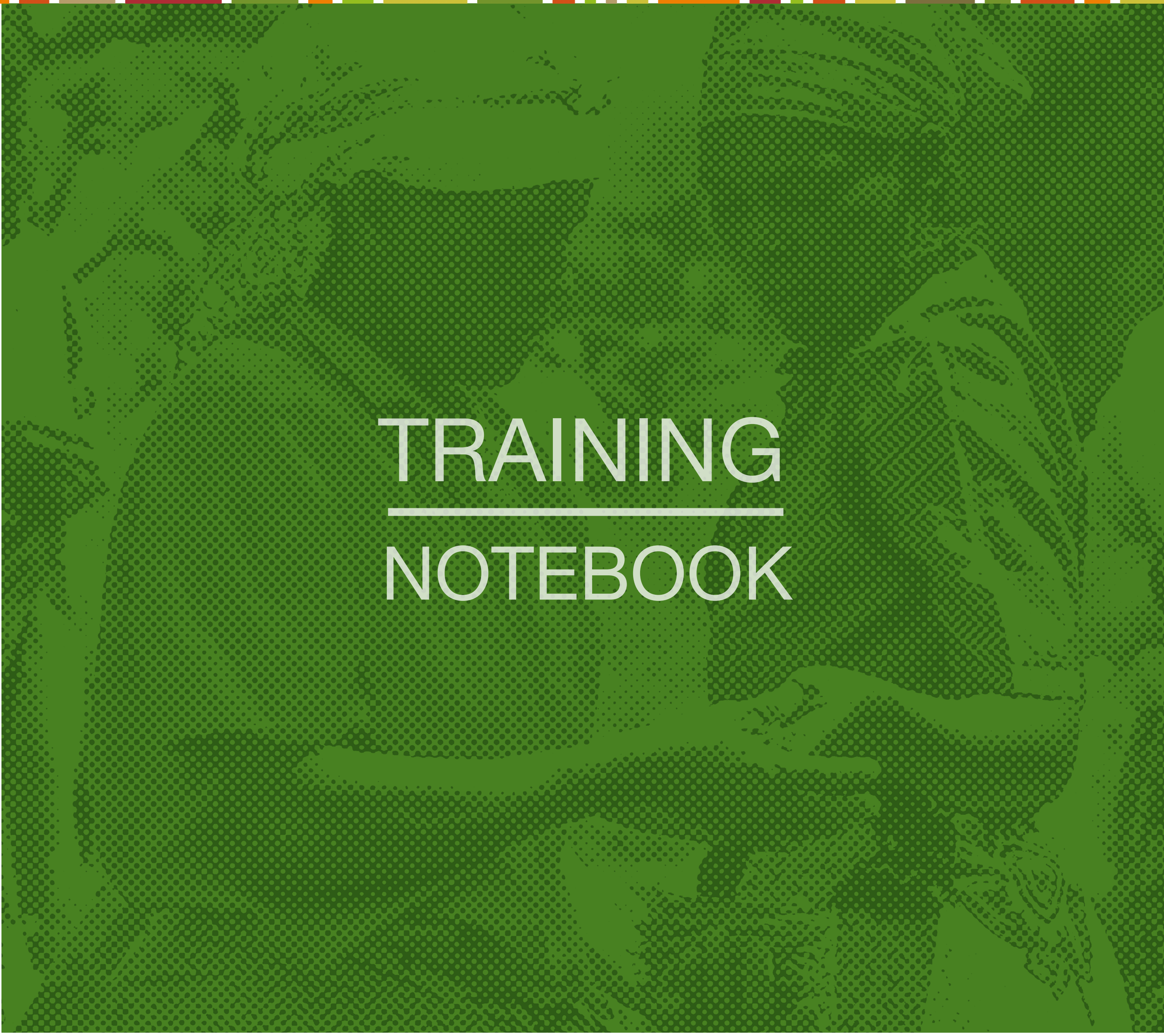

TRAINING NOTEBOOK

- ENVIRONMENTAL MANAGEMENT -

SUSTAINABLE WATER MANAGEMENT

COLEACP

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This publication is an integral part of a COLEACP collection, which is made up of educational and technical tools and materials. All of them are suited to different types of learners and beneficiaries and levels of education found in agricultural supply chains, production and sales.

This collection is available online for COLEACP members and beneficiaries.

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SUSTAINABLE WATER MANAGEMENT

Dear trainers, some advice...

WHY A TRAINING NOTEBOOK?

The 'Manuals' edited by COLEACP are valuable training materials. To write them, COLEACP approached the best experts in the field with the aim of producing a technical document for a large public on a given theme that brings together and structures most of the current knowledge. These manuals are intended to be as accurate and complete as possible, adapted to the ACP context and focused on cross-cutting issues in horticulture. But the objective was also to make them affordable, understandable and enjoyable to read by people who are not necessarily experts in the field. Nevertheless, it is a considerable effort to assimilate all the material collected in a short time.

The training manuals, which are aimed primarily at experts and the most qualified people, are often voluminous and complex, and it was necessary to help the expert trainers to identify the most important elements to retain, and to collect for them a list of 'key messages' to be disseminated to learners during COLEACP training. This Training Notebook is therefore a valuable and practical tool that is at your disposal to help you prepare your training on the topic covered in this Booklet.

WHAT DOES THE TRAINING NOTEBOOK CONTAIN?

Each Training Notebook contains:

1. The list of materials to be delivered to participants during the training

This is a summary table of contents of the Training Manual. This list allows you to have an **overview of** all the **main points that** will have to be covered during the training. The **order of the list does not necessarily have to be respected,** as the organisation of the sequences is left to your discretion and may depend on other factors (e.g. availability of an expert trainer; timing of the training sequences; space reserved for exercises...).

In some cases, **only certain aspects** (or chapters) of the **subject will be covered** (for example: if the participants have a perfect command of certain parts of the subject covered in the training, it is not necessary to present them in detail; a small reminder may be sufficient and effective to cover the rest).

However, when you cover part of the material (a chapter), the main 'points' listed for each chapter allow you to organise your presentations and animations in a logical and relevant way for the learner. **You are also advised to present all the points of a chapter.**

2. Training leaflets

A Training Notebook contains as many 'leaflets' as there are chapters in the training manual (only the 'case study' is not included). Each sheet contains, on the one hand, the **Training objectives** of this part of the subject to be delivered (what the learner must be able to deliver...), and on the other hand, according to the structure of the table, the 'key messages' (what the learner must absolutely have assimilated at the end of the training). It is therefore very important to ensure that **all messages are well distributed during the training sequence.**

3. A summary of the content of the manual

A summary of the manual has been included in this Training Notebook. Structured in the same way as the manual, it contains most of the content in 15-20 pages but remains much less complete (the summary does not include figures or case studies).

This summary is **primarily intended for the trainer.**

- **At the beginning of the mission**, when preparing its intervention sequences and supports, it allows you to quickly become familiar with all the content you will need to address and to visualise the links between the different parts of the material to be delivered.
- **During the training,** you can use this summary **to prepare your daily summaries,** reminding participants of the essential elements seen during a day (15-20 minute summary at the end of the day with answers to questions).
- **At the beginning or end of the training,** if you wish, you can give participants a copy of this summary. If the summary is distributed at the beginning of the training, it is advisable to ask participants to highlight the passages mentioned in your end-of-day summary (benchmarks in the subject).

The summary is also useful for learners at the end of the course: it will allow them to **remember in a** few minutes the **main part of the topic covered** (for example, before an assessment of prior learning), whereas reading the entire manual could be tedious.

HOW CAN THIS TRAINING NOTEBOOK HELP YOU PREPARE YOUR TRAINING INTERVENTIONS?

The intention of making this Training Notebook available to you is to **help you prepare your training sequences and structure your program day by day.**

- **Consider that each leaflet represents a whole:** if there are, for example, 4 leaflets, it means that there must be 4 distinct parts in your training. Sufficient time must therefore be allowed in the programme for each of these 4 parts. Each part of the subject will also have to be subject to a competency assessment.
- **Then consider the training objectives:** this will help you to choose: (a) the most appropriate training method for achieving your objectives (e.g. should you plan exercises, simulations, group activities etc.); (b) the method for evaluating the learning acquired in this part.
- **Finally, prepare your materials** (e.g. PowerPoint, flipcharts or animation sheets, evaluation questions) by ensuring that all key messages are included ("Have I planned to discuss all these points? Have I planned an evaluation on each key point?").

DON'T FORGET TO COMPLETE THIS TRAINING NOTEBOOK!

This Training Notebook is made **for you**... It is **a tool that must live!**

At the end of each leaflet, a space was left free to add your personal notes: as a trainer you can note some thoughts on how to get messages across, note your questions, participants' reactions, points that raise difficulties... *i.e.* **capitalise on your experience as a trainer!**

You can also **note the types of media you have used.** This will be very useful when you have a new session to facilitate on the same theme. COLEACP provides you with many tools and materials, but do not hesitate to create others or use other existing materials that may be available... the **rule is to master each of the materials used in training** and to ensure that they help to convey key messages more effectively than in their absence.

Materials to be delivered

CHAPTER 1 — HYDROLOGICAL CONTEXT OF AGRICULTURE

- Introduction: agriculture, food and water
- The agriculture of the future
- The role of agricultural practices
- The role of irrigation
- Horticultural considerations

CHAPTER 2 — FOUNDATIONS OF THE GLOBAL WATER SYSTEM

- Hydrological cycle
- Hydrological units, river basins and aquifers
- Hydrological balance of a basin
- Human consumption and water pollution

CHAPTER 3 — WATER FOR PLANT DEVELOPMENT

- The importance of water for plants
- Water requirements for crops
- Soil and water
- Water requirements for crops and irrigation

CHAPTER 4 — AGRICULTURE AND WATER QUALITY

- Introduction
- The impact of agriculture on water quality
- The importance of water quality for agriculture
- Avoid water pollution

CHAPTER 5 — IRRIGATION

- Introduction
- Irrigation methods
- The choice of appropriate irrigation methods
- Design and development of irrigation systems
- Irrigation water sources, water collection, storage and recycling
- The performance of irrigation systems

CHAPTER 6 — IRRIGATION MANAGEMENT

- What is irrigation management?
- Measures for efficient use of irrigation water
- Management of drained water
- Measures to reduce the environmental impact of irrigation
- Measures to mitigate social impacts

CHAPTER 7 — WATER FOR WASHING AND POST-HARVEST TREATMENT

- Introduction
- Post-harvest water use
- Water problems during post-harvest washing and treatment
- Water conservation during washing and treatment
- Post-harvest water use and food losses

CHAPTER 8 — WATER RIGHTS, EXTRACTION AND SUSTAINABILITY OF WATER USE

- Understanding water legislation: the right to water
- Guiding the action: why and where to start?

Training leaflets

LEAFLET 1

Hydrological context of agriculture

TRAINING OBJECTIVES

At the end of this training sequence, the participant must be able to:

- understand the importance of water in food production and the extent to which agriculture contributes to meeting food needs;
- understand what the agriculture of the future will be made of;
- understand the impact of agricultural practices on water;
- understand the principles of sustainable water management in irrigation;
- master water resource management considerations in horticulture.

KEY MESSAGES

1) The importance of water in food production and the participation of agriculture in meeting food needs

- Water is considered a renewable resource, since it circulates on the Earth's surface in a cycle.
- Water is necessary for food production, and most of the water that humans consume is incorporated into the food they eat.
- It takes between 1,000 and 3,000 litres of water to produce 1 kg of rice, and about 2,000 to 5,000 litres of water to produce one person's daily food needs.
- Agriculture is the largest consumer of fresh water, with 70% of the world's freshwater withdrawals compared to 22% for the industrial sector and 8% for households.
- Water scarcity is a major challenge for agricultural development.
- Food production consumes a lot of water, but also a lot of energy.
- Soil and water quality must be sufficient to provide conditions suitable for crop production.
- Climate change significantly affects the availability of water worldwide.
- Agriculture must minimise all its negative impacts on ecosystems and human health, while being able to increase production to meet the growing demand for food.
- Agriculture must use all resources, including water, more effectively and efficiently.
- Water, food production and agriculture are sectors under pressure, as is the energy sector.

- To meet the challenge of food security, changing diets, coupled with reducing food waste, are solutions to be explored.
- Increased crop yields, linked to land improvement, water management and agricultural development on already degraded land, will help to address the challenge of food security.

