to this fact, tipping of the weed community composition balance from dominance by noxious species within the agroecosystem toward a preponderance of species that crops can better tolerate is required. This can be performed by suppression (selective and direct) of undesirable species and then avoiding their re-establishment by manipulation of environmental conditions.

It is important to note that the most effective and economical weed control plan always requires several types of approach. In an ideal integrated weed management strategy in organic farming, it is essential to consider the cultural, mechanical, and biological methods contained in the weed management toolbox and each component contributes to the overall level of weed control like several "little hammers". Without this knowledge it is impossible to evaluate the impact of weed control tactics on a given weed population.

Difference between preventive and control (cultural and curative) actions

Weed control in ecological farming means a systematical approach for minimalization of the impact of weeds, optimalization of the cultivation and includes prevention and defense, as well. The ecological concept of "maximum diversification of disturbance" means to diversify crops and agricultural practices in the agro-ecosystem as much as possible in order to develop a long-term effective weed management strategy. This concept results in a constant disturbance of weed ecological niches and hence in a minimized risk of weed flora evolution towards the presence of highly competitive species. Moreover, a cropping system with high diversification reduces the possibility for development of herbicide-resistant weed populations.

Based on ecological concept, a weed management process should integrate preventive (indirect) methods and cultural/curative (direct) methods. Indirect category includes every method applied before a crop is sown (i.e. crop rotation, cover crops, tillage systems, seed bed preparation, soil solarization, management of drainage and irrigation systems and of crop residues), while the second includes any methods used during the crop vegetation cycle (i.e. crop sowing time and spatial arrangement, crop genotype choice, cover crops, intercropping, fertilization). Methods in both categories can influence either weed density (i.e. the number of individuals per unit area) and/or weed development (biomass production and soil cover). However, while indirect methods aim mainly to reduce the numbers of plants emerging in a crop, direct methods also aim to increase crop competitive ability against weeds.

Classification of cultural practices potentially applicable in an integrated weed management system, based on their prevailing effect are summarized in Table 5.1.

Table 5.1 Cultural practices and their effects applied in ecological weed management

Cultural practice	Category	Prevailing effect	Example

Crop rotation	Preventive	Reduction of weed emergence	Alternation between winter and spring-summer crops, alteration between leaf and root vegetables and cereals
Cover crops (green manures, dead mulches)	Preventive	Reduction of weed emergence	Cover crop grown in-between two cash crops
Primary tillage	Preventive	Reduction of weed emergence	Deep ploughing, alternation between ploughing and reduced tillage
Seed bed preparation	Preventive	Reduction of weed emergence	False (stale)-seed bed technique
Soil solarization	Preventive	Reduction of weed emergence	Use of black or transparent films
Irrigation and drainage system	Preventive	Reduction of weed emergence	Irrigation placement (micro/trickle-irrigation), clearance of vegetation growing along ditches
Crop residue management	Preventive	Reduction of weed emergence	Stubble cultivation
Sowing/planting time, crop spatial arrangement	Cultural	Improvement of crop competitive ability	Use of transplants, anticipation or delay of sowing/transplant date
Crop genotype choice	Cultural	Improvement of crop competitive ability	Use of varieties characterised by quick emergence, high growth and soil cover rates in early stages
Cover crops (living mulches)	Cultural	Improvement of crop (canopy) competitive ability	Legume cover crop sown in the inter-row of a row crop
Intercropping	Cultural	Reduction of weed emergence, improvement of crop competitive ability	Intercropped cash crops
Fertilization	Cultural	Reduction of weed emergence, improvement of crop competitive ability	Use of slow nutrient-releasing organic fertilizers and amendments, fertilizer placement, anticipation or delay of pre-sowing or top-dressing N fertilization, nitrogen fixer plants as intercrop
Cultivation	Curative	Killing of existing vegetation, reduction of weed emergence	Post-emergence harrowing or hoeing, ridging
Thermal weed control	Curative	Killing of existing vegetation, reduction of weed emergence	Pre-emergence or localized post-emergence flame-weeding
Biological weed control	Curative	Killing of existing vegetation, reduction of weed emergence	Use of (weed) species-specific pathogens or pests

A common problem concerning non-chemical methods is that effective control needs more frequently repeated treatments than chemical weed management in fact non-chemical tools mainly affect the aboveground part of the plants, whereas systemic herbicides kill the entire plant and therefore only require one or two applications per year. Different factors could affect the frequency of the treatments such as weed species composition, weed cover, weed acceptance level, weed control methods, climate, and type of soil surface. For this reason, the integration of cropping and weed management strategies is vital for the future success of a farming system that relies on non-chemical methods of weed management.

Revision questions

1) What is the mathematical relationship between yield loss and weed density? (Mark the correct answer)

a) Linear
b) Sigmoid
c) Hyperboloid

2) Which one is a preventive cultural practice? (Mark the correct answer)

a) Thermal weed control
b) Cover crops
c) Fertilization

3) The prevailing effect of intercropping technique is: (Mark the correct answer)

a) To reduce the emergence of weed
b) To improve the competitive ability of crop
c) Both a) and b)

4) Which are the main objectives of weed management from the point of view of plant protection? (Mark the correct answer/s)

a) Eliminate all weeds in order to increase crop yield.
b) Weed density shall be reduced to tolerable levels.
c) Shift of weed community composition toward less aggressive, easier-to-manage species.
d) Eradication of weeds is desirable rather than weed management.
e) Reduction of the damage amount that a given density of weeds inflicts.

5) Weeds can be evaluated as beneficial component of agroecosystem, because they (Mark the correct answer/s)

a) Provide habitat for natural enemies of pests
b) Reduce soil erosion
c) Provide a huge amount of human food
d) Offer of habitat for wildlife species
e) Decrease moisture

6) Which factors can affect the frequency of the treatments? (Mark the correct answer/s)

a) Type of plant protection products applied
b) Weed species composition
c) Application rate of fertilizers
d) Weed acceptance level
e) Climate

7) Indicate by T or F if the statement is true (T) or false (F)

a) The most important principle of ecological weed control is the destruction of weeds. _____
b) Weed control in organic farming cannot be performed successfully by a single method. ____

8) Indicate by T or F if the statement is true (T) or false (F)

a) Weed management can be performed easily in ecological farming, because species act in the same way in their relationship with the crops. ______
b) Indirect techniques include every method applied before a crop is sown. ______

9) Indicate by T or F if the statement is true (T) or false (F)

a) Crop rotation is a curative method, where alteration between winter and spring-summer crops, alteration between leaf and root vegetables and cereals are applied. _____
b) Fertilization can improve the competitive ability of crops. _____

10) Indicate by T or F if the statement is true (T) or false (F)?

a) Tipping of the weed community composition balance from dominance toward a preponderance of species that crops can better tolerate is required. _____
b) The ecological concept of minimum diversification of disturbance means to diversify crops and agricultural practices in the agro-ecosystem at low level in order to develop a long-term effective weed management strategy. ___

5.2 Plant protection products for weed control in organic farming

Learning outcomes

- Describe the types of plant protection products allowed to apply in organic farming.
- Choose the appropriate plant protection products for weed control.
- Get knowledge of the legal background of plant protection products in prganic farming.

5.2.1 Non synthetic, natural originated compounds

Some naturally sourced ingredients are allowed for herbicidal use. Currently, however, organic herbicides and herbicides with organic active ingredient play a minor role in the organic weed control. These include certain formulations of acetic acid (concentrated vinegar), Pelargonic acid, corn gluten meal, and essential oils.