2) The agriculture of the future

- Food security exists when all people at all times have access to not only sufficient, but also safe and nutritious food, enabling them to meet their dietary needs and food preferences for an active and healthy life.
- The global food security problem is exacerbated by the projected growth of the world population, which is expected to increase from about 7 billion to about 10 billion or more in 2050.
- For agriculture to reach a balance with the environment, it must stop being managed as an extractive industry and become a more renewable/sustainable activity.
- Development must be based on sustainable agriculture that is based on inclusion and resilience to climate change.
- Inclusion solves the problems faced by small- and medium-sized farmers and women farmers.
- Resilience to climate change is an approach to create the technical, political and investment conditions for the development of sustainable agriculture that will ensure food security.
- Agricultural practices must be adapted to increase crop productivity and sustainable water management.
- The agriculture of the future will take into account the search for high yields through healthy agro-ecological systems.
- The agriculture of the future must invest in agricultural systems that respect water resources to restore soil health, conserve natural habitats, and restore degraded agricultural and pastoral habitats.
- Integrated water resources management (IWRM) is based on the principle that water is an integral part of the ecosystem, a natural resource and a social and economic good that must be protected.
- The purpose of IWRM is to engage the various institutions and policy measures taken in an integrated management system.

3) The impact of agricultural practices on sustainable water management

- Agricultural practices have a major impact on the efficient use of resources such as water, land and other agricultural inputs.
- Agricultural practices must be examined from the perspective of a more rational use of resources.
- The operator must have an integrated view of his farm and its surroundings.
- In his/her agricultural management, the farmer must take into account the situation of the climate, soils, crops, the quantity and quality of water required, as well as the needs for Fertilisers and pesticides.

- The operator must plan and implement agricultural practices that are financially and operationally feasible.

4) The role of irrigation in agriculture and its impact on sustainable water management

- Irrigated agriculture occupies 20% of cultivated land and generates 40% of world food production.
- According to IFAD, irrigation increases yields of most crops by 2 to 5 times and allows diversification to higher value crops.
- Higher value crops consume large amounts of inputs and depend on a reliable and flexible water supply.
- Irrigation projects, which increase the overall costs of implementation, operation and maintenance and the necessary investments, are not accessible to poor farmers.
- The inclusion of poor farmers in irrigation projects must be a prerequisite for strengthening rural economies and improving access to food.
- Irrigation plans devalue environmental and agricultural knowledge and farmers' experience in water management.
- Small irrigation systems, combined with ecological management of soil, organic matter and water, are a crucial strategy for including poor farmers and preventing the devaluation of their agro-environmental knowledge.
- The development of irrigation systems, as part of a sustainable management approach, must take into account the principles of sustainable agriculture and local realities.

5) Horticultural considerations

- FAO defines agriculture as a combination of all types of production (agronomy, horticulture and forestry).
- The horticultural sector plays an important role in solving global problems of food production and water resource management.
- Fruits and vegetables are an essential component of the human diet.
- The economic potential of fruit and vegetables per unit of land is generally higher than that of cereals and other crops.
- The development of horticulture plays a major role in achieving poverty reduction and food security objectives with a higher average ratio of monetary units per cubic metre of water.
- The development of horticulture must implement responsible water management, in accordance with the principles of the agriculture of the future.
- The benefits and difficulties of horticulture show that the development of the horticultural sector represents a real business opportunity.

PERSONAL NOTES

LEAFLET 2

Foundation of the world water system

TRAINING OBJECTIVES

At the end of this training sequence, the participant must be able to:

- understand and analyse basic concepts related to the water cycle;
- define hydrological units, watersheds and aquifers, and understand their importance in the hydrological cycle;
- understand how to determine the water balance of a basin;
- understand the importance of human water consumption and the origin of water pollution.

KEY MESSAGES

1) Basic concepts of the water cycle

- The amount of water on Earth is about 1,386 million km^3, but about 97% of this volume is saline water from the oceans.
- Fresh water represents only about 3% of the available water on the planet (but only part of it is actually available).
- Less than 1% of all the world's water resources are directly accessible for human use, but its distribution is not uniform across the globe.
- The water molecule is composed of an oxygen atom and two hydrogen atoms linked together by covalent bonds.
- Water behaves like a liquid, but water is also present on Earth in solid and gaseous form. In its liquid form, water is odourless, tasteless and transparent.
- Depending on atmospheric pressure, water is transformed into three phases: vapour, liquid or ice.
- Water mobility depends on the phase or state in which it is located.
- The continuous phase change of water, combined with its movement around the Earth, is called the 'hydrological cycle'.
- The water cycle begins and ends at the ocean level (vaporization under the action of the sun's energy) and repeats itself indefinitely over time.
- The gravity, the topography of the Earth, the climatic zones, the wind, the temperature and pressure variations cause changes in the phase of the water.
- The water cycle connects parts of the world that are very distant from each other and therefore takes place over very long distances.

2) Hydrological units, river basins and aquifers

- Water flows under gravity to the lowest point on any surface.
- The flow of water to the lowest point is the source of watercourses.
- The entire area supplying a river with water is called a 'watershed'.
- The movement and distribution of water is studied and explained by geographical units of variable dimensions called 'hydrological units'.
- A hydrological unit is a geographical area that covers part or all of a watershed, or a distinct hydrological element.
- The terms 'watershed' and 'river basin' are used interchangeably.
- The nature and shape of watersheds are determined by topography, geology and water, which can be an exoreic or endoreic basin.
- A watershed is an imaginary line that separates a watershed from other ones.
- A watershed has specific climatic, geological, soil, ecosystem and river characteristics that shape agricultural production systems.
- Water does not only run off at the surface: it also infiltrates the soil and rocks deeper down.
- 'Aquifers' are groundwater reservoirs and can therefore store water for very long periods of time.
- The two types of aquifers are: a free-water aquifer, covered with permeable rocks and capable of receiving water from the surface; and a confined aquifer, which is a body of groundwater located between two layers of less permeable rocks.
- Aquifers naturally recharge themselves with water from surface water bodies, rain, melting ice or snow, through the process of deep percolation.
- The balance between extraction and recharge is essential for sustainable groundwater management.
- Groundwater will be polluted if water containing biological or chemical pollutants enters the aquifer.

3) The water balance of a basin

- The production of a 'water balance' is the basic method for understanding the water status of any basin.
- The water balance of a river basin is expressed in volume units: cubic metres (m^3) or million cubic metres (Mm^3).
- The production of the balance is based on the principles of mass conservation applied to water, taking into account everything that enters and leaves the system, as well as all changes that affect water accumulation.
- The concept of water balance makes it possible to understand the hydrological behaviour of a hydrographic basin.
- For the water balance of a basin, a distinction must be made between 'green' and 'blue' water.
- Green water refers to the part of precipitation that evaporates or is transpired by plants (absorption and evaporation from plants).

- The ‘environmental need’ for green water is defined as the amount of green water from land that must be conserved to preserve biodiversity in natural area ecosystems.
- Blue water refers to water that flows into ditches, rivers and streams, as well as water that infiltrates and percolates into aquifers.
- The required blue environmental flows play an essential role in the creation and maintenance of many ecologically important natural habitats.
- ‘Environmental flows’ (green and blue) are important concepts for assessing the sustainability of water consumption in a given basin.
- The water balance takes into account the required environmental flows, but especially the blue environmental flows.

4) The importance of human water consumption and water pollution

- The notion of ‘water footprint’ and ‘virtual water’ are proposed indicators to assess human appropriation and use of water.
- The water footprint has three components: green water, blue water and grey water footprints.
- The blue water footprint refers to the volume of surface and groundwater consumed to produce a good or service.
- The green water footprint refers to the volume of water in precipitation consumed by the production process and is particularly applicable to agricultural and forest products.
- The grey water footprint refers to water pollution expressed as the volume of fresh water required to dilute a given load of pollutants.
- The global average water footprint over the period 1996-2005 was 9,087 Gm^3/year.
- The global water footprints of the agricultural and industrial sectors plus households are 92% for green water, 4.4% for blue water and 3.6% for grey water.
- In an industrialised country, the industrial sector accounts for 80% of freshwater resource use.
- In South Asia, Africa, Central America and South America, agriculture is the largest consumer of water.
- In ACP countries, agriculture uses more than 85% of the water extracted.
- The virtual water content of a product refers to the volume of fresh water considered as ‘content’ in the product (in the virtual and not real sense).
- The virtual water footprint is the indicator that refers to the water consumed or polluted to produce the product, including crop and forage evapotranspiration.
- The virtual water content refers only to a volume of water consumed or polluted. The water footprint also indicates where and when these volumes of water were extracted or polluted, and takes into account its impacts over time and space.
- Not all regions of the world have the same freshwater resources, and water scarcity is a situation in which the relationship between water use and availability exceeds a certain threshold.
- ‘Water quality’ refers to all aspects of water quality necessary to preserve the sustainability of ecosystems, biodiversity and human well-being.
- There are two types of pollution sources: point and non-point sources.

PERSONAL NOTES

LEAFLET 3

Water for plant development

TRAINING OBJECTIVES

At the end of this training sequence, the participant must be able to:

- understand the role and importance of water for plants;
- define water requirements for crops;
- understand the role of soils and the processes used in soils to release water for plant development;
- define water requirements for crops under irrigation.

KEY MESSAGES

1) The role and importance of water for plants

- Water is the basis of many physiological processes necessary for plant growth.
- The main process that causes water to circulate in plants is perspiration.
- Perspiration is the emission of water vapour by plants or evaporation.
- The gradient of water potential from leaves to roots depends of the plant sweating.
- The transpiration rate of plants depends on the availability of water in the plant and in the soil, and the energy available for vaporising water from the leaves of the plant.
- Turgidity guarantees mechanical stability of plant tissues so that they do not weaken and their physiological processes are not inhibited.
- The 'soil water content' determines the maintenance of plant turgidity.
- The 'wilting point ' (WP) is the water content of the soil below which the plant can no longer take the water it needs. The WP is reversible until the permanent wilting point (PWP) is reached.
- The 'permanent wilting point (PWP)' is the threshold at which the continuous flow of water into the xylem, and the plant tissues, is interrupted. The plant dies when the PWP is exceeded.
- Water plays an essential role in plant nutrition. Water carries sugars and nutrients, but sometimes also systemic pesticides, in the plant.

2) Water requirements for crops

- Crop water requirements are defined as the depth or amount of water required for evapotranspiration (ET) of a given crop.
- Crop water requirements are fully correlated with crop evapotranspiration.
- The ET is the sum of transpiration by the leaves of plants and evaporation from the soil surface.
- Evaporation covers all processes in which liquid water is released into the atmosphere as water vapour.
- Crop water requirements are based on its four growth phases: initial phase, development phase, mid-season phase, and post-season phase.
- To calculate the water requirements of a crop, consider the 'potential evapotranspiration' (PET).
- To calculate the PET, a coefficient (Kc, specific to each type of crop), which depends not only on the crop but also on soil moisture, is used. The coefficient Kc is multiplied by a stress coefficient Ks (Ks is 0 at wilting point and 1 at field capacity).
- The Kc value generally oscillates from 0.5 when the soil is 25-40% covered, to 0.7 when the soil is 40-60% covered. As a crop grows, the soil cover can increase from 10% to 100% (full soil cover by the crop).
- At the end of the season (end of season phase), the final value of Kc reflects the quality and sustainability of water management practices according to crop needs.

3) Soils and water

- The amount of water available to the roots is determined by the soil moisture content and the water retention properties of the soil around the roots.
- The loss of stability of the plant due to a loss of turgidity of its cells causes its wilting, hinders its growth and ultimately leads to the death of the plant.
- The amount of water made available to crops by the soil depends on water and soil processes as well as the water needs of plants.
- Soils provide plants with physical support, air, water, nutrients, protection against toxins and a ventilation system.
- Knowledge and management of soil chemistry is essential to provide the best growing conditions for crops.
- The porosity of the soil determines its water retention capacity and characterises its permeability, *i.e.* the circulation of water in and through the soil.
- The soil water content (SWC) is the amount of water retained by the soil.
- A soil is saturated when, after rainfall or irrigation, all the pores of the soil are filled with water.
- Saturated soils do not contain air, while plants and their roots need both air and water to develop.
- 'Field capacity' (FC) is the situation where the air and water content/proportion is considered ideal for plant growth. At field capacity, large soil pores hold air and water and the smaller soil pores hold water.

- Soil moisture content is often calculated using the concept of 'root zone drying', which refers to water scarcity in relation to FC.

4) Water requirements for crops under irrigation

- The estimation of water requirements for crops under irrigation must take into account the prior establishment of the soil's water balance.
- The FAO CROPWAT model, through its planning module, can be used to calculate the daily water balance of soils before they are irrigated.
- To ensure the proper management of gravity irrigation, CROPWAT uses a default value of 70% irrigation efficiency.
- The default value of CROPWAT corresponds to a net irrigation depth of 70% of the volume of the gross irrigation depth.
- The actual volume of water required for irrigation can also be calculated in cubic metres (m^3): irrigation requirements expressed in millimetres (mm) are transformed into metres (m) and multiplied by the area (in m^2) of the field concerned.

PERSONAL NOTES AND REFERENCES OF THE MATERIALS USED

LEAFLET 4

Agriculture and water quality

TRAINING OBJECTIVES

At the end of this training sequence, the participant must be able to:

- identify the impact of agriculture on water quality;
- better understand the importance of water quality for agriculture;
- understand how the farmer can avoid water pollution.

KEY MESSAGES

1) Impact of agriculture on water quality

- Water quality standards and regulations are used as a reference to describe levels of pollution of surface water or groundwater.
- Agriculture and water quality are closely linked, it is both a source of water pollution and a victim of it.
- There are two types of agricultural pollution sources: point and non-point sources.
- The main water quality problems directly related to agriculture are: salinisation, nutrient loads to water sources and pesticide pollution.
- ‘Saline’ (or ‘sodium’) water becomes a risk to crop growth and yield because of dissolved salts such as: sodium chloride (Na^+Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfate (SO_4^{2-}) or bicarbonate (HCO_3).
- High salt concentrations impede water uptake by plants and result in lower crop yields.
- Sodium (Na^+) has a greater impact on soils and crops than other cations.
- Poor agricultural practices also have a direct impact on water quality, the deposition or accumulation of sediment in water due to soil erosion.
- The release of pathogens into water is an indirect pollution problem.
- The presence of high levels of nutrients in the water causes the proliferation of aquatic plants, phytoplankton, algae and macrophytes.
- Excess nutrients in the water cause hypoxia (or low oxygen level in the water) and anoxia (or lack of oxygen in the water) problems.

2) Importance of water quality for agriculture

- Millions of farmers around the world routinely use poor quality water for crop irrigation.
- Poor water quality has negative effects on crop yields.
- Poor chemical water quality creates risks of salinity/toxicity to soils, plants and corrosion or obstruction of irrigation system pipes.
- The poor physical quality of the water leads to blockage problems due to suspended solids and other impurities.
- Poor biological water quality is a source of the proliferation of pathogens that are harmful to human and animal health, soils, plants and even the irrigation system (drip plugging).
- Waste and/or polluted water must be treated before its use in agriculture or after an analysis of the various parameters, but based on existing guidelines, in particular those of WHO or FAO.

3) Water pollution from agriculture can be avoided

- Awareness of the major impacts of agriculture on the environment and health is an indisputable prerequisite for avoiding water pollution by agriculture.
- Water pollution from agriculture can be prevented or reduced in two ways: by treating wastewater and reducing the release of pollutants into the environment.
- Treatment is an option for point sources of pollution, because effluents are easily collected and treated.
- Practices to reduce pollutant releases to the environment include: the nutrient management plan, integrated plant nutrient management (IPNM) and integrated pest management (IPM).
- Erosion control, agricultural runoff recovery and treatment, as well as recycling are also practices to reduce pollutant releases to the environment.

PERSONAL NOTES AND REFERENCES OF THE MATERIALS USED

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LEAFLET 5

Irrigation

TRAINING OBJECTIVES

At the end of this training sequence, the participant must be able to:

- identify the different irrigation methods;
- make a judicious choice of appropriate irrigation methods;
- understand the design and layout of irrigation systems;
- identify potential irrigation water sources;
- understand the importance of collecting, storing or recycling water;
- understand the elements important for the performance of irrigation systems.

KEY MESSAGES

1) The different irrigation methods

- Irrigation techniques and methods used in agriculture are a direct legacy of centuries of technological development and are present in all civilisations.
- The wide variety of existing irrigation methods can be divided into two main categories: gravity irrigation (by submersion or basins, furrows or borders) and pressure irrigation (by spraying or drip irrigation).
- The gravity irrigation method is used on gentle, regular slopes and on soils with a medium to low infiltration rate, with a medium to fine texture.
- The submersion irrigation method (or basin irrigation) is not very efficient, because more than half of the water is lost (evaporation, runoff, leaching) but it allows to control some pathogens.
- The furrow irrigation method is characterised by the construction of trenches or gutters, dug between rows of seedlings where water flows by gravity, which allow irrigation to be managed more efficiently. It is used for crops in tight rows or in orchards.
- The edge irrigation method is a variant of bowl irrigation that is suitable for sloping land, usually of elongated and rectangular shapes.
- Furrow irrigation can be carried out in the presence of the vegetation cover.
- In furrow irrigation, the water body is less extensive and evaporation losses are lower.
- The sprinkler irrigation method is based on the natural rain model and, although used worldwide on small and large fields, is particularly recommended in water-deficient regions.

- The efficiency of the sprinkling sometimes exceeds 75%, but it is not possible when the winds are too strong.
- Drip irrigation consists of watering each plant separately with a specific amount of water, and, using drippers, bringing the water constantly to the same place.
- The drip system exists by gravity (small systems) or under pressure.

2) The choice of appropriate irrigation methods

- Irrigation aims to supplement crop water requirements when rainfall is insufficient to ensure optimal crop growth.
- Irrigation may be necessary to ensure optimal crop yield but this will depend on the method used and the overall good management of the irrigation system.
- The choice of an irrigation method takes into account: the natural conditions, the type of crop, the particularities of the method, with its advantages and disadvantages, as well as various natural, social and economic factors.
- The natural conditions to consider are: soil type, slope, climate, water availability (constant or not) and water quality (salinity).
- All irrigation methods have advantages and disadvantages: what is crucial is to have a good knowledge of local conditions before making a decision.

3) Design and development of irrigation systems

- The choice of appropriate irrigation methods precedes the selection of the 'irrigation system' which must be adapted to each particular situation (development cost and maintenance cost, for example).
- Various irrigation systems are possible, adapted to different scales and to use different water sources.
- To develop an irrigation system, it is essential to know the water availability in the geographical area concerned.
- The installation of a pressurised irrigation system, consisting of a network of pressurised pipes, requires the design of a detailed plan and the assistance of a specialist.
- The pressure irrigation system is complex and includes a pump, pipes, fittings, flow control systems, filters, etc.
- The design of a pressurised irrigation system requires a general preliminary approach (surface, emission method, water requirements).
- The pressurised irrigation system requires rigorous monitoring at all stages of implementation.
- Fertiliser irrigation in pressure irrigation systems is the combined administration of nutrients (Fertiliser) and water to a crop. Incorrect implementation can damage crops and pollute the environment.
- Hydroponics systems, which consist of growing above ground or in an aquatic environment in a greenhouse, are efficient and productive because plants receive exactly what they need, when they need it.

- Hydroponic systems that operate in a closed circuit minimise the environmental impact of water-related pollution.
- Drainage plays a very important role in irrigation because it eliminates excess irrigation water from irrigation systems, prevents salinisation, prevents the lowering of the water table and eliminates salts and toxins that have accumulated.
- A drainage system consists of a main drain, targeting both surface and deep drainage, and a pour point.

4) Irrigation water sources, water collection, storage and recycling

- The water source used for irrigation depends mainly on the availability of water in a given geographical area (sometimes access to water must be shared).
- The various sources of water are: groundwater from springs, wells or boreholes, and surface water from rivers, lakes or reservoirs.
- The use of non-conventional sources such as wastewater, desalinated water, collected rainwater, or drainage water is possible.
- It is important to plan how to capture water when the water source is identified.
- Rivers are often used for irrigation, but the flow is not constant (flow variation) and therefore the amount of water available fluctuates over time. Dams regulate water levels and facilitate collection.
- Collection, which can be done on the supply channels through water intakes equipped with valves, is easily controlled.
- Collection can also be done by pumping when the water cannot be diverted by gravity (pumping is more expensive than storing in a dam).
- Water storage (river, rainwater) is possible through the artificial construction of reservoirs, or water from a river can be diverted to the dead arms of the river, or accumulated in a valley (control dams).
- Water stored in a reservoir is used for irrigation by the gravity system, or by the pipe system or pumped upstream during the dry season.
- Groundwater is extracted either naturally, directly at the source, or artificially, by pumps and/or wells.
- The basic principle of groundwater use is that water extraction should never exceed replenishment.
- Control dams increase water infiltration to the groundwater table.
- Twig mattresses made of brush, tree branches and stems, earth plugs, are designed to collect rainwater flowing on the ground and direct it to the basement to store it.
- Wastewater (sanitary) can be recycled but its chemical and biological quality must be checked.
- The combined use of several water sources is the best way to ensure a sustainable and efficient water supply in the long term.

5) Performance of irrigation systems

- The performance of irrigation systems is assessed in two ways: from the point of view of irrigation efficiency (IE) and distribution uniformity (DU) (DU is a measure of how evenly water soaks into the ground across a field during irrigation).
- System irrigation efficiency (IE) is the percentage of the volume of water captured, and directed to an irrigation system, which is actually used (evaporated) by the plants.
- EI, which is essential to improve hydraulic efficiency, is reduced to two factors: transport efficiency (ec) and irrigation application efficiency (ea).
- Ec is the efficiency of water transport from source to field, which depends on: the length of the pipes, the permeability of the soil type, the condition and maintenance of the canals.
- Ea is the efficiency of water application in the field, which depends mainly on: the irrigation method used and the farmer's discipline (gravity: 60%; drip: 75-90%).
- Water use efficiency of productivity (WUE) is defined as the ratio of dry matter produced to the rate of transpiration.
- Water storage plays a crucial role in IE because knowing the quantity of water stored and the storage conditions allows us to control its availability.
- The parameters that determine irrigation efficiency are: the volume of water captured and stored, storage and distribution methods in the field, infiltration into the soil, evaporation at ground level, water retention capacity, crop type and drainage needs.
- The hydraulic yield of irrigation is the ratio between the quantity of water captured and the agricultural yield or profit generated.
- Distribution uniformity (DU) indicates the extent to which water seeps uniformly into the soil during irrigation. It varies from 100 to 0%. DU is a measure of the performance of the irrigation system.

PERSONAL NOTES AND REFERENCES OF THE MATERIALS USED

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LEAFLET 6

Irrigation management

TRAINING OBJECTIVES

At the end of this training sequence, the participant must be able to:

- describe irrigation management;
- understand and apply appropriate measures for efficient use of irrigation water;
- diversify irrigation water sources through the management of drained water;
- understand the importance of implementing measures to reduce the environmental and social impacts of irrigation.

KEY MESSAGES

1) What is sustainable irrigation management?

- Sustainable irrigation management is about using water in the most effective and efficient way possible.
- Effective and efficient irrigation management aims to save energy and minimise pollution and other negative environmental and social impacts.
- Good management must be applied to all stages of the irrigation system put in place.
- The different steps are: sampling or pumping, transport and distribution to the field and drainage. Each step is a ‘system’ to be analysed.
- Effective and efficient management means water conservation.
- Water conservation is possible through any reduction in water use, loss or waste.
- Water conservation also refers to improved water management and agricultural practices that optimise the use of water resources for the benefit of people and the environment.

2) Appropriate measures for efficient use of irrigation water

- Measures adopted for the efficient use of irrigation water are aimed at water conservation.
- The best results are achieved when water conservation efforts are coordinated at the farm and watershed levels.
- In an irrigation system, water conservation is achieved by reducing losses during the supply and transport of irrigation water, and by improving agricultural practices.

- In an irrigation system, water conservation is also achieved through optimal timing of irrigation water inputs based on careful planning.
- The efficiency of irrigation water transport is obtained by the efficiency of the supply and the efficiency of the application on the field.
- The appropriate measures are derived from the distribution of water from the source to the farm and, on the farm itself, the ratio between the water used and the water spread on the field.
- The transition from an open channel system to a pipe system is a means of limiting water losses through percolation or infiltration into the ground, or through evaporation.
- The sharing of responsibilities and work for the inspection, maintenance and repair of canals, facilitates the establishment of an effective irrigation water conservation system.
- Proper irrigation planning is essential to improve hydraulic performance at the farm level.
- The essence of irrigation planning is to determine when and how much water crops need.
- The FAO CROPWAT 8.0 model is a practical tool for irrigation planning.
- Deficit irrigation planning allows the operator to optimise the use of available water, especially when available water quantities are limited.
- Smart irrigation uses innovative technologies that help farmers to more accurately determine crop water requirements in quantity and time.
- Agricultural practices that include conservation tillage, cover crops, crop rotations, windbreaks, and other wind erosion control measures are measures to be considered in water conservation.