Corn gluten meal is applied as a pre-emergent herbicide against crabgrass (*Digitaria* sp.) and other lawn weeds by inhibition of roots formation of weeds. Timing of application is crucial, because if weeds have already germinated and taken roots, corn gluten will serve as fertilizer. It also has nutritional properties with 10 percent nitrogen by weight, thus can be used as organic source of nitrogen. Corn gluten needs water just after application, but a dry period is then required in order to trigger inhibitor effects on root production. The first application will suppress only about 60% of the weed seeds, and a single application may help suppress weeds for 4 to 6 weeks. Heavy soils extended rainy weather and hot spells may require a monthly application or a second application in late summer. After several applications, corn gluten sometimes reaches 80% effectiveness. Application rates vary by form:

powder, pelletized or granulated. The standard application rate is 10 kg of corn gluten per 100 square meters of lawn. This rate also provides about 1 kg of nitrogen per 10 square meters. The effects of corn gluten are cumulative, meaning that the results improve with repeated use over time.
The most prominent weed killing essential oils is clove (*Syzygium aromaticum*), that can be the only oil you apply as a natural weed killer spray. Wintergreen (*Gaultheria fragrantissima*), cinnamon (*Cinnamomum verum*) and summer savory (*Satureja hortensis*) can enhance the weed killer effect of clover.

A few selective herbicides with organic active ingredient based on fungal pathogens have also been developed consisting of phytotoxins, pathogens, and other microbes used as biological weed control. Herbicides with organic active ingredient may be compounds and secondary metabolites derived from microbes such as fungi, bacteria, or protozoa; or phytotoxic plant residues, extracts or single compounds derived from other plant species. On a global scale, only thirteen herbicides with organic active ingredient derived from micro-organisms or natural molecules have been developed. Among the thirteen authorized herbicides of biological origin, nine are based on fungal microorganisms, three on bacterial micro-organisms, and one contains an active substance that is a natural plant extract (Table 5.2).

Table 5.2 Herbicides with organic active ingredient developed for weed management in ecological farming

Product name	Active agent	Weed	Registration	On market
De Vine®	strain MVW of the oomycete *Phytophthora palmivora*	strangler vine (*Morrenia odorata*)	1981, USA	unknown
Collego™ (LockDown)	spores of *Colletotrichum gloeosporioides* 20358 strain	northern jointvetch (*Aeschynomene virginica*)	1982/2006, USA	available
BioMal®	*Colletotrichum gloeosporioides* f.sp. *malvae*	low mallow (*Malva pusilla*)	1992, Canada	available but production limited
Camperico®	*Xanthomonas campestris* strain JTP482	annual meadow grass (*Poa annua*)	1997, Japan	not available
Woad Warrior	fungus *Puccinia thlaspeos*	glastum (*Isatis tinctoria*)	2002, USA	not available
Chontrol®=Ecoclear®	*Chondrostereum purpureum* strain PFC 2139	shoots from black cherry (*Prunus serotina*) stumps canadian poplar (*Populus euramericana*) in the sandy soils of conifer forests	2004/2007	available
Mycotech™	*Chondrostereum purpureum* strain HQ1	shoots from black cherry (*Prunus serotina*) stumps canadian poplar (*Populus euramericana*) in the sandy soils of conifer forests	2004/2007, Canada	not available

Smoulder WP, Smoulder G	*Alternaria destruens* strain 059.	hell-weed species (*Cuscuta* sp.)	2005, USA	available
Sarritor	*Sclerotinia minor* strain IMI 344141	dicot weeds in turf	2007, Canada	available
Organo-Sol® (Kona)	*Lactobacillus casei* strain LPT-111 *L. rhamnosus* strain LPT-21 *L. lactis ssp. lactis* strain LL64/CSL *L. lactis ssp. lactis* strain LL102/CSL *L. lactis ssp. cremoris* strain M11/CSL	white clover (*Trifolium repens*) red clover (*Trifolium pratense*) bird's-foot trefoil (*Lotus corniculatus*) black medick (*Medicago lupulina*) wood sorrel (*Oxalis acetosella*)	2010, Canada	available
Phoma	*Phoma macrostoma* strain 94-44B	dicots	2011, USA and Canada	available
Opportune™	thaxtomin A, a compound that is produced by fermentation from the *Streptomyces acidiscabies* strain RL-110.	dandelion (*Taraxacum officinale*)	2012, USA	available
Beloukha®*	derived from rapeseed oil, using a natural extraction process (nonanoic acid and pelargonic acid)	grapevine to kill suckers and control weeds, and on potatoes to kill stems and leaves.	2015, USA	available

* Allowed in the EU

Herbicides with organic active ingredient could help increase both the efficacy of individual weed control techniques and the overall efficacy of the integrated weed management systems.

Herbal active ingredients

Many biologically active compounds are known to be produced by shoot plants. These compounds are secondary metabolites. Their biosynthesis can be derived from the metabolism of the primary compounds, i.e. they are only secondary in their biosynthesis and not in their significance. Secondary metabolites are end products that are synthesized from different materials in different metabolic pathways. Although attractive and repellent compounds are also found among them, the majority have an effect on living organisms mainly due to their inhibitory (toxic) nature. These secondary compounds can be biochemically diverse.

- thiophenes. Thiophenes are sulfur-containing aromatic compounds. Typical thiophenes are α-tertienyl and butene bitienyl. Both active ingredients can be found in our popular garden ornamental plant, the marigold species (*Tagetes* spp.). Thiophenes are likely to function as toxins in the plant-animal and plant-plant relationships, respectively. Thiophenes show a wide range of biological activity. They act primarily as phototoxins. In addition, their fungicidal, herbicidal and nematode effects are significant.

- coumarins. Coumarins are compounds made up of cinnamic acids. Their simplest structure is coumarin itself, but other coumarins (pyrano- and furanocoumarins) are also known. In plants, coumarins occur mainly as glycosides in sugar-like compounds. Physiologically extremely important compounds. Some coumarins (including coumarin itself) inhibit germination and cell elongation. One hundred times more effective growth inhibitors, such as phenolic acids used in practice.

- mono- and sesquiterpenes. Monoterpenes occur as essential oil components in the plant kingdom. They are found in the largest numbers in the family of lips, rutans and umbrellas. The synthesis of essential oils often takes place in specific cells or glandular hairs. It is known that glandular hairs on the leaf surface can produce and secrete essential oils. The function of essential oils differs from case to case. They have an inhibitory effect on germination and plant growth. For this reason, they are also important in the competition between plant species. This makes them suitable for weed control. Under laboratory conditions, the inhibitory effect of essential oils on the growth of bacteria and fungi was observed.

- triterpenes. Their glycosides are called saponins. Saponins are common in plants as complexes. For example, alfalfa, known as a forage plant, contains 11 saponins in addition to medicinal acid. They accumulate mainly in the leaves and fruits of the plant species concerned.

Table 5.3 Plant species and their parts can be applied in weed management as extract. H- herbicide, I – insecticide, F – fungicide, SD – soil disinfectant

Plant	Typical picture of the genus or the species	Plant part applied	Active ingredient	Biological effect			
				H	I	F	SD
Tagetes sp.	**Figure 5.2** (E. Takács) 	flowering sprout	α-tertiaryl, butene bitienyl	+		+	
Ranunculus sp.	 **Figure 5.3** (M. Ábele)	leaf shoot	ranunculin	+			+
Achillea sp.	 **Figure 5.4** (M. Ábele)	inflorescence, leaf	achillin, anacycline, procamazulene	+			+
Tanacetum vulgare	 **Figure 5.5** (M. Ábele)	flowering sprout	borneol, cineol, isothujon	+	+		+

Prunella sp.	 **Figure 5.6** (M. Ábele)	leaf shoot	ursolic acid	+			
Centaurea sp.	 **Figure 5.7** (M. Ábele)	flowering sprout	centaurepenzin	+			
Calendula officinalis	 **Figure 5.8** (https://www.shutterstock.com)	inflorescence	isorhamnetine	+	+		
Aristolochia sp.	 **Figure 5.9** (M. Ábele)	fruit, rootstock	aristolochic acid	+			+
Mentha sp.	 **Figure 5.10** (M. Ábele)	leaf shoot	limonene, menthol, menton, mentofuran, pulegon	+		+	+
Artemisia sp.	 **Figure 5.11** ((https://www.shutterstock.com)	leaf shoot	absinthin, bisabolene, artemisinin, thujon, cineol, tauremizine	+	+		+

Stachys annua	 **Figure 5.12** (M. Ábele)	flowering sprout	stachydrin	+			
Salvia sp.	 **Figure 5.13** (M. Ábele)	leaf	cineol, cimol	+	+		+

Due to their short duration of action, plant extracts should be used in short-growing crops. Due to the relatively large amount of extract required to achieve the desired weed control effect, it is advisable to use plant extracts in a small area. In our opinion, plant extracts can be well integrated into the tools of organic farming with due care.