3) Management of drained water

- Drainage water management is an integral part of irrigation management, as good drainage management increases water use efficiency and reduces pollution.
- Drainage should create a root environment suitable for plant growth with sufficiently aerated soil and manage the salt content in the root zone.
- Good drainage water management practices include groundwater level management, drainage water reuse, drainage water treatment and grassed strips.
- Limiting the flow of water through an underground drain makes it possible to manage the water table level and raise it.
- Drainage water reuse is a solution in cases where water supply is limited to reduce nutrient loads in receiving waters.
- Drainage water treatment can be achieved by using filters made up of plantations (strips or areas of vegetation) that are effective in removing sediment, organic matter and other pollutants from drainage water leaving the fields

4) Measures to reduce the environmental impact of irrigation

- Measures to reduce the environmental impacts of irrigation are mainly concerned with salinity management.
- Salinity control practices include reducing salt intake, selecting suitable sites and crops, and applying good soil and/or water management practices.
- Good soil and/or water management practices include: crop selection, acid injection into drip irrigation systems and irrigation planning.
- Seedbed layout and maintenance of soil organic matter (OM) are also good soil and/ or water management practices.

5) Measures to mitigate the social impacts of irrigation

- The use of irrigation water often leads to a reduction in the water available for other uses, particularly for domestic uses.
- Reduced water availability or increased pollution has negative impacts on ecosystems and their services.
- Limiting social impacts goes hand in hand with sustainable and responsible water management, and good irrigation practices.
- Environmental impacts also have social impacts, *i.e.* they directly affect the population.
- Measures to mitigate the social and environmental impacts of irrigation must be based on knowledge of local regulations.
- The complete irrigation system must be designed to integrate harmoniously with the local political situation and context.
- Participatory irrigation management (PIM) is an advisable measure to mitigate the social impacts of irrigation.
- A 'water and irrigation management plan' is a good measure for mitigating the social impacts of irrigation to ensure the best possible water management.

PERSONAL NOTES AND REFERENCES OF THE MATERIALS USED

LEAFLET 7

Water management for washing and post-harvest treatment

TRAINING OBJECTIVES

At the end of this training sequence, the participant must be able to:

- understand the importance of post-harvest water management;
- identify water-related problems during washing and post-harvest treatments;
- consider water conservation during washing and post-harvest treatment;
- explain the relationship between post-harvest water use and food loss.

KEY MESSAGES

1) Post-harvest water use

- Post-harvest water management is essential to maintain the quality of the harvested product until it is consumed.
- Sweating of the fruit or evaporation of water affects the weight, appearance and quality of the harvested product.
- Post-harvest water is a potential source of contamination, and it is important to understand and manage the associated risks.
- The amount of water consumed after harvest to wash and treat the products is significant, and most of the water used returns to the system as effluent.
- The use of water for washing post-harvest products is subject to quality standards and the regulations in force must be respected.
- The control of water quality and temperature criteria is essential for the use of water in post-harvest phytosanitary treatments.
- Water plays an important role in packaging and storage, especially for perishable foods with short shelf lives.

2) Water problems during post-harvest washing and treatment

- To ensure the continued availability of clean water for post-harvest uses, problems related to appropriate distribution infrastructure and the quantity of drinking water are recurrent.
- The water used for cleaning, washing or packaging operations is often contaminated by pollutants.
- Wastewater effluents generally have negative effects on other water users or on the environment.

- Effluent management requires a verification of contaminants: its must be decided what form of discharge is appropriate and whether treatment before discharge is necessary.
- A risk assessment to determine the degree of hazardousness of contaminants must be implemented, measures must be taken to avoid them or to mitigate their environmental impacts.

3) Water conservation during washing and treatment

- Effluent treatment and recycling are water conservation measures that must be applied after harvesting.
- For recycling, domestic water purification devices exist and allow process water to be reused for certain domestic uses.
- Treatment and recycling can be achieved through ultrafiltration, a system that significantly reduces water and energy use, while providing high levels of water quality.
- An agricultural holding may install a small purification unit to treat its effluents, allowing it to reuse the contaminated water in its conditioning plant, for irrigation or for domestic purposes.

4) Post-harvest water use and food losses

- Poor water and moisture management in the post-harvest stages generates significant losses and leads to the waste of harvested products.
- Significant losses and waste of harvested products result in food safety problems and deterioration of product quality.
- Most food losses occur after harvest and during processing.
- Sustainable water use and improved post-harvest product handling are of crucial importance, particularly in developing countries.

PERSONAL NOTES AND REFERENCES OF THE MATERIALS USED

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LEAFLET 8

Water rights, extraction and sustainability of water use

TRAINING OBJECTIVES

At the end of this training sequence, the participant must be able to:

- understand the origin of the right to water and its evolution according to time, local customs and the history of the place;
- define the right to water (according to FAO);
- understand the role of farmers in the right to water and in the management of water resources, especially horticulturists;
- know the quality requirements of water bodies (legislative framework);
- understand the principles of IWRM (integrated water resources management);
- understand what is involved in private sector interest in water management and the requirements embedded in private voluntary standards such as GLOBALG.AP.

KEY MESSAGES

1) Understanding water legislation: the right to water

- Mechanisms for regulating water use or access have developed differently from one society to another over time (local customs; Roman law in Europe)
- Local customs and customary law are alive and well, and must be considered.
- European regulations strongly influence the legislation of many States.
- The end of the 20th century saw the beginning of the process of water sector reform and water legislation moving towards a rights-based approach to water
- The FAO defines the right to water as *"a legal right to extract and use a volume of water from a natural source such as a river, stream or aquifer"*.
- In an irrigation system, a farmer has a right to a certain volume of irrigation water from a supplier (for which he pays a certain price).
- Water rights under water legislation should not be confused with the 'human right to water' recognised by the United Nations.
- In situations where water resources are scarce, modern water legislation can determine which uses prevail over others ('water use hierarchy').
- A 'right of reservation' may also exist in some countries to guarantee basic and ecological needs.

- Modern water legislation also addresses water quality and other environmental aspects related to water use and management (e.g. EU Water Framework Directive).
- Good surface water 'status' means the status achieved by a body of surface water when its ecological and chemical status is at least 'good'.
- It is important to understand how horticulturalists can participate in the governance and allocation of water resources.
- Current water laws often require a high degree of transparency.
- The value of horticultural products per volume of water consumed is often higher. In other words, they allow for greater economic productivity of water.

2) Guiding the action: why and where to start?

- At the 1992 Rio Summit, UN Member States endorsed the integrated water resources management (IWRM) strategy as the way forward for the efficient, equitable and sustainable development, and management of the world's limited water resources.
- IWRM is based on 5 principles.
- In 2012, 80% of countries reported that they had initiated reforms to improve the environment for integrated water resources management; risks and rivalries had also increased.
- The private sector has become increasingly interested in water resource management.
- The assessment of the 'water footprint' has been standardised through the Water Footprint Network and ISO 14046.
- GLOBALG.A.P. has introduced water requirements into its Integrated Farm Assurance (IFA) standard.
- Advanced tools to understand water-related risks for companies have been made freely available (e.g. AQUEDUCT).
- In order to make the best use of water in the most productive, efficient and sustainable way possible in horticulture, the 5 principles of IWRM must become an integral part of water use and agricultural practices.
- A 5-step approach is proposed to incorporate integrated water resources management into a horticultural environment.

PERSONAL NOTES AND REFERENCES OF THE MATERIALS USED

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Summary of the manual

Sustainable water management

Water is essential to life and is used daily in our homes for drinking, washing, cooking and cleaning. The physiological requirement for drinking water is 2 to 4 litres per person per day, but total water consumption varies from 47 litres/person/day in Africa, 95 litres/person/day in Asia, 334 litres/person/day in the United Kingdom and 578 litres/person/day in the United States.

Water is also necessary for **food production, and most of the water we consume is incorporated into the food we eat.** Thus, it takes between 1,000 and 3,000 litres of water to produce 1 kg of rice, and about 2,000 to 5,000 litres of water to produce a person's daily food needs.

1. HYDROLOGICAL CONTEXT OF AGRICULTURE

Agriculture is the largest consumer of fresh water, with about 70% of the world's freshwater withdrawals from watersheds and lakes, compared to 22% for the industrial sector and 8% for households.

The most urgent problems facing agriculture worldwide are as follows:

- growing demand for agricultural products: increased competition for land and water resources;
- water scarcity: water is a limited resource;
- climate change: agriculture contributes to it while being affected by it;
- degraded lands and ecosystems: soil and water quality must be sufficient to provide suitable conditions for crop production;
- energy needs: food production consumes a lot of water, but also a lot of energy;
- environmental impacts: while increasing production, to meet growing demand, agriculture must minimise its negative impacts on ecosystems and human health.

These global problems mean that agriculture must use resources, especially water, more efficiently. This applies to all sectors of the economy, but particularly to agriculture, which is the world's largest water user.

Water in food production and agriculture's participation in meeting food needs

According to FAO, agriculture includes animal and plant production (plants, fungi, fibres and bioenergy crops). Food production represents only a part of agriculture. According to the FAO, "food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". In its 2015 report, FAO points out that about 795 million people are undernourished worldwide, a **decrease of** 167 million people over the past decade, and 216 million fewer than in 1990-1992. The global food security problem is exacerbated by the projected growth of the world population, which is expected to increase from about 7 billion in 2012 to 9.6 billion in 2050, as well as by **changing consumption patterns.**

Water is considered a renewable resource, since it circulates on the Earth's surface by completing the water cycle. But although renewable, **water remains a finite resource, which** means that the amount of water available on Earth is limited.

Fresh water is an essential factor of production for our economies and for life in general, but also a resource that faces many present and future challenges. According to UNESCO, by 2025:

- water withdrawals will increase by 50% in developing countries and by 18% in developed countries;
- the world's seven billion inhabitants currently use 54% of the fresh water reserves available in watersheds, lakes and groundwater;
- worldwide, more than one in six people do not have access to the volume of 20 to 50 litres of safe fresh water per day per person recommended by the United Nations for drinking, cooking and washing;
- every day, **2 million tonnes of human waste** are dumped into rivers and pollute usable water supplies.

The United Nations General Assembly explicitly recognizes **the human right to water** and sanitation (2010 resolution). Through this resolution, all the nations of the world recognised that **water plays an essential role in all human societies**.

Activities, from industry to tourism, are growing rapidly and all require more and more services involving water use. This puts pressure on water resources and natural ecosystems, and fosters competition between water-using sectors. Increased agricultural production significantly increases water consumption and can put the agro-industrial sector in competition with local communities. According to the Global Water Forum, increased consumption of water for export agriculture, for example, would have had negative impacts on local ecosystems and populations, while increasing water scarcity.

Water pollution significantly increases pressures on the water sector. According to UNEP14, while developed countries have seen improvements in surface water quality in recent decades, many other regions of the world are experiencing the opposite trend. This increase in water pollution poses a risk to public health, food security, and livelihoods. **Water quality has become a global issue,** but UNEP remains optimistic that there are feasible solutions to this challenge, such as wastewater treatment and new forms of water governance.

Water, food production and agriculture are sectors under pressure, as is the energy sector itself. This pressure is expected to increase in the coming years. As these sectors are closely linked, promoting dialogue between them, both locally and globally, will be essential to meet the challenges they face more and more frequently.

The agriculture of the future

According to the WRI, agriculture will have to achieve a subtle balance in the coming years and should make it possible to envisage a sustainable future in terms of food. This requires **the simultaneous achievement of the following three objectives:**

- close the food gap by producing enough food to meet the population's needs by 2050;
- supporting economic development;
- reduce the environmental impact of agriculture.

To achieve this balance, organisations such as the United Nations DESA and FAO are promoting the development of agriculture from being managed as an extractive industry to **becoming a more renewable activity.** This development is based on the following principles.

- **Inclusion**: addressing the challenges faced by small and medium-sized farmers and women farmers to ensure their full participation in agriculture and value chains.
- **Resilience** to climate change: FAO has proposed an approach to create the technical, political and investment conditions that will enable the development of sustainable agriculture that will ensure food security under climate change conditions. This approach concerns not only varieties of crops resistant to climate change, but also the application of the concept of intelligent agriculture in the face of climate (AIC).
- **Greater hydraulic efficiency:** agricultural practices must be adapted to increase crop and water productivity. This means more food production per drop of water. This principle requires the adoption of better crop and soil management practices, such as organic matter management to improve soil structure or cover and reduce evaporation, in order to reduce irrigation needs.
- **The search for high yields through healthy agro-ecological systems** by investing in agricultural systems that respect water resources to restore soil health, conserve natural habitats, and restore degraded agricultural and pastoral habitats.
- **Integration of agricultural water management** with integrated water resources management (IWRM): Integrated water resources management is based on the principle that water is an integral part of the ecosystem, and that it is a natural resource as well as a social and economic good that must be protected.

The impact and role of agricultural practices and irrigation in sustainable water management

Agricultural practices have **major impacts on the efficient** use of resources such as water, land and other agricultural inputs. It is useful to examine agricultural practices from the perspective of a more rational use of resources, before studying technological solutions, including new irrigation techniques. To do this, the **operator must have an integrated view of his/her farm and its surroundings,** taking into account the situation, climate, soils, crops, quantity and quality of water required, as well as the needs for Fertilisers and pesticides. The operator can therefore **plan and implement farming practices that are** financially and operationally feasible, **and will lead to greater efficiency** and profitability for the farm.

To survive and develop, crops need water; it can be provided either by rain-fed or irrigated agriculture. Of the estimated 1.4 billion hectares of cultivated land in the world, about 80% is dependent on rainfall and accounts for about 60% of crop production. **Irrigated agriculture occupies the remaining 20% of** cultivated land, which covers about 280 million hectares and **represents 40%** of world food **production**. Crop intensity levels and higher average yields explain the higher productivity levels of irrigated agriculture. According to IFAD, **irrigation increases yields by 2 to 5 times for** most crops.

In addition, irrigation allows diversification to higher value crops that consume large amounts of inputs and depend on a reliable and flexible water supply.

The importance of irrigation must be taken as a central element in efforts to achieve food security. Attention is also drawn to **two common and undesirable side effects of** irrigation projects.

- Irrigation projects seek to **favour the richest farmers** and therefore leave the poorest out. The inclusion of the poor in irrigation projects is described as a prerequisite for strengthening rural economies, improving access to food, and thus reducing poverty and malnutrition.

- Irrigation plans often upset local balances, rights and customs, devalue environmental and agricultural **knowledge**, and the experience that farmers have accumulated from generation to generation.

Irrigation plays a fundamental role in achieving more resilient, efficient and productive agricultural systems. The solution lies in the development of irrigation systems, within the framework of a sustainable management approach that takes into account the principles of 'agriculture of the future', the global context described, and local realities and policies.

Horticultural considerations

The general problems described for the entire agricultural sector also concern the horticultural sector and may even be **more complex in the case of resource-intensive crops,** which allow high value-added production and whose field operations, post-harvest operations and processing **require significant supplies of good quality water.**

The horticultural sector faces risks and challenges related to the effective and efficient management and use of water. At the global level, the horticultural sector plays an important role in solving global food and water production problems.

- Fruits and vegetables are an essential component of the human diet, in addition to cereals and other crops.
- The current global trend towards increased meat consumption is a cause for concern, as livestock farming has a much larger footprint on water resources than cereals or plant products. Given the pressure that will be exerted in the future to produce more food with less water, plant production will be of increasing interest as a source of protein.
- The economic potential of fruit and vegetables per unit of land is generally higher than that of cereals and other crops. The **economic profitability compared to water use in this sector is therefore on average higher.** The development of this sector plays a major role in achieving the objectives of poverty reduction and food security, but this goal must be achieved through the implementation of responsible water management, and in accordance with the agricultural principles of the future.

The horticultural sector also faces many challenges and some problems specific to horticulture, particularly in Africa. The benefits and difficulties of horticulture show that the development of this sector represents a real business opportunity, while continuing efforts to achieve a more efficient use of resources and to minimise the sector's environmental impacts.

2. FOUNDATIONS OF THE GLOBAL WATER SYSTEM

Water is the most important resource for life on Earth and its molecule is composed of an oxygen atom and two hydrogen atoms linked together by covalent bonds. Under normal conditions of pressure and temperature (1 bar at 20 °C), water behaves like a liquid, but it is also present on Earth in solid and gaseous form. In its liquid form, water is odourless, tasteless and transparent.

Basic concepts of the water cycle

The amount of water on Earth is about 1,386 million km^3. Of this volume, about 97% is saline water from the oceans. **Fresh water represents about 3% of the water on Earth and is not fully available for human consumption.** About two-thirds of freshwater is stored in ice caps and glaciers. The remainder is found in aquifers and surface water units such as lakes, rivers and wetlands. Less than 1% of all the world's water resources are directly accessible for human use and are not even uniformly distributed around the world. Today, nearly a third of the world's water resources are found in South America. A**frica and Europe, on the other hand, have barely 15% of all available water resources.**

Water on Earth is extremely dynamic with changes in temperature and pressure in the Earth's environment. Water changes from a gaseous state to a liquid and solid state, and vice versa. At 1 bar and 0 °C, pure liquid water turns into ice, the mobility of the water depends on the phase in which it is present:

- ice is less mobile than liquid water;
- liquid water is less mobile than water vapour.

Gravity, topography, climatic zones, wind, temperature and pressure variations not only cause water to change phase, but also allow it to move on the Earth in its different phases. The continuous phase change of water, combined with its movement around the Earth, is called the hydrological cycle. To describe the water cycle, it is necessary to start with the ocean.

- **Water vapour:** the sun heats the ocean surface and when the surface tension of the ocean is broken by the wind, the water evaporates. Water vapour is warmer than ambient air over the ocean. As a result, the air containing the water vapour rises. The oceans are not the only sources of water vapour; other sources include inland water bodies, direct evaporation of water from the soil, and plant transpiration. Steam is also produced directly by sublimation of the ice.
- **Groundwater:** water that falls as rain on the Earth's surface flows under the action of gravity. It flows in different directions, depending on the physical characteristics of the soil, geomorphology and geology. Water can flow over land by surface runoff and reach streams and rivers, lakes and other inland freshwater bodies before returning to the ocean. **Water that does not run off can evaporate from or infiltrate the soil, in which case it can be used by vegetation in the transpiration process.** Water that seeps deeper into the soil becomes groundwater.

The water cycle is much more complex and recent studies show that precipitation falling on the land in one region of the planet is highly dependent on water evaporation from the land in other regions.

Moisture generated by soil evaporation contributes significantly to rainfall. The **water cycle connects parts of the world that are very distant from each other.** Evaporation from soil and plants is also highly variable. Some plants and crops are characterised by a higher evaporation of water than others. These facts illustrate three important points:

- there is a strong link between soil evaporation and precipitation;
- the water cycle takes place over long distances;
- there is a link between evaporation, moisture, crop production and health.

This means that human activities and land use in one place have a significant impact on the condition and availability of water for agriculture, energy, livestock, industry and households in other places.

Hydrological units, river basins and aquifers

In a landscape, the process of 'flowing water to the lowest point' is at the origin of rivers. All the watercourses in the area that feeds the river are called a **watershed or river basin**. In a watershed, small streams meet to create larger rivers. Hydrologists and hydrogeographers study and explain the movement and distribution of water in geographical units of varying sizes. They are called hydrological units.

- **A hydrological unit** is the geographical area covering part or all of a watershed, or a distinct hydrological element such as a reservoir, lake, aquifer or artesian well (NOAA, 2015). The terms 'watershed' and 'river basin' are used interchangeably. All these hydrological units are defined as a delineated geographical area from which water from various sources converges to a common stream or outlet.
- **The nature and shape of watersheds** are determined by topography, geology and water. A watershed with an outlet to the sea is an 'exoreic basin'. If the waters of a watershed converge on a continental body of water, such as a lake, it is called an 'endorheic basin'.

A watershed is always delimited by a **watershed line**, which is only an imaginary line separating a watershed from other contiguous watersheds. Watersheds are the highest 'lines', at the top of hills or mountains that surround rivers.

Water does not only run off on the surface: it also seeps into the soil and rocks deeper down. This process results in the **creation of a hydrological unit called an aquifer. Aquifers are** groundwater **reservoirs** and can store water for long periods of time that can last thousands or even millions of years. There are two types of aquifers:

- a free-water aquifer is covered with permeable rocks and can receive water from the surface;
- a confined aquifer is a body of groundwater located between two layers of less permeable rocks.

In general, aquifers naturally replenish with water from surface water bodies, rain, melting ice or snow, through the process of deep percolation.

Water leaves aquifers in different ways:

- it can occur naturally from **springs** and thus be added to surface water resources;
- it **can be extracted artificially by wells or pumping wells** for households, agriculture or industries.

The balance between extraction and replenishment is essential for sustainable groundwater management. As a general rule, for good groundwater management, the volume of water extracted from an aquifer must always be less than or at most equal to the replenish volume. In addition, groundwater is increasingly affected by **water quality problems.** Groundwater is polluted if water containing biological or chemical pollutants infiltrates the aquifer; or if it is overexploited, it **becomes saline as a result of salt water infiltration.** Groundwater management therefore requires not only attention to quantity issues, but also careful consideration of water quality issues.

Hydrological balance of a basin

The basic method for understanding the hydrological state of any basin is to produce a '**water balance**'. The water balance of a system over a given period of time takes into account everything that enters and leaves the system, as well as all changes affecting water accumulation. The concept of water balance makes it possible to understand the hydrological behaviour of a hydrographic basin.

To estimate the water balance of a basin, a **distinction must be made between green and blue water:**

- **green water** refers to the part of precipitation that evaporates or is transpired by plants;
- **blue wate***r* refers to water that flows into rivers and streams, as well as water that infiltrates and percolates into aquifers.

The water balance of a river basin is expressed in volume units: cubic metre (m^3) or million cubic metres (Mm^3). **Irrigated agriculture uses both green and blue water** if crops use both soil moisture from rainfall and irrigation water from surface and/or ground sources. **Blue water consumption needs, *i.e.* irrigation needs,** depend mainly on local climatic conditions. **Grey water** comes from the collection, recycling and reuse of green or blue water that has already been used for various purposes.

The required environmental flows

'**Required environmental flows**' refers to the quantity, quality and seasonality of **blue water flows, necessary to maintain the sustainability of** freshwater and estuarine ecosystems as well as the livelihoods and well-being of people who depend on these ecosystems, according to the Brisbane Declaration (2007). In order to combat this degradation and preserve rivers as well as the productivity and biodiversity of their ecosystems, the Declaration commits to **establish environmental flows for all the world's rivers** and to work towards their integration into water management frameworks and strategies.

In the case of green water, the environmental need for green water is defined as "the amount of green water from land that must be conserved to preserve nature and biodiversity as well as the livelihoods of people who depend on ecosystems in natural areas" according to Water Footprint Network (2015).

The environmental need for green water is also part of the framework for integrated water resources management, but in a slightly different way. **Blue and green environmental flows are important concepts for assessing the sustainability of water consumption in a given basin.** Both concepts derive from the basic principle of preserving freshwater (and estuarine) ecosystems to ensure the services provided by the river basin that human populations need.

The importance of human water consumption and water pollution

The water footprint is a proposed **indicator to** assess human appropriation and use of water. It is used to determine human consumption and assess water pollution. The water footprint has **three components**.

- **The blue water footprint** refers to the volume of surface and groundwater consumed to produce a good or service. Consumption represents the volume of fresh water used and then evaporated or incorporated into a product. It is the amount of water extracted from the subsoil or surface that does not return to the watershed from which it was collected.

- **The green water footprint** refers to the volume of water in precipitation consumed by the production process. **This indicator applies particularly to agricultural and forest products.**
- **The grey water footprint** refers to water pollution expressed as the volume of fresh water required to dilute a given load of pollutants, depending on specific natural conditions and concentrations set by ambient water quality standards. **The grey water footprint depends on the pollutant used in the calculation.**

The global average water footprint over the period 1996-2005 was 9.087 Gm^3/year: 74% green water, 11% blue water and 15% grey water. The global water footprints of the agricultural, industrial and household sectors amount to 92%, 4.4% and 3.6% of the total respectively. The blue water footprint of agriculture worldwide, *i.e.* **the water consumed by irrigation, represents 10% of the total water footprint** (945 Gm^3/year) worldwide. The main uses of freshwater vary from country to country, for example, in ACP countries, agriculture uses more than 85% of the water extracted. In **South Asia, Africa, Central America and South America, agriculture is the largest consumer of water.**

The virtual water content of a product refers to the volume of fresh water 'content' in the product, in the virtual sense. It **refers to the water consumed or polluted to produce the product,** including evapotranspiration from crops and fodder. This indicator is calculated in exactly the same way as the water footprint. These two indicators are expressed in units of water, but the water footprint also indicates where and when these volumes of water were extracted or polluted, and takes into account its impacts over time and space.

In the context of globalization, the term **virtual water import or export is used** to explain that if a country imports or exports a product, it also virtually imports or exports the water used to make the product. The import/export of virtual water has been described as a potential solution to alleviate pressure on local water resources in water-deficit areas. This concept refers to the import/export of agricultural products that consume a lot of water. Although trade is seen as a possible solution to address some of the future challenges of agriculture and water scarcity, it must be viewed with caution because of its side effects, including increased carbon emissions from transport, impacts on ecosystems and livelihoods in producing countries, and political dependence.