Revision questions

1) Which herbicide with organic active ingredient is allowed in the EU? (Mark the correct answer)

a) Woad Warrior
b) Beloukha®
c) Mycotech™

2) Which one is the most prominent weed killing essential oil? (Mark the correct answer)

a) Clover
b) Cinnamon
c) Peppermint

3) What is the herbal active ingredient of *Artemisia* sp.? (Mark the correct answer)

a) Absinthin
b) Limonene
c) Borneol

4) Name this plant: (Mark the correct answer)

a) *Tanacetum vulgare*
b) *Artemisia* sp.
c) *Ranunculus* sp.

5) Which are secondary metabolites of plants? (Mark the correct answer/s)

a) Thiols
b) Thiophenes
c) Triticonazole

d) Triterpenes
e) Terbutylazine

6) Flowering sprout is applied as plant extract in case of (Mark the correct answer/s)

a) *Stachys annua*
b) *Centaurea* sp.
c) *Salvia* sp.
d) *Ranunculus* sp.
e) *Tanacetum vulgare*

7) Which plants have herbicide and soil disinfectants effects, as well? (Mark the correct answer/s)

a) *Tagetes* sp.
b) *Artemisia* sp.
c) *Mentha* sp.
d) *Achillea* sp.

8) Indicate by T or F if the statement is true (T) or false (F)?

a) Some naturally sourced chemicals are allowed for herbicidal use. ____
b) Secondary metabolites are the first compounds in synthesis of different materials in different metabolic pathways. _____

9) Indicate by T or F if the statement is true (T) or false (F)?

a) Only a small amount of extract required to achieve the desired weed control effect. ____
b) On a global scale, thirteen herbicides with organic active ingredient have been developed. ___

10) Indicate by T or F if the statement is true (T) or false (F)?

a) Coumarins are compounds made up of formic acids. ____
b) Glycosides of triterpenes are called saponins. ____

5.3. Mechanical, agrotechnical and biological weed management

Nowadays there are a various number of non-chemical weed control techniques developments. The followings are common techniques available to non-chemical weed management strategies for organic farming.

Learning outcomes

- Explain the difference between direct and indirect weed control practices in organic farming and the different types of methods.
- Choose and recommend the appropriate method for weed control according to the advantages and disadvantage of practices.

5.3.1 Direct weed control

Direct control needs to be linked with long term preventative measures to maintain the weed population at a manageable level.

Thermal weed control

Thermal weed control includes application of fire, flaming, hot water, steam and freezing. These techniques control weeds without disturbing the soil and do not bring the buried seeds to the soil surface. Several factors (i.e. temperature, exposure time, energy input) can influence the effectiveness of thermal control, however many of these methods only kill the shoots of target plants, thus repeated treatments may be necessary to avoid regeneration. Based on mode of action thermal control methods can be divided into three groups: (i) the direct heating methods (flaming/burning, solarization, infrared weeders, hot water, steaming, hot air), (ii) indirect heating methods (electrocution, microwaves, laser radiation, ultra violet light), and (iii) freezing as opposite plant stress factor.

- Flaming/burning. Plant processes can be damaged by high temperature through protein coagulation and denaturation, increase of membrane permeability and enzyme inactivation. The thermal dead point for most plant tissues is 45 - 55°C after prolonged exposure. Effectiveness of procedure is mostly influenced by plant size at treatment time less than density of weed plant. The most tolerant species cannot be controlled with flaming regardless of the numbers of applications. Flaming is a successful type of weed control, however due to its high cost and higher effectiveness of other methods, it is not used much in crops. Only seeds present in the windrow and on the immediate soil surface below the windrow are affected by burning. For soil stewardship and preservation of organic matter, burning should only be practiced on windrowed straw or on gathered weed materials from patches within the field known as spot burning.

The most commonly applied fuel in the burners is liquefied petroleum gas (LPG), usually propane, however as renewable alternatives such as hydrogen have been evaluated. Flame weeding (Figure 5.14) can be cheaper than hand-weeding but there is a high machine cost. It is concluded that treating an area of 6-20 hectares brings costs down to a reasonable level but treating smaller areas could also be profitable depending upon the crop.

Figure 5.14 Flame weeder (https://www.shutterstock.com)

- Steaming. The application of steam for weed control results in a minor reduction in water quantity and provide better canopy penetration compared to hot water (Figure 5.15). Effectiveness of this method is influenced by temperature of steam, weed species, duration of exposure and plant size. Perennial weed species can regenerate, thus it is necessary to repeat exposure. Seed coat of annual weed species can offer some protection to steam. Mobile soil steaming is commercially applied to manage weeds in the field and glasshouses for controlling both pathogens and weed and for sterilizing the soil. The interest was renewed for the steam sterilization methods as a result of related concern with the usage of the highly toxic methyl bromide. Steam is applied under pressure beneath metal pans forced down onto freshly formed beds for periods of 3-8 minutes. The steam raises the soil temperature to 70-100°C killing most weed seeds to a depth of at least 10 cm, however weed seeds below the treated layer are unaffected. If there is no further following cultivation treatment, weed control can remain effective for two seasons.

Figure 5.15 Weed killing steamer (https://www.shutterstock.com)

- Solarization. Solarization is a preventive process that exploits the heat of the sun for controlling the weeds. For this, a black or clear plastic cover is laid over the soil surface to trap solar radiation (Figure 5.16). The increased soil temperature kills plants, seeds, plant pathogens and different life stages of pests, thus high soil temperature is declared as a soil disinfection technique. For effective solarization method warm, moist soil and intense radiation is required, that lasts throughout the day. Moisture of soil is required for an effective process. Therefore, irrigation of soil before solarization is necessary. It is also concluded, that the success of soil solarization does not depend on the peak temperature measured in soil but rather on the duration of temperature above a certain threshold (45°C) day by day. For retaining the weed control effect of solarization, the soil must not be cultivated subsequently because otherwise weed seeds present in deeper soil layers (less affected by heating) are brought up to the soil surface and can germinate.

Figure 5.16 Solarization as a tool in weed management (https://www.shutterstock.com)

- Infrared radiation. The burner applied in this method uses infrared radiation (IR) to kill the weeds. The burner heats ceramic and metal surfaces that radiate the heat (in the form of IR) towards the weed plants. A ceramic disc heated by gas from a small butane cylinder generates IR when incandescent. Then the so called 'hot spear' (projecting metal spike) heated is pressed into the center of the plant to be destroyed and held there for a few seconds (for most weeds. about 1.5 second is enough, however for harder plants increase of time is needed). The intense heat boils the moisture in the plants' cells that results in them bursting. The leaves will wilt and turn a darker green immediately after treatment. Moreover, the method damages the proteins in the cells, thus in absence of photosynthesis the plant will die. Infrared weeders have the disadvantages of needing time to heat up, the IR panels are sensitive to mechanical damage, and they are more expensive than flame weeders. However, unlike flame weeders, they can be used in situations where an open flame would be extremely dangerous.

- Direct heat. Before application of direct heat for destroying weed seeds in field soil, the soil is cultivated and set in ridges. The worked ridge of soil is lifted, passed through a chamber heated to 68-70 °C by a diesel-fired burner, and then placed back onto the ground, thus providing a band of weed free soil. The depth of treatment ranges from 10 cm for shallow rooted crops to 25 cm for potatoes. The dry heat system comparing to steaming allows faster coverage of a filed.