Water scarcity around the world and quality standards with water pollution levels

Not all regions of the world have the same freshwater resources. **Water scarcity is defined as a situation in which the ratio between water use and availability exceeds a certain threshold.** Modern water scarcity indicators attempt to integrate the required environmental flows also into water scarcity indicators.

Due to geographical differences in availability and use, **there are different models of water scarcity** around the world. Water scarcity is one of the world's major problems in the 21st century. Many countries suffer from water scarcity, and their situation may be exacerbated by weak policies, institutions and financing frameworks for water management and development.

Access to safe water for human consumption and sanitation is a prerequisite for the health and well-being of populations. Similarly, our ecosystems have an essential need for clean and unpolluted water. **Water quality is defined as the "physical, chemical and biological**

characteristics of water necessary for its intended uses". Water quality refers to all aspects of water quality necessary to preserve the sustainability of ecosystems, biodiversity and human well-being such as health, food production, and economic development. Water quality therefore has a significant influence on poverty, health and human education levels.

Two sources of pollution are generally observed.

- **Point sources of pollution,** such as discharges from urban wastewater treatment, industries and fish farms, are defined as 'stationary sites or installations discharging pollutants'.
- **Non-point source** pollution can be caused by a series of activities that do not have a specific discharge point, such as agriculture, which is a major source of non-point source pollution (e.g. Fertilisers, pesticides, sediments, parasites, toxins, viruses). But also human drugs or chemicals and medicines, oil, detergents, heavy metals and faecal microbes.

The **water pollution level** is defined as the degree of pollution of the runoff streams measured to represent the fraction of the runoff waste assimilation capacity actually used. A water pollution level of 100% means that the waste assimilation capacity of the runoff streams has been fully utilised.

When the level of water pollution exceeds 100%, ambient water quality standards are violated. The water pollution level can give an indication of the overall pollution level.

Standards are put in place to protect against anticipated adverse effects on human health or well-being, wildlife or ecosystem functioning; they may be published for a particular State, country or group of countries.

3. WATER FOR PLANT DEVELOPMENT

Water is the basis of the many physiological processes necessary for plant growth. The main process that causes water to circulate in plants is transpiration, *i.e.* the emission of water vapour by plants or evaporation. About 95% of the water pumped into the soil by plants are used for transpiration. Only a small part of this water, about 5%, is consumed in photosynthesis, which aims to produce the carbohydrates needed for plant growth.

The importance of water for plants

Sweating conditions the gradient of water potential from leaves to roots. Water moves from the highest to the lowest water potential. It therefore rises from the soil to the leaves through the roots and is then released into the atmosphere. The **transpiration rate of plants depends on the availability of water in the plant and in the soil,** and the energy available for vaporising water from the leaves of the plant. Transpiration varies according to the stage of development of the plant and is highest when the plant is mature. Most of the energy used for perspiration comes directly from the sun, through solar radiation. To grow in warm regions, plants generally need more water.

Turgidity guarantees mechanical stability of the tissues of non-woody plants. Without the stability provided by turgidity, many plants would collapse and their physiological processes would be inhibited. These processes include, but are not limited to, cell enlargement or plant growth, gas exchange in leaves, water and sugar transport in the plant. If the soil moisture content is low, plants may not be able to maintain their turgidity. When this happens, the plant reaches its **wilting point** (WP), which is the water content of the soil below which the plant can no longer take the water it needs. Wilting is reversible if the plant is supplied with water again and has not reached the **permanent wilting point** (PWP), *i.e.* the threshold at which the continuous flow of water into the xylem and plant tissues is interrupted. If the PWP is exceeded, the wilting is irreversible and the plant dies.

Water carries sugars, nutrients and, sometimes, systemic pesticides in the plant. As we have seen previously, water enters the plant through the root system, largely due to the difference in water potential between the roots and the soil. Water facilitates the absorption of nutrients by roots through a complex set of processes, including active transport. The movement of water through the plant results from two phenomena:

- the main one is perspiration through the leaves;
- the second process occurs when water flows from the roots to the leaves due to a high concentration of solutes in the roots. As a result, the pressure of water in the roots increases, and the water is then pushed upwards and expelled by the leaves during guttation.

Water requirements for crops

Crop water requirements are defined as the depth or amount of water required for evapotranspiration of a given crop or potential evapotranspiration.

Evapotranspiration (ET) is the sum of transpiration by the leaves of plants and evaporation from the soil surface. Evaporation is a term that covers all processes in which liquid water is released into the atmosphere as water vapour. Crop water requirements are based on its four growth phases: initial phase, development phase, mid-season phase, and late season phase.

To calculate the water requirements of a crop or **'potential evapotranspiration' (PET)**, a coefficient (Kc), specific to each type of crop, is used. Kc depends on the type of crop and soil moisture, and its value generally varies from 0.5 if the soil is 25-40% covered, to 0.7 if the soil is 40-60% covered. As a crop grows, the land cover can increase from 10% to 100%, which represents the total land cover by the crop. At the end of the season or the so-called 'after-season phase', the final value of Kc reflects the quality and sustainability of water management practices and crop needs.

Soils and water

The amount of water available to the roots is determined by the soil moisture content and the water retention properties of the soil around the roots. Of course, if the soil does not contain enough water, the plant perspires less, which causes a loss of turgidity of the cells. The loss of stability of the plant causes its wilting, hinders its growth and eventually leads to the death of the plant. To determine the amount of water available to crops, we need to better understand water and soil processes and the water needs of plants. Soils provide plants with:

- a physical support;
- air, water;
- nutrients;
- protection against toxins and a ventilation system.

Soils are living and complex environments that have important physical and chemical properties for farmers, particularly those related to water. Knowledge and management of these physical and chemical properties are essential to provide the best growing conditions for crops. Indeed, the **porosity of the soil** determines its water retention capacity and characterises its permeability, *i.e.* the circulation of water in and through the soil. **Soil water content (SWC)** is the amount of water retained by the soil. A soil is saturated when, after rainfall or irrigation, all the pores of the soil are filled with water. Saturated soils do not contain air, but plants and their roots need both air and water to grow. **Field capacity (FC)** is the situation where the air and water content is considered ideal for plant growth. Soil moisture content is often calculated using the concept of root zone drainage, which refers to water scarcity in relation to FC.

Humus is a carbon reservoir in the soil, and microbes in the soil breathe faster if carbon concentrations are higher. Soil organic matter is very beneficial for water retention in soils. It absorbs water directly, but they also contribute indirectly to the formation of soil aggregates, improving soil structure and, consequently, its water retention capacity.

Water requirements for crops and irrigation

The assessment of water needs of crops under irrigation must take into account the prior establishment of the soil's water balance. **CROPWAT is an FAO model** that calculates the daily water balance of soils before they are irrigated. To ensure the proper management of gravity irrigation, CROPWAT uses a default value of 70% irrigation efficiency. This means that the net irrigation depth corresponds to 70% of the volume of the gross irrigation depth. In this model, **30% of the irrigation water is therefore 'lost' because of deficiencies.** To do this, the irrigation needs expressed in mm are transformed into m by a division by 1,000. The resulting figure is then multiplied by the area in m² of the field concerned.

4. AGRICULTURE AND WATER QUALITY

Agriculture and water quality are closely linked, as agriculture is both a source of water pollution and a victim of it. It is a source of pollution because of the discharge of pollutants and sediments into surface or groundwater, the net loss of soil by erosion due to poor agricultural practices, and the salinisation and clogging of irrigated land. It suffers from pollution because of polluted wastewater, surface and groundwater, or saline water, which contaminates crops and transmits diseases to consumers and agricultural workers. There are two types of agricultural pollution sources: point and non-point sources. In the **horticultural sector, the most common sources of point pollution are effluents from the water used to treat and wash products.**

The impact of agriculture on water quality

Throughout the world, **agriculture is a major cause of degradation of surface and groundwater quality.** The main water quality problems directly related to agriculture worldwide are **salinisation**, nutrient loads in water sources due to fertiliser leaching, and pesticide pollution. **Sediments due to** soil **erosion** are also a direct consequence of poor agricultural practices. The **release of pathogens** is an indirect pollution problem.

Saline water is water that contains high concentrations of dissolved salts. This is not only common salt as we know it (sodium chloride NaCl, Na^+ and Cl^- in its dissolved form), but also other cations and anions such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sulphate

(SO_4^{2-}) or bicarbonate (HCO_3). Salinity is a problem that affects both soil and water, as one influences the other.

High salt concentrations impede water uptake by plants and result in lower crop yields. Sodium (Na^+) has a greater impact on soils and crops than other cations. Poor agricultural practices also have a direct impact on water quality: the deposit or accumulation of sediment in water due to soil erosion. The release of pathogens into water is an indirect pollution problem.

The presence of high levels of nutrients in the water causes the proliferation of aquatic plants, phytoplankton, algae and macrophytes. The excess of nutrients in the water causes a hypoxia problem, which is the low level of oxygen in the water, and anoxia or lack of oxygen in the water.

Some of the **pesticides** reach a destination other than their target and enter the air, water, soil, sediment, and even our food, especially when they are misused. There are **four** main **trajectories** that pesticides can follow before reaching water with the potential for pollution or contamination and they can:

- divert outside the area where they were sprayed;
- infiltrate into the ground or percolate and reach groundwater;
- be washed away by runoff water;
- spread accidentally.

The problem with synthetic pesticides is that, if they enter the environment as pollutants, **they can harm non-target organisms,** and if they enter the food chain at high levels, they could have negative effects on consumers. Pesticide pollution is largely the result of pesticide misuse. Recommendations for the use of each commercial product are intended to ensure that these potential negative effects are avoided or minimised. In addition, the first compounds, which were more toxic, have now been replaced by active ingredients that present fewer risks.

The importance of water quality for agriculture

If farmers need water for irrigation, they must find a valuable source from resources that are physically and economically available. Poor water quality is defined as follows: 'water that has characteristics that have the potential to cause problems when used for the purpose for which it is intended'. Poor water quality also has negative effects on crop yields such as reduced yields at different salinity levels. In general, irrigation water can be of poor quality in **three different ways:**

- chemical: risks of salinity/toxicity to soils, plants and even the irrigation system due to pipe corrosion or chemical obstruction;
- physics: blockage problems due to suspended solid particles and other impurities;
- biological: pathogens harmful to human and animal health as well as to soils, plants and the irrigation system.

The use of urban wastewater in agriculture

Urban wastewater is generally a combination of domestic effluent, *i.e.*, kitchen and bathroom water, effluent from commercial or institutional establishments, including hospitals, industrial effluent, if any, and storm water and other urban runoff.

In agriculture, wastewater can be used, treated or untreated, directly or indirectly. In the case of direct use of untreated wastewater, the water is discharged directly onto land for cultivation, while in the case of direct use of treated wastewater, the water is recycled for agriculture after treatment, usually in a planned manner.

In the case of **indirect use of** treated or untreated urban **wastewater**, water from a stream that receives urban wastewater is extracted downstream by farmers for irrigation purposes. Urban wastewater often contains a wide range of pollutants: salts, metals, pathogens, drug residues, organic compounds, endocrine disrupters and active residues of personal care products. Many of these substances **persist in water** even after treatment. They can harm human health: farmers can suffer adverse effects as a result of direct contact with water.

However, the use of treated wastewater in agriculture can also have positive effects: it is a new source of fertiliser, as wastewater contains macro- and micronutrients, and is available all year round. The agricultural use of this wastewater simply requires adequate treatment according to existing standards or guidelines, particularly those of WHO and/or FAO, before its use.

Avoid water pollution

Water pollution from agriculture can be prevented or reduced in **two ways:**

- **Wastewater treatment:** treatment is an option for point sources of pollution, because effluents can be easily collected and treated
- **Reducing the release of pollutants into the environment,** thereby reducing the risk of these pollutants reaching water sources. Indeed, there is a whole series of practices aimed at reducing the release of pollutants into the environment.

The first step to avoid pollution from diffuse sources of agricultural origin is to be aware of the major impacts of agriculture on the environment and health. Then, it is **necessary to adopt a responsible attitude,** and to be informed and to study the best possible options. Often, a significant part of water pollution can be avoided by simple changes in farming and agricultural practices.

Here are some very common techniques.

- The nutrient management plan: this is the management of nutrient inputs to plants for both efficient crop growth and water quality protection.
- The integrated plant nutrient management (IPNM): it is the result of awareness that the best way to meet the nutrient needs of plants is an integrated use of the various nutrient sources. IPNM aims to optimise the state of the soil, in terms of its physical, chemical, biological and hydrological properties, with the aim of improving farm productivity while minimising land degradation. To do this, it combines complementary crop, livestock and land management practices that maximise the supply of organic matter and recycle agricultural waste to maintain and increase organic matter levels.
- Integrated pest management (IPM) is an ecosystem approach to crop production and

protection that combines different management strategies and practices to achieve healthy crops, and minimise pesticide use.

- Erosion control can easily be reduced by land use practices at the farm level.
- Recovery and treatment of agricultural runoff: agricultural runoff and drainage water can be recovered so that after watering the fields, the drainage water passes through man-made structures, such as gravel beds or artificial marshes, which function as natural water purifiers. It is a cheap, simple and environmentally friendly way to treat water, and trap pollutants such as nutrients.
- Recycling: potential applications for 'waste' water within the same farm are assessed. If the water quality is acceptable, the water used for treatment and cleaning is then used for irrigation.

5. IRRIGATION

Archaeological remains attest to the existence of irrigation and water storage systems in the Indus Valley of northern India in 2600 BC, while in Latin America, terrace irrigation systems and water collection and storage methods were developed around 750 BC. In Europe, the Romans already used concrete pipes to transport water. They built the first aqueduct around 300 BC.

The different irrigation methods

The irrigation techniques and methods used in agriculture today are the **direct legacy of centuries of technical development of** all these civilisations. **Irrigation aims to supplement crop water requirements when rainfall is insufficient to** ensure optimal crop growth. The factors that influence crop water requirements are crop type, cropping system, climate, soil type and topography. Irrigation systems and methods should be selected and implemented taking into account these factors.

While irrigation can be fundamental to ensure optimal crop yields, the method used and the overall good management of irrigation systems have important consequences. **Irrigation is one of the main consumers of water, especially for intensive crops such as horticulture.** There is a wide variety of irrigation methods, which can be subdivided into two main categories:

- gravity irrigation: basins, furrows, borders;
- pressure irrigation: sprinkling and drip irrigation.

Gravity irrigation is the method used for centuries and remains the most widely used. This method is generally used on gentle and regular slopes, on soils with a medium to low infiltration rate and a medium to fine texture. Its purpose is to promote the lateral flow of water on the surface of the field. Under these conditions, gravity irrigation **is the simplest and least expensive method of irrigation**, since no additional investment or machinery is required to level the field. The most common methods of gravity irrigation are irrigation bybasins, borders and furrows.

- The submersion or basin irrigation method is mainly used on square-shaped land, although it can also be applied to rectangular or irregularly shaped fields.
- The edge irrigation method is a variant of bowl irrigation. It is suitable for sloping

terrain, generally elongated and rectangular in shape. It is also suitable for large farms where agricultural work is mechanised but is not recommended for heavy clay soils.

- The main characteristic of the furrow irrigation method is the trenches or gutters dug between the rows of seedlings. Water is released at the upper end of the quaternary canal through siphons or feed pipes.

Pressure irrigation methods are suitable for all surfaces, including irregular surfaces. The most common pressure irrigation methods are sprinkler systems, sprinkler guns, and drip irrigation.

Pressure irrigation methods make better use of water resources and are particularly recommended in water-deficient areas. The irrigation method called '**sprinkler irrigation**' is based on the natural rain model. It is used all over the world, on small and large fields. Spray irrigation systems are adaptable to all types of soils, crops and surfaces. **Drip irrigation** consists of watering each plant separately with a specific amount of water using drippers. The water constantly falls in the same place. Drip irrigation, micro-irrigation, or localised irrigation allows water to slowly enter the soil to the roots of the plant or to reach the root zone directly by groundwater flow. Since water can be spread according to crop needs, this system is more efficient than others, and consumes less water and fertiliser. The use of a drip irrigation system makes it possible to consider fertilising irrigation.

The choice of appropriate irrigation methods

To find the most appropriate irrigation method for a particular crop and situation, **it is important to know their particularities, advantages and disadvantages,** as well as the various natural, social and economic factors that come into play. The choice of an irrigation method takes into account the crop, the particularities of the method with its advantages and disadvantages, as well as the various natural, social and economic factors that come into play. Natural conditions are: soil type, slopes, climate, water availability and water quality. All methods have advantages and disadvantages, but what is crucial is to have a good knowledge of local conditions before making a decision.

Design and development of irrigation systems

A good knowledge of local conditions and factors allows the selection of the appropriate irrigation method(s). The choice of appropriate irrigation methods precedes the selection of the irrigation system to be developed for each particular situation. Various irrigation systems are developed at different scales to use different water sources and to develop an irrigation system, and are essential to understand the availability of water in the geographical area concerned.

The installation of a pressurised irrigation system requires the design of a detailed plan. For this purpose, the help of a specialist is required. Its design requires rigorous and mandatory monitoring at all stages of implementation. The method of fertiliser irrigation in pressure irrigation systems is the combined administration of nutrients and water to a crop, a mixture of fertiliser and irrigation. **Hydroponic systems in a greenhouse** are efficient and productive because plants receive exactly what they need, when they need it. Closed-loop hydroponics systems minimise the environmental impact of water-related pollution, but recycling should not be carried out on inert environments.

Drainage plays a very important role in irrigation because it eliminates excess irrigation water from irrigation systems. Drainage is also a method that prevents salinisation, prevents the lowering of groundwater levels and eliminates salts and toxins that have accumulated. A drainage system consists of a main drain that targets both **surface and deep drainage** and a pour point. A drainage system generally consists of a main drain that targets both surface and deep drainage, and a pour point. At the point of discharge, the water is discharged into another body of water.

Irrigation water sources, water collection, storage and recycling

The water source used for irrigation depends mainly on the availability of water in a given geographical area. The most common sources are: rivers, lakes, reservoirs, and groundwater. As water availability decreases, other more innovative techniques are increasingly being used to obtain rainwater, fog collection, wastewater reuse, desalination.

The various sources of water are: groundwater from springs, wells or boreholes, surface water from rivers, lakes or reservoirs.

Rivers have been used for irrigation for centuries. Water flows constantly through them, often resulting in fluctuations over time in the amount of water available in rivers. Water from **rivers** is **abstracted by** dams but also by pumping when the water cannot be diverted by gravity. The **use of non-conventional sources such as wastewater, desalinated water, collected rainwater,** or drainage water is possible. It is important to understand and plan how to capture water when the water source is identified. Water intakes with valves and easily controlled irrigation channels are a means of collecting water. The artificial construction of reservoirs to store water in a valley or to store rainwater makes it possible to accumulate water, even if the water can be diverted to the dead arms of a river. Water stored in a reservoir is used for irrigation by the gravity system, or by the pipe system, or pumped upstream during the dry season.

Groundwater is naturally extracted directly from the source and artificially by pumps and/or wells. The basic principle of groundwater use is that extraction should never exceed replenishment. This requires good cooperation between water users and accurate groundwater level measurements.

Twig mattresses made of brush, tree branches and stems, earth plugs and infiltration, and storage systems in the ground are designed to **collect runoff rainwater and direct it to the subsoil.** The combined use of several water sources is the best way to ensure a sustainable and efficient water supply in the long term.

The performance of irrigation systems

The performance of irrigation systems is assessed in two ways: from the point of view of **irrigation efficiency (IE)**, and from the point of view of **distribution uniformity (DU).** While IE and UD are linked, their relevance to the performance of an irrigation system is from two different perspectives.

Improving system irrigation efficiency is essential to improve irrigation system performance and hydraulic efficiency. Irrigation efficiency can be reduced to two factors.

- **Transport efficiency (ec):** *i.e.* the efficiency of water transport from the source to the field. The factors that influence transport efficiency are the length of the pipes, the permeability of the **soil type, the condition and maintenance of the canals.**

- **Irrigation application efficiency (ea):** this is the parameter that indicates the efficiency of water distribution in the field. The factors that influence this parameter are mainly the irrigation method used and the discipline the farmer shows when applying this method. The application efficiency for gravity irrigation methods is **about 60%.**

With the two above-mentioned parameters, irrigation efficiency (IE) is calculated using the formula and the EI depends mainly on water losses at all stages.

The **hydraulic yield of an irrigation** is the ratio between the dry matter produced and the transpiration rate. The overall hydraulic yield of the system is the ratio between the amount of water captured and the agricultural yield or profit generated. Water storage also plays a crucial role in the efficiency of irrigation, as water availability may depend on it at critical times. Knowing the quantity of water stored and the storage conditions makes it possible to control the availability of water in the short and long term. In many cases, the efficiency of tank storage is not taken into account in the design and management of irrigation water. Each system has developed its own approach to achieve the highest possible level of efficiency.

The experience and knowledge accumulated by farmers and irrigation specialists are compiled in specialised books, which include some 'basic rules'. Better management of land, water and crops, increases their productivity and improves irrigation efficiency. **Distribution uniformity (DU)** indicates the extent to which water seeps uniformly into the soil during irrigation. Uniformity of distribution can be calculated as a measure of irrigation performance. Its value varies between 100% and 0% (in theory). It corresponds to the ratio between the average irrigation volume and the driest area of the field, divided by the average volume applied to the entire field.

6. IRRIGATION MANAGEMENT

Once in place, the irrigation system must be managed in all stages of the system: from the sampling point or pumping station, transport system and distribution system to the field application and drainage system. A well-designed and managed irrigation system reduces water losses through evaporation, deep percolation and runoff, while limiting erosion from applied irrigation water.

How to define irrigation management

Irrigation management is the most effective and efficient use of water. Effective and efficient irrigation management aims to save energy and minimise pollution and other negative environmental and social impacts. Effective and efficient management refers to water conservation, which is any beneficial reduction in the use, loss or waste of water. Water conservation also refers to improved water management and agricultural practices that optimise the use of water resources and benefit people and the environment.

Measures for efficient use of irrigation water

The issue of agricultural water conservation concerns both the farm and the catchment area. Measures for the efficient use of irrigation water are aimed at water conservation. The best results are achieved when water conservation efforts are coordinated at both levels. It is important to understand why water conservation is so important for irrigation management. Water conservation is not only about protecting water resources from an environmental point of view, it is also about reducing the physical, social and economic risks associated with water.

In an irrigation system, water conservation is pursued by:

- the reduction of losses during the adduction process;
- the transport of irrigation water;
- improving agricultural practices;
- optimal timing of irrigation water supplies through careful planning.

The efficiency of irrigation **water transport** is obtained by the efficiency of the supply and the efficiency of the application on the field. Transport losses can account for 50% or more of irrigation water in long, uncoated open canals, depending on the type of soil in the canals. Losses in uncoated open channels are due to infiltration, percolation, flow, overflow and evaporation.

Two problems are generated by losses during transport:

- lost water is no longer available in the river to supply its ecosystem; nor is it used for crop production;
- the operator must pay the full cost of the water extracted and transported (energy, infrastructure), while it uses only part of the water.

The appropriate measures concern the distribution of water from the source to the farm and on the farm, *i.e.* the ratio between the water used and the water spread on the field. As such, the **transition from an open-air canal system to a pipe network** is a means of **limiting water losses by percolation or infiltration into the ground or by evaporation.**

In addition, there is the sharing of responsibilities, inspection, maintenance and repair work on the canals, which facilitates the establishment of an efficient irrigation water conservation system. Proper irrigation planning is essential to improve hydraulic performance at the farm level. Irrigation planning broadly refers to the daily consideration of the field water budget or soil water balance, and the determination and control of the rate, quantity and timing of irrigation water inputs in a planned and efficient manner. The objective is to determine and apply only and fully the amount of water that crops need to achieve optimal growth, with controlled and time-programmed applications.

Poor irrigation planning can lead to insufficient water supply for crops, or to timing of water supply, which can lead to underirrigation.

Excessive irrigation occurs when the amount of water supplied is excess, or when the amount of water is supplied too early. Under-irrigation and excessive irrigation lead to reduced yields, reduced crop quality, and inefficient use of nutrients and pesticides.

To ensure **proper irrigation planning,** the minimum information required by the operator is as follows:

- the capacity in the ground field;
- the easily usable reserve for the different stages of plant growth;
- the depletion of soil moisture during the growing season.

The essence of irrigation planning is to determine when and how much water crops need. There are several methods and tools to help you navigate through them, ranging from direct monitoring of soil and plant moisture, to soil water balance calculations and planning using simulation models. All these methods can be used to measure crop water consumption and soil moisture content.

They are classified into three types.