- Electrocution. There are two types of the systems used for the electrical treatment. The „spark discharge" method applied high-voltage, short-duration pulses (e.g. 25–60 kV, 1–3 µs) for weed control, plant thinning and the acceleration of ripening. The „continuous contact" method applies a metal applicator connected to a high-voltage source (e.g. 15 kV, 54kW, 30 Ampere). Electric current flows in a closed circuit through the plants into their roots, through communicating roots into neighboring plants, and from there back into a current collector at the soil surface. In such a circuit, the plant forms a resistance. The electric voltage damages the chlorophyll of the touched plants and kills the plant cells. This method is used for pruning and desiccation of root crop foliage, as well as area wide weed control and row crop thinning.

- Freezing (cryogenic weed control). Two different media are applied for the freezing treatments: liquid nitrogen and carbon dioxide snow (dry ice). The cryogenic system applies liquid nitrogen to target weeds through a modified sprayer and then crushes the weeds with a ballasted mechanical roller. Liquid nitrogen is more effective than carbon dioxide, however neither is as effective as flaming. Freezing is only advantageous where there is an obvious fire risk from flaming.

There is some other thermal weed control technics applying infrared radiation, microwave radiation, electrostatic field, irradiation, lasers, or ultraviolet light, however these methods are not detailed in this chapter.

Mechanical weed control

A wide range of mechanical weeders from basic hand tools to tractor driven devices are availabe for farmers. These include cultivating tools (i.e. hoes, harrows, tines and brush weeders), cutting tools (i.e. mowers and strimmers) and implements (i.e. thistle-bars) that perform both. Basically, complete burial of seedling weeds to 1 cm depth and cut them at or close to the soil surface is the most effective mechanical method of weed management. Crop and weed population determine essentially the type of implement and the timing/frequency of its application providing effective weed control. For example, fixed harrows are more suitable for arable crops, while others like inter-row brush weeders may be more effective for horticultural use. Disadvantages of mechanical weed control include low work rates, delays due to wet conditions and the subsequent risk of weed control failure as weeds become larger. Weed control is not necessarily better at earlier weed stages because missing late germinating weeds can survive the treatment. The additional cultivations associated with mechanical weeding could harm soil structure and possibly encourage soil erosion. The increased mineralization of soil nitrogen due to cultivation can be a problem or an advantage for farmers.

- Hand tools. Removing weeds by hand is often the most effective way to prevent weed from spreading and therefore becoming a serious problem. Hand tools are more effective for annual rather than perennial weeds due to its capacity of vegetative reproduction. Manually operated weeders are classified as follows:

(i) small tools: They are traditional hand-held type hoes applied by the farmers. Although these tools are appropriate for removing weeds between plants and are very effective, operation is only possible in squatting posture and has very low work output. Hand hoes, push hoes and other traditional methods of hand-weeding are still used worldwide in horticultural crops. Hand-weeding is often used after mechanical inter-row weeding to deal with the weeds left in the crop row. Application during the heat of the day in bright sunlight is the best, because under this weather condition weeds desiccate quickly. Recovery or survive of weeds in rainy weather and wet cloddy soils can be happened.

(ii) spades or chopping hoes. These weeders have straight, curved, or pronged blades. Weeds are removed by digging, cutting, and uprooting. These are operated in the bending posture. The operation is normally slow and tiring.

(iii) long handle tools. Long handle tools have a soil working tool fixed at the end of a 1.5 to 2 m long handle. These tools are operated in push, push-pull or pull mode, and in standing posture. These are designed to work under friable soil moisture conditions and give high work output at the early stages of crop growth when weeds are small.

- Harrows. Harrowing is a traditional form of mechanical weed control (Figure 5.17) for dealing with annual weeds but is ineffective against perennial and established deep-rooted weeds. For giving the crop an early advantage, killing the first emerging weeds by spring tine, chain or drag harrows, blind or pre-emergent harrowing can be carried out after drilling but before crop emergence. Early harrowing is successful in case of dry weather, but soil moisture is adequate. Disadvantage of blind harrowing is the low efficiency if few weeds emerged and sometimes the slow crop emergence. Harrows also can be applied post-emergence, however, in this way it can cause crop injury. Increasing the working depth from 10 to 30 mm doubles the number of uprooted plants and is further improved by higher soil moisture and faster working speeds. Sorting action of tines increases with wider tines and slower forward speed, while throwing action increases with forward speed, working depth and tin width.

Chain harrows with round and/or shuttle shaped links bury the weeds but do not pull them up. They are especially effective on light soils and prior to crop emergence, or in short crops. Tine weeders with either rigid or spring-loaded tines, superficially cultivate the whole soil surface and cause less crop damage. They are more effective on lighter soils and less successful on heavy land.

Weeders fitted with flexible tines (flexi-tines) can be used selectively at the late tillering stage of cereals when the dense crop foliage forces the tines into the inter-row. It is the most effective when weeds are in white thread (weed that have germinated but not emerged) or cotyledon stage. Advantages of flexi-tines are fast speed operation, break of soil crusts, lifting of sections over crop without injury.

Torsion weeders, with pairs of tines set either side of the crop row offer more precise inter-row. Crops must be extremely well-rooted with sufficient row spacing. Optimal crop stage for application of Torsion weeders is 2+ leaves and very well rooting.

Rotary-tine weeders, with two ground-driven 'star' or 'spider-tine' rotors covering each row, also allow inter-row weed control. The angle of the rotors can be set to move soil away from, or towards the row; the latter ridging up the crop to bury small intra-row weeds.

Figure 5.17 Harrows in weed management: chaine harrow (left - (https://www.shutterstock.com), tine weeder (middle – I. Tirczka), finger weeder (right – I. Tirczka)

- Tractor hoes. Tractor hoes cut through the soil at 2-4 cm depth by an 'A' or 'L' shaped fixed, vibrating or revolving. Increasing the working depth does little to improve weed kill, but higher forward speed increases soil covering of weeds and reduces survival. Soil structure is important: in rough soil weeds may continue to grow in the lumps of soil lifted by the hoe. Desiccation on the soil surface is a critical factor in preventing weed regeneration, and wet conditions after hoeing can decrease the level of control. Hoeing is particularly effective against mature weeds. Hoe weeders control weeds within the inter-row. The shares undercut everything, so it is necessary to steer the hoes very carefully between the crop rows. A good seedbed and precise drilling of the crop are prerequisites for successful hoeing. For avoiding the removal of significant number of crop plants and the covering them by soil, different types of protectors can be fitted. These may take the form of discs, plates, or protective hoods.

The powered rotary hoe is PTO (power take-off) driven and fitted with rotating L-shaped blades on a horizontal axle (Figure 5.18). The width of the rotor can be adjusted to different row widths, thus more intensive cultivation of the soil can be performed and can deal with larger weeds. The rotary hoe serves two basic functions: (i) removing small weeds, and (ii) loosening crusted or compacted soil to aid in crop emergence. A further development has been the rotary ground driven weeder or rolling cultivator with usually two ground driven ‘star’ or ‘spider tine’ rotors covering each row. The rotary hoe causes very little disturbance of crop residue, thereby enhancing infiltration and preventing erosion. Its use is generally limited to large-seeded crops such as corn and soybeans, because these crops are planted relatively deep and have root systems that develop fast enough to anchor the young seedlings.

Figure 5.18 Rotary hoe (E. Takács)

- Brush weeders. The brush weeder (Figure 5.19) is primarily intended for inter-row weeding of vegetable crops, however application in cereals also can be performed. Two main types of brush hoe have been developed: (i) with disc brushes operating in the vertical plane on a horizontal axis, and (ii) with circular brushes operating in the horizontal plane on a vertical axis. In general, the brushes are made of fibreglass and are flexible. These weeders working very superficially mainly uproot but do also bury or break weeds. A protective shield panel or tent can be used to protect the crop. When using horizontal-axis brushes, their rotation speed should be only slightly faster than the tractor speed, otherwise too much dust will be generated. For brush hoe on a horizontal axis, working depth is the most important factor in ensuring good weed control. Tractor speed, brush velocity and soil conditions interact to determine the working depth. A higher rotational speed will not improve the effect; however, the bristles will wear out more rapidly. It has the advantage that it can be operated under moister soil conditions than a tractor steerage hoe. When the soil is too hard, the brush weeder will remove only the part of the weeds above the soil, and the weeds will readily regrow. Application on moist soil, the effect will diminish as a result of soil sticking to the bristles. Some models of vertical-axis brushes can have the angle, rpm and rotating direction of the brushes adjusted. Vertical-axis brushes can be adjusted to throw soil towards the crop row or to remove soil and weeds away from the row.

Figure 5.19 Brush weeder (https://www.shutterstock.com)

- Mowers, cutters and strimmers. These methods are commonly used in turf, and can be used in vineyards, in orchards, in pastures and in forage crops if used in the appropriate way. Where weeds are much taller than the crop it may be possible to 'top' the weed and at least prevent further seeding. Although, cutting and mowing techniques enable us to control the size of weeds and their seed production and to minimize the competition between weeds and crops. Handheld and wheeled strimmers offer the potential to cut down seedling and larger weeds pre-emergence overall, or post-emergence between the crop rows without disturbing the soil surface. These techniques are seldom efficient enough to obtain a total weed control. Cutting and mowing weeds reduces their leaf area, slows their growth, and decreases or prevents seed production. Repeated mowing reduces weed competitive ability, depletes carbohydrate reserves in the roots, and prevents seed production. Some weeds, mowed when they are young, are readily consumed by livestock. Mowing can kill or suppress annual, biennial and perennial weeds and help restrict their spread. A single mowing will not satisfactorily control most weeds; however, mowing three or four times per year over several years can greatly reduce and occasionally eliminate certain weeds. Regular mowing helps prevent weeds from establishing, spreading, and competing with desirable forage crops.

Table 5.4 The advantage and disadvantage of main implements applied in integrated weed management in ecological farming

Implement	Positive weed control effect	Negative weed control effect
Plough	Disrupts growth and seed production. Buries seeds produced this year and buries perennial weeds and their below ground root/stem systems.	Weed seeds from the seed bank are moved up to the soil surface.
Cultivator/Disc cultivator	Disrupts weed growth and seed production. Buries seeds produced this year and buries /fragments perennial weeds and their underground root/stem systems.	May stimulate shoot development from below ground root/stem systems of perennial weeds.
Harrow	Destroys/kills small weed plants. Fragmenting root/stem parts of perennial weeds near the soil surface.	Stimulates weed seed germination. May spread viable root/stem parts of perennial weeds.
Roller	Improves germination conditions for the crop.	Improves germination conditions for the weed seeds.
Weed harrow	Covers small weed plants with soil and/or uproots them.	Stimulates weed seed germination. May more or less damage the crop.

Inter-row cultivator	Covers small weed plants with soil, uproots them or cuts them off.	May damage the crop.
Brush weeder	Covers small weed plants with soil or uproots them.	May damage the crop.
Weed mower	Cuts of weeds in growing crops.	If used after stem elongation, the crop will be damaged.

Mulching

Mulch is a layer of various material applied to the soil surface. The mulch provides a physical barrier on the soil surface, blocks nearly all light reaching the surface. It keeps soil surface shaded and cool, reduces daily fluctuations of soil temperature, thus weeds emerging emerge under the mulch do not have sufficient light to survive. For example, when a cover crop is killed by extreme temperature, mowing, or rolling, their residues left on the soil surface as a mulch. Effectiveness is depending on the type of weed. For example, small-seeded broadleaf weeds sprouting is effectively blocked by a 2–3-inch-thick layer of cover crop residues. However, larger-seeded broadleaf seedlings, grass seedlings, and perennial weed shooting from buried rhizomes and tubers get through, but their growth can be delayed by residues of a high biomass cover crop. The mulch effect can be enhanced by the release of allelopathy substances from the decaying residues. Moreover, mulch provides habitat for ground beetles and other predators of weed seeds, as well as microorganisms that can attack and kill weed seedlings. There are different types of mulches according to the nature of the soil covering material: organic (leaves, grass clippings, peat moss, wood chips, bark chips, straw mulch, pine straw, biodegradable mulch, cardboard/newspaper) and synthetic (rubber, plastic, polypropylene and polyethylene, carpet, colored mulch). Mulches can be classified in the following way, as well:

- Sheeted mulches. Black polyethylene mulches are widely used for weed control in organic systems, however they are generally not practical for lower-valued, large-scale field crops. Plastic mulches have dual efficiency, they selectively filter out the photosynthetically active radiation (PAR) and let through infra red light to warm the soil (thermal weed control). Regarding the colour of the mulch it is concluded that white and green coverings had little effect on the weeds, however brown, black, blue, and white on black (double colour) films prevented weeds emerging. The latter has the advantage, that the higher rate of light reflectance is beneficial to the crop. Plastic and other durable mulches have the drawback of not degrade in field. Mulches made from paper (Figure 5.20), non-woven natural fibres and degradable plastics have the advantage of breaking down naturally and can be incorporated into the soil after use. Correct laying of the paper can avoid damage provided by rain or wind. There can be additional environmental benefits if the paper mulch is made from recycled materials such as cardboard cartons. In January 2018, the European Standard EN 17033: "*Plastics–Biodegradable mulch films for use in agriculture and horticulture–Requirements and test methods*" was released. The standard was developed by the European Committee for Standardization, Technical Committee CEN/TC 249 Plastics and applies to all European Union countries plus Macedonia, Norway, Sweden, Switzerland, Serbia, Turkey, and the United Kingdom. This standard regulates the requirements for biodegradable plastic mulch films (BDMs): their composition, biodegradability in soil, effect on the soil environment (ecotoxicity), mechanical and optical properties, and the test procedures for each of the listed categories. It does not apply to mulch films that are being removed from the fields after use.

Picture 5.20 Mulches made from paper (E. Takács)

- <u>Living mulches (groundcovers)</u>. Living mulch consists of a dense stand of low growing species (Figure 5.21) established prior to or after the crop (i.e. undersowing of cereals with clover and grass) to slow the development of weeds and provide other benefits (nitrogen fixation, protecting soil from water and wind erosion, increase enemies of crop pests). Living mulches control weeds in two ways: When they are seeded before weed establishment, they suppress weeds by competition. In some situations, the allopathic properties of living mulches can be used to control weeds. It has been argued that annual weeds would provide a natural ground cover if managed properly. Living mulches are sometimes referred to as cover crops, but they grow at least part of the time simultaneously with the crop. Cover crops are generally killed off prior to crop establishment. Often, the primary purpose of a living mulch is that of improving soil structure, aiding nutrition or avoiding pest attack, and weed suppression may be just an added benefit. Disadvantages of living mulch is, that it competes for nutrients and water with the main crop and this can reduce yields. Although leguminous cover crops have large biomass production and turnover, they are not likely to increase soil organic matter. This is because legumes used as living mulches have greater N contents and a low C to N ratio. So when legume residue decomposes, soil microbes have sufficient N available to enhance their breakdown of organic materials in the soil. Thus, application of legumes is primarily recommended when there is already enough organic matter in the soil.

Figure 5.21 Living mulch (Marigold) and sugarcanes (https://www.shutterstock.com)

- Particle mulches. Particle mulches are composed of a mass of material spread on the ground, loose materials like straw, bark and composted municipal green waste (Figure 5.22). The particle mulch may be composed of compost, manure, straw, sawdust, rock, gravel, or any other material that covers the ground. Effectiveness of weed control is directly proportional with the thickness of the mulch layer. Weed seeds in the mulch itself can be a problem if the composting process has not been fully effective or there is contamination by windblown seeds. In straw mulches, volunteer cereal seedlings are a particular problem due to shed cereal grains and even whole ears remaining in the straw after crop harvest. There may be a risk of crop damage from herbicide or growth regulator residues remaining on straw from conventionally grown cereals. With particle mulches like straw that consist of light materials there is the possibility of them being blown around by the wind.