- **The observational method,** based on a simple visual and tactile appreciation. During field visits, it is possible to assess, on the basis of personal experience, the stress status of plants and soil moisture.
- **The measurement of the soil moisture content** using specialised equipment designed for this purpose. This practice is frequently used in irrigation planning because daily soil moisture monitoring determines how much irrigation water to bring and when it should be brought in.
- **Modelling the permanent wilting point during the growing season** using the soil water balance. This method uses the estimation of daily water losses by evapotranspiration (ET) from the soil to determine irrigation water requirements. These methods require accurate data management and accurate input information on precipitation, crops and soil. They also require the farmer to know the level of depletion associated with the yield threshold, below which crops are affected by water stress and below which yield decreases. Some of these methods are:
    - **FAO's CROPWAT 8.0 model** is a computer model that establishes the soil water balance on a daily basis using data on climate, crop, soil and irrigation;
    - **deficit irrigation planning:** implemented with the objective of covering all crop water needs, or designed to ensure optimal water use by crops. With deficit irrigation, the crop is exposed to a certain level of water stress at a particular stage of its growth or throughout the growing season. Deficit irrigation planning allows the farmer to optimise the use of available water for different crops or plots, especially when the quantities of available water are limited.

Finally, **irrigation needs will decrease when farms use practices that increase the soil's ability to retain moisture** (soil moisture retention capacity) and/or reduce crop evaporation. These practices include conservation tillage, cover crops, crop rotations, windbreaks, and other wind erosion control measures.

Management of drained water

The objective of drainage is to create a root environment adapted to plant growth. Drainage is also aimed at ensuring that the soil is sufficiently aerated and at managing the salt content in the root zone.

Drainage water management is an integral part of irrigation management, as good drainage management increases water use efficiency and reduces pollution. **Drainage management is as important in drylands as in wetlands.**

In arid areas, drainage may be necessary to prevent salt accumulation in the root zone and to prevent groundwater level rise. In these areas, water is often brought in excess to prevent salt deposition. This need for additional water is called the '**leaching need**'.

In wetlands, drainage systems play an important role in managing high groundwater levels or flooding.

- Drainage water potentially contains high concentrations of fertilisers, toxic trace elements, sediments generally carrying pesticides, salts and pathogens. To ensure water quality, it is therefore important to pay attention to this issue. Good drainage water management practices include the following.

- Groundwater level management should be the limitation of water flow by an underground drain to raise and control the groundwater level.
- Drainage water reuse must be the right solution in cases where water supply is limited, and to reduce nutrient loads in receiving waters. This solution is implemented in combination with nutrient management techniques.
- Drainage water treatment should be carried out most often, using planted filters. Planted filters are effective in removing sediment and nutrients.
- Grass strips are strips or areas of vegetation designed to remove sediment, organic matter and other pollutants from drainage water leaving fields. The principle of grassed strips is similar to that of planted filters for wastewater treatment, except that they do not require special engineering design to remove as many pollutants as possible.

Measures to reduce the environmental impact of irrigation

To maintain yields, it is necessary to manage the salts that concentrate in the soil. Measures to reduce the environmental impacts of irrigation are mainly concerned with salinity management. The **main measures** are the following.

- **Salinity control** practices include reducing salt intake, selecting suitable sites and crops with the application of good soil and/or water management practices.
- **Good soil** and/or water **management practices** include: crop selection, acid injection into drip irrigation systems and irrigation planning.
- The placement of seedbeds and the **maintenance of soil organic matter (OMS)** are also good soil and/or water management practices.

Measures to mitigate the social impacts of irrigation

Limiting social impacts goes hand in hand with sustainable and responsible water management and good irrigation practices. Irrigation water operators and managers must be aware that they are among the many water users in the catchment area, and that water is a precious and essential resource for everyone.

The person in charge of managing irrigation water must **pursue the objective of optimising the water situation for the farm, but also for the benefit of other users and the environment.** This basic principle is essential to mitigate all types of social impacts.

The social impacts of water consumption are a complex issue that is not addressed exhaustively here. Social impacts are defined as secondary impacts that directly affect the population as a result of primary environmental impacts. The reduction in water availability for other uses, particularly for domestic uses and the reduced availability of water due to increased pollution, has negative impacts on ecosystems and their services. Measures to mitigate the social and environmental impacts of irrigation must be based on knowledge of local regulations. Indeed, the complete irrigation system must be designed to integrate harmoniously with the local political situation and context, namely:

- **participatory irrigation management** is a measure to mitigate the social impacts of irrigation;
- the **water and irrigation management plan** is a measure to mitigate the social impacts of irrigation ensures the best possible water management.

7. WATER MANAGEMENT FOR WASHING AND POST-HARVEST TREATMENT

The current world situation is marked by population growth with an increased need for food, and by globalisation, which poses new challenges to sustainable food production. Globalisation eventually produces increasingly complex supply chains from producer to consumer. This complexity, combined with expectations and demand for food safety and quality, means that supply chains are also increasingly subject to controls. Operators must use good practices and methods at each step, and prove this to their customers through certification.

Water is an essential factor in supply chains, especially in the early stages on farms. Production, including irrigation and post-harvest treatments, require water of sufficient quantity and quality. To this end, it is necessary to examine the use of water in the various post-harvest activities in order to be able to explain the need for rigorous management of water problems. **Particular attention should be paid to water recycling and effluent treatment, and emphasis should also be placed on what is feasible and recommended at the farm level,** taking into account regulations and private standards, including food safety.

Post-harvest water use

Post-harvest water management is essential to maintain product quality from harvest to consumption. The quality of the products, and therefore their value, decreases seriously if the water is not properly managed in post-harvest operations. After harvesting, the plants maintain their biological activity, but if they are not in contact with water, they immediately begin to dry out. Sweating or evaporation of water is the main cause of deterioration of fruits and vegetables after harvesting. These phenomena affect the weight, appearance and quality of the product.

Post-harvest water is also a potential source of contamination. This is why it is important to understand and manage the associated risks. The amount of water consumed after harvest to wash and treat the products is relatively small compared to the water used during the production phase.

Consumption refers to water that is used and no longer available for other uses. Most of the water used after harvesting returns to the system as effluent, so only a small portion of the water is actually consumed. Several post-harvest activities, each using water in a different way, take place depending on the crop, regulations and customer demands. Water then plays an important role in packaging and storage, especially for perishable foods with short shelf lives.

The control of water quality and temperature criteria is essential for the use of water in post-harvest phytosanitary treatments.

Water problems during post-harvest washing and treatment

To ensure the constant availability of clean water for post-harvest uses, problems related to appropriate distribution infrastructure and the quantity of drinking water are recurrent. Two aspects must be well controlled when using water for product treatment:

- **the availability of clean water for treatment**, in quantity and quality, on the one hand;
- **effluent management** on the other hand.

Indeed, after washing, the product is treated with a fungicide, insecticide or other preservatives to avoid diseases and possible mycotoxins in some cases, to comply with phytosanitary rules, and to extend the shelf life. The **presence of pathogenic organisms in standing water is a potential risk** and creates serious problems during storage and consumption. Fruits and vegetables are perishable foods with short shelf lives.

After harvest, several refrigeration methods are applied to the products to extend the shelf life and maintain their freshness. Not all of these methods use water; some simply use cold drafts or refrigerators.

The **cooling methods** that use water are as follows.

- Pre-refrigeration: the fruit is said to be pre-refrigerated when its temperature is reduced from 3 °C to 6 °C and it is cold enough to allow safe transport.
- Glazing: a layer of crushed ice is placed directly above the products in the boxes.
- Forced air refrigeration: forced air refrigeration systems blow air at very high speeds, which results in the drying of products.
- Chilled water refrigeration: the crop is immersed in cold water that circulates permanently through a heat exchanger.

Effluent management requires verification of contaminants and the appropriate form of discharge, and **this requires treatment before discharge. A risk assessment to determine their degree of dangerousness must be implemented** with measures taken to avoid or mitigate environmental impacts.

Water conservation during washing and treatment

Water conservation is defined as any beneficial reduction in the use, loss or waste of water. This concept refers to water management practices that improve and reduce the use of water resources for the benefit of people and the environment in the post-harvest stages. Effluent treatment and recycling are examples of water conservation measures that can be applied after harvesting. At the farm level, the various basic measures that are implemented to reduce water consumption and effluent pollution are:

- **effluent treatment and recycling by** ultrafiltration is a system that significantly reduces water and energy use while providing high levels of water quality;
- **recycling by** domestic devices for the purification of domestic water;
- the installation of a small **purification unit** to treat effluents and allow wastewater to be reused.

Post-harvest water use and food losses

Poor water and moisture management in the post-harvest stages generates significant losses and **leads to the waste of harvested products.** The consequences are food safety problems, deterioration in product quality, or simply a deterioration in appearance that makes products less attractive to the retailer or consumer.

In industrialised countries, food losses occur mainly at the consumer stage, while in developing countries, almost all food losses occur after harvest and during processing.

High losses are due to factors such as climate, lack of transport and adequate crop storage facilities. In the context of sustainable water use, improving post-harvest product handling is of crucial importance, particularly in developing countries.

8. WATER RIGHTS, EXTRACTION AND SUSTAINABILITY OF WATER USE

Understanding water legislation: the right to water

Historically, mechanisms for regulating water use or access have developed differently from one society to another. As a result, each society had its own customs and ideas about how to allocate water to different uses. Many of these are still part of customary or local law practices today and often also interact with religious laws. Nowadays, in most countries, water use is governed by specific and specialised legislation. In many countries, the basis of this legislation is strongly influenced by European legislation. Mainly due to the increasing pressure on water resources, water sector reform is underway in many countries, with the introduction of modern water legislation to replace many of these traditional water laws. Water legislation varies greatly from one country to another.

Nor is there a common definition of 'water rights', but according to FAO, the simplest definition of a right to water is "a legal right to extract and use a volume of water from a natural source such as a river, stream or aquifer". Water rights govern both consumer and non-consumer use of water. In situations where water resources are scarce, modern water legislation can also determine which uses prevail over others. This is called the 'water use hierarchy'. For example, the South African Water Act of 1998 clearly gives priority to the use of water for basic human needs and ecosystems.

Modern water legislation also addresses water quality, and other environmental aspects related to water use and water resource management. The European Union's Water Framework Directive is a good example. Each Member State must define the 'good status' of its water bodies, develop river basin management plans and define a programme of measures to achieve this status.

In an irrigation system, a farmer has a right to a certain volume of irrigation water from a supplier (for which he pays a certain price). This 'contractual water right' concerns the right to provide a certain volume of water through artificial structures, the right to provide a service. It is important to understand how farmers can participate in governance and water allocation.

Guiding the action: why and where to start?

At the Rio Summit in 1992, UN Member States endorsed the **integrated water resources management (IWRM)** strategy as the way forward for the efficient, equitable, sustainable development and management of the world's limited water resources as part of a comprehensive action plan on sustainable development. **IWRM is based on 5 principles.**

1. Freshwater is essential for life, development and the environment.
2. Water resources management and development must involve users, planners and decision-makers.
3. Women play an essential role.
4. Water is a public good and has an economic and social value.
5. Integrated water resources management is based on the equitable and efficient management and sustainable use of water.

Twenty years after Rio, 80% of countries report that they have initiated reforms to improve the environment for integrated water resources management. Increased attention to the sustainable use of freshwater resources has led to a growing interest in water management on the part of the private sector at the beginning of the 21st century. For example, the application of the **water footprint assessment** method has been standardised through the Water Footprint Network and ISO 14046. **GLOBALG.A.P. has introduced water requirements into its Integrated Farm Assurance (IFA) standard.**

A **5-step method** allows farmers to meet IWRM objectives:

1. assess the water footprint, risks, investment needed for irrigation.
2. understand the current physical water situation of the operation.
3. understand the risks and opportunities for your operation and the sustainability of water use;
4. develop a water management plan;
5. continuously monitor and adapt the efficiency and impact of agricultural activities in the water management plan.

PERSONAL NOTES AND REFERENCES OF THE MATERIALS USED

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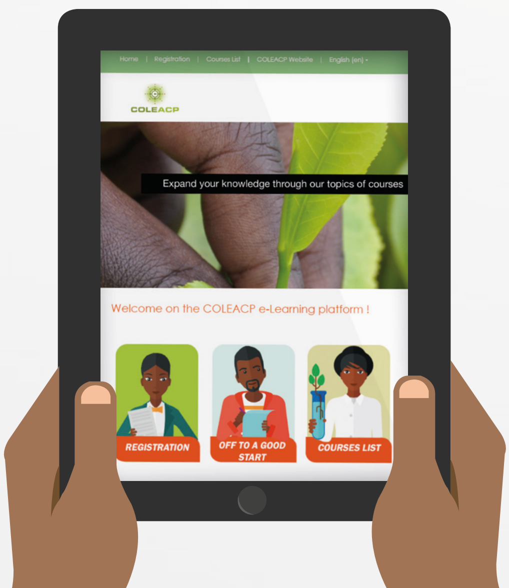

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