Picture 5.22 Particle mulch (https://www.shutterstock.com)

Biological weed control

Biological weed control methods apply living organisms, such as insects, nematodes, bacteria, or fungi, to reduce weed populations. Classical (or inoculative) control describes the introduction of host-specific, exotic natural enemies to control alien weeds. Inundative (or augmentative) control involves the mass production and release of native (usually) natural enemies against native (usually) weeds. The basic criteria for organic products are host specificity and durability. However, as weed populations of mixed species usually occur in the field, this (also) makes their practical applicability difficult. In a broader sense, allelopathy (secondary, inhibitory metabolic products produced by certain plants) is also included. Susceptible weeds will not die, but will suffer significant biological depreciation, so they will not be competitive partners for healthy crops. Preventive cultural practices, together with physical controls such as cultivation, flaming, and mulching, normally include into an organic farm's weed management strategy, with biological products or agents playing at most a minor role. However, biological processes may contribute to the efficacy of practices such as cover cropping, mulching, crop rotation, and farm diversification in reducing weed pressure. Biological processes that can impact weeds include: (i) herbivory—direct consumption of weed seedlings, or foliage or roots of adult weeds, (ii) disease caused by bacteria, fungi, and other microorganisms, (iii) plant–soil–microorganism interactions that change weed vigor and competitiveness relative to the crop, (iv) allelopathy—suppression of weed growth by substances released by other plants, (v) weed seed consumption and (vi) weed seed decay.

It is essential to test biocontrol agents in detail for host specificity. Much of this is still in the research and discovery phase; however, some biological processes are sufficiently well understood and documented to be utilized as effective methods for enhancement the successful of the overall weed management program. In addition, many diversified farms utilize livestock and poultry as weed consumers, often to significant benefit.

- Allelopathy. It is the effect, when a plant releases natural substance that suppress or hinder weed seed germination and early growth (Figure 5.23). The origin of these substances can be: (i) excretion by living plant roots, (ii) leaching from foliage, and (iii) release during microbial decay of plant residues. These allelochemicals, some of which are potent enough to be considered nature's herbicides, have the greatest impact on germinating seeds, seedlings, and young plants, retarding their growth, causing visible damage to roots or shoots, or even killing them outright. Many cover crops and a few vegetable varieties have been shown to exert significant allelopathic activity against weeds, especially young annual weeds. Cover crops in the brassica family, including rapeseed, mustards, and radishes, contain a number of compounds called mustard oil glycosides, which break down into powerful volatile allelochemicals called isothiocyanates during residue decomposition, which can affect plant growth as well as microbial activity. Well-documented examples within crops including rye, other cereal grains, sorghum, sorghum—sudangrass hybrids, forage radish and other brassicas, and sweet potatoes. Here is an example, that an allelopathic relationships can be quite specific. For example, sunflower root exudates inhibit seedling growth of wild mustard and other broadleaf weeds but have little effect on grasses. In no-till field trials, rye residues are strongly allelopathic against Amaranthus sp. and *Chenopodium album*, but not ragweed. There are some cases, when allelopathy is not so effective. Transplants and large seeds are less responsive to allelopathic suppression due to their deep plantation, the allelochemicals produced by a cover crop mulch are concentrated above the soil surface. As specific allelopathic relationships become better understood, crop rotations and cropping systems can be designed to give crops an edge over the major weeds present in a given field. Unlike direct competition, allelopathic weed suppression can persist for a few weeks after a cover crop is terminated. Tilling the top growth in as a green manure causes an intense but relatively brief burst of allelopathic activity throughout the till depth. Leaving the residues on the surface as an in situ mulch creates a shallow (less than 2.5 cm) but more persistent allelopathic zone that can last for three to ten weeks depending on weather conditions.

- Soil microbiota. The ability of the soil's microbiota to influence the growth and competitiveness of weeds relative to crops has been a subject of much fascinating research. Plant–soil–microbe relationships are highly complex, and research findings have not yet been consistent enough to warrant recommendation of procedures to introduce, encourage, or limit certain soil microbes as weed control tactics.

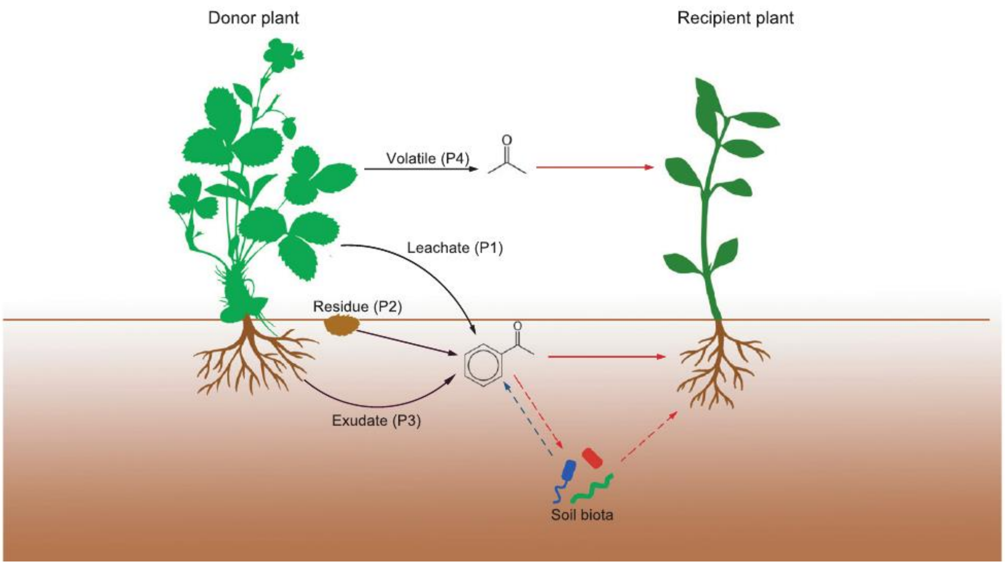


Figure 5.23 The different release pathways and effects of allelochemicals. The allelopathy plant (left) can release allelochemicals through four pathways (blackarrows): leaching by rain (P1), decomposition of plant residues (P2), exudation from roots (P3) and volatilisation (P4) (Zhang et al., 2021).

5.3.2 Indirect weed control

Management of drainage and irrigation systems

Careful choice and maintenance of drainage and irrigation systems is an important preventive measure to reduce on-field weed infestation. Periodical clearance of weed vegetation established along ditches prevents it from invading the field. Where it is economically feasible, substitution of ditches with subterranean drains eliminates a potential source of weed infestation. Use of localized (e.g. trickle) irrigation systems favour crop development to the detriment of weeds. In contrast, broadcast irrigation systems often favour weeds because most of them have a higher water use efficiency (dry biomass production per unit water used for evapotranspiration) than the crop.

Tillage

One of the most important goals of all tillage processes, among other beneficial effects, has always been to reduce the stock of weed seeds in the soil and to deplete the reserve nutrient reserves of underground vegetative reproductive organs in perennial species. The weed seeds in the soil are placed in more favorable layers close to the soil for germination as a result of the disturbance, and the seedlings can be easily destroyed during a repeated tillage. The use of conventional tillage systems is of great importance in organic farming. It consists primarily of an autumn deep plowing or stubble plowing and then, in the spring of the following year, of the tillage procedures in preparation for sowing (disc, cultivator, harrow, combine, etc.). Later, in the vegetation, several inter-row additional mechanical weed control may become necessary (cultivator, weed comb, weed brush, spoke hoe, etc.). Soil cultivation or tillage, as an effective method has long been involved into control weed management. Various factors, like depth, timing and frequency of cultivation can influence different parameters of the weed population (composition, density, and long-term persistence). However, similarly to other weed management methods, tillage also have conflicts. Finer seedbeds produce more weed seedlings, but a smooth surface makes the direct weed control easier. Larger clods of soil produce fewer weed seedlings, but the rough surface gives emerged weeds protection against direct weeding methods. Soil structure can be damaged by excessive cultivation that leads to erosion in longer term. Although, reduced tillage results in better control of soil erosion, conservation of soil moisture and more efficient use of fossil fuel, but not all soils are suitable for reduced tillage. Tillage is often divided into three forms primary, secondary and tertiary, but there are other cultivations that do not fall into these categories.

- Primary tillage. Primary tillage is the principal method chosen for cultivation prior to crop establishment. It is the first soil-working operation in cropping systems that is performed for preparing the soil for planting. Primary tillage is always aggressive and carried out at a considerable depth in order to control annual and/or perennial weeds by burying a portion of germinable seeds and/or propagules at depths at which weed seeds are not able to emerge. The main tools used to perform primary tillage are mould-board ploughs, disc ploughs, diggers, and chisel ploughs.

- Secondary tillage. Secondary tillage is used to prepare seedbeds and leave a level surface for drilling; thus the soil is not worked aggressively or deeply. The aim is to prepare the soil for planting or transplanting or it is used for carrying out the false seedbed. The equipment for secondary tillage are cultivators, harrows (disc, spring tine, radial blade, and rolling) and power take-off machines applied to a depth of 10 cm. In conservation tillage this equipment could be used as a substitute for ploughs in primary tillage. Conservation tillage is useful for conserving or increasing the organic matter content in the soil and for saving time, fuel and. Although, reduced tillage techniques could cause some problems with weeds, farmers can optimally alternate primary and secondary tillage in order to optimize soil management by changing mechanical actions year after year and thus improving annual and perennial weed species control. The timing of seedbed preparation affects weed populations considerably and is an opportunity to reduce weed numbers that emerge in the growing crop. One traditional method of weed control is the stale or false seedbed technique. Cultivation for seed bed preparation has two contrasting effects on weeds: (i) elimination the emerged vegetation resulting from after primary tillage, and (ii) stimulation of weed seed germination and consequent seedling emergence. Utilize these two effects can be achieved by false (stale) seed bed technique. A stale seedbed is a technique where a seedbed is prepared several days/weeks/moths before planting or transplanting crops in order to stimulate the emergence of weeds prior to sowing. The success of a stale seedbed depends on the length of time before planting and on weed spectrum. Late-emerging weeds will still be a potential problem. Application of the false seed bed technique can reduce weed emergence > 80% compared to standard seed bed preparation. The most important factor beside the temperature is the moisture of soil. In dry years the stale seedbed method does not serve as a good method of weed control without the intervention of irrigation. A novel method of reducing seedling emergence is to carry out the seedbed preparations in the dark to avoid stimulating weed seed germination, however this technique does not provide consequent results.

- Cultivation tillage. Cultivating tillage is performed after crop planting in order to achieve a shallow tillage which loosens the soil and controls weeds. For this purpose, cultivators are used which can control weeds in different ways. The complete or partial burial of weeds and their seeds can be an important cause of mortality. Another mode of action is by uprooting and breakage of the weed root contact with the soil. It is preferable to carry out cultivation tillage when the soil is not too wet because it can damage the soil structure and favor the spread of perennial weeds. Cultivators are generally classified according to their application in a crop: broadcast cultivators could be used both on and between the crop rows; inter-row cultivators are used only between crop rows; and intra-row cultivators which are used for removing weeds from the crop rows. For example, the methods against Cirsium arvense: With wire rope method the field is mounded up by using mounding equipment in place of plow. For tillage, the mounds or ridges are dragged down to a greater or lesser extent, depending on the crop, and sown with cereals, for example, or planted with field vegetables. While the seed is now emerging, but the roots of the crops are still short, the tilled ridges are undercut at the boundary between topsoil and subsoil with a wire rope stretched across the hill implement, thus cutting off the thistle shoots. Undercutting with the wire rope can be done both in the fall and in the spring.

Crop rotation

Crop rotation is a basic technique in organic farming to help pest and disease control and to provide optimum soil fertility, moreover, weed control is achieved effectively by combining crop rotation with other cultural treatments. Crop rotation involves alternating different crops in a systematic sequence on the same land (Figure 5.24). Monoculture or high proportion of similar crops results in a weed species composition that are adapted to the growing conditions of the crop (for limiting the field thistle, the cereal content should be limited to a maximum of 50%). Rotating crops at different life cycles can disrupt the development of weed-crop associations, through different planting and harvest dates preventing weed establishment and therefore seed production. Since different crops favour different types of weed species, it is important to change between annual and perennial crops in the crop rotation. Autumn- and spring-sown annual crops also favour different types of weed species, which makes it important to rotate between such crops within a crop rotation. Traditionally, potato (*Solanum tuberosum*) is included in the rotation to reduce weed problems before a less competitive crop is grown. For an organic farmer, consideration of soil fertility level and including fertility building periods in rotation complicate the crop choice. The inclusion of a fallow period in the rotation in known to reduce perennial weeds. It is best to alternate legumes with grasses, spring planted crops with fall planted crops, row crops with close planted crops and heavy feeders with light feeders. Despite the use of rotations, some weeds have been identified as particular problems in organic farming systems. Couch grass (*Elymus repens*) and other creeping perennial grasses, and creeping thistle (*Cirsium arvense*) are often declared as the main problem weeds in all organic systems. Blackgrass (*Alopecurus myosuroides*) and *Cirsium arvense* can become more frequent when cereals form a significant part of the rotation. Docks (*Rumex* spp.) are a particular problem in grassland and bracken (*Pteridium aquilinum*), has become a severe problem in upland areas of pasture.

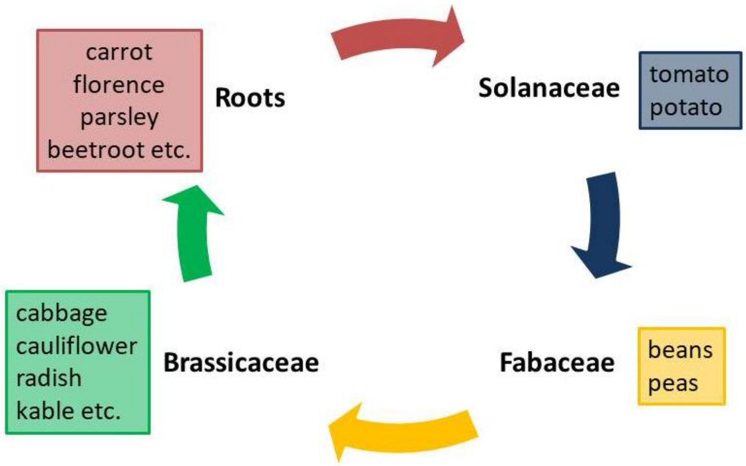


Figure 5.24 Possibilities for crop rotation (E. Takács)

Cultivar

It is not simply the choice of crop that influences weed development within a rotation, the characteristics of the cultivar such as morphology and growth rate can have a significant effect on both crop and weed development. Cultivar choice and crop seed rate can be effective in suppressing weeds and hence minimising weed control inputs, as well. For example, spring barley cv. Atem has taller development than cv. Triumph and has a major influence in its greater weed suppression. Similarly, number of weed species found on the plots were significantly reduced in the presence of the traditional longer strawed Maris Huntsman winter weed cultivar in contrast with Mercia cultivar. Morphological traits can influence the competitive ability of crops over weeds. For example, earliness of crop ground cover is vital in weed suppression, and research has indicated that larger initial crop seed size can significantly improve early crop establishment and hence increase the competitive ability of winter wheat cultivars. Identifying and quantifying the traits associated with competitive ability against weeds is indeed complicated by the fact that, although different cultivars have unique characteristics, many of these traits can change over development stage. However, differential rooting patterns, early vigour, leaf size and allelochemical properties may influence the ability of a cultivar to suppress weeds and be successfully selected in breeding programmes.

Intercropping

Intercropping process means to grow smother crop between rows of the main crop (Figure 5.25). Increased yield, not improved weed control, is probably the main benefit expected from intercropping. It is declared that intercrops are able to suppress weeds, however it should be carefully applied. Without any attentiveness, intercrops can greatly reduce the yields of the main crop if competition for water or nutrients occurs. Like cover crops, intercrops increase the ecological diversity and use of natural resources by canopying, moreover, compete better with weeds for light, water and nutrients. For example, a leek-celery intercrops sown in a row-by-row layout decrease relative soil cover of weeds by 41%, reduce the density and biomass of *Senecio vulgaris* by 58% and 98% respectively, and increase total crop yield by 10% compared to solo cropping. Increased weed suppression and crop yield has also been demonstrated in many environments for cereal-legume intercrops. As in the case of living mulching, the success of intercropping relies on the best match between the requirements of component species for light, water, and nutrients, which increases resource use complementarity and reduces competition between the intercrops. In practice, this means optimizing intercrop spatial arrangement, relative plant densities and crop relative growth over time in any given environment.

Picture 5.25 Sugarcane intercropping with cabbage or cauliflower. (https://www.shutterstock.com)

Fertilization

Nutrient level of soil in agro-ecosystem is altered by application of fertilizers, thus they directly affect weed population dynamics and crop-weed competitions. Numerous weeds are high consumers of nitrogen and therefore able to reduce the availability of nitrogen for crop growth. Strong effects in weed control can be detected by timing, dosage, and placement of fertilizer. Organic farming uses organic manure and compost to replenish nutrients, which, as a consequence of improper treatment, have a “weed-growing” effect on the viable weed seeds in it. It is known that weeds absorb nutrients earlier and in greater amounts than their associated crops, so they need to be treated very carefully with nutrient replenishment.

Cover crops

Cover crops include a wide range of plants grown for various ecological reasons and cover the soil. Cover crops (Figure 5.26) suppress weeds by competing for resources, moreover their residues laying on the surface of the soil inhibit weeds through physical (barrier to weed emergence and establishment, increase of space for normal development of weeds), biotic (blocking of light, avoidance of temperature fluctuation, alteration of moisture conditions necessary for germination) and allelopathic interactions (compound released from living or decaying plant tissue). In general, the larger the cover crop and greater the biomass or dry matter production, the greater the impact on weeds. Despite these potential benefits, physical and biochemical effects from cover crops may not provide adequate weed control. Weed suppression by cover crop residue can vary from negligible to highly effective for anywhere from two weeks to several months, depending on cover crop biomass and nitrogen (N) content, season, weather, and soil conditions. Warm, moist weather combined with high soil biological activity accelerates decomposition of cover crop residues and their allelochemicals, thus shortening the weed control period. Strawy, low N residues last longer than succulent, high-N residues. Use mechanical control tactics and cultural controls to complement cover crops for weed management. The inclusion of cover crops such as rye, red clover, buckwheat and oilseed radish, over wintering crops (i.e. winter wheat) or forages in the cropping system can suppress weed growth. Highly competitive crops may be grown as short duration 'smother' crops within the rotation. When choosing a cover crop, consideration should always be given to how the cover crop will affect the succeeding crop. Examples of highly weed suppressive cover crops are rye, sorghum, kale, rocket, and mustard. In contrast, although direct weed suppression by legumes can be significant, their residual weed control effect is usually lower because the high quantity of N released from their residues after cover crop destruction stimulates weed emergence, especially when legumes are used as a green manure.

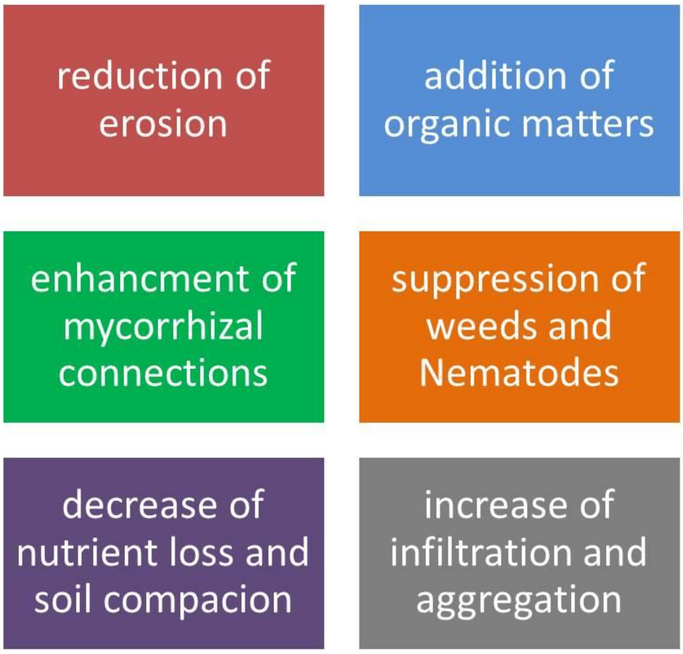


Figure 5.26 Benefit of cover crops (E. Takács)

Sanitation

It is possible to prevent many new weeds from being introduced onto the farm and to prevent existing weeds from producing large quantities of seed. The use of clean seed, mowing weeds around the edges of fields or after harvest to prevent weeds from going to seed, and thoroughly composting manure before application can greatly reduce the introduction of weed seeds and difficult weed species. It is even possible to selectively hand-eradicate isolated outbreaks of new weeds, effectively avoiding future infestations. Planting clean, high-quality seed is essential to crop success. Other sanitation factors to consider would include thorough cleaning of any machinery which might have been used in weedy fields or washing stations, and the establishment of hedgerows to limit windblown seeds.

Revision questions

1) Solarization is a process that exploits the heat of the sun for controlling the weeds. Please choose correct type of the process.

a) Preventive
b) Curative
c) Indirect

2) Intercropping process means to grow ………………….. crop between rows of the main crop. Please choose correct answer to fill the sentence.

a) Taller
b) Legume
c) Smother

3) Mulch is a layer of organic material applied ……….. Please choose correct answer to finalize the sentence.

a) On the soil surface
b) Only on sunny days
c) Only on rainy days

4) Name this weed management technology:

a) Infrared radiation
b) Solarization
c) Mulch

5) The origin of natural substances triggering allelopathy effect can be (Please mark the correct answer/s)

a) Mediated by pollinators
b) Excretion by living plant roots
c) Release during microbial decay of plant residues
d) Leaching from foliage
e) Produced by microorganism

6) Which are direct weed management methods? (Please mark the correct answer/s)

a) Mulch
b) Thermal technologies
c) Management of the irrigation system
d) Biological methods
e) Cover crops

7) Which ways can cover crops enhance soil health? (Please mark the correct answer/s)

a) Weaken mycorrhizal number
b) Suppress weeds
c) Decrease soil aggregation
d) Reduce erosion
e) Add organic matter

8) Indicate by T or F if the statement is true (T) or false (F)?

a) Thermal weed control includes application of fire, flaming, hot water, steam and freezing. _
b) Intercrops decrease the ecological diversity. ____

9) Indicate by T or F if the statement is true (T) or false (F)?

a) Biological weed control methods apply living organisms, such as insects, nematodes, bacteria, or fungi, to reduce weed populations. ___
b) In general, the larger the cover crop and greater the biomass or dry matter production, the lower the impact on weeds. ____

10) Indicate by T or F if the statement is true (T) or false (F)?

a) Primary tillage is the second soil-working operation in cropping systems that is performed for preparing the soil for planting.

b) The success of soil solarization mainly depends on the duration of temperature above a certain threshold (45°C) day by day.

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