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Introduction

Introduction

Water is an essential resource for life and is utilized in various ways by humans, being crucial for agriculture, energy production, and industry. However, water resources are fragile and limited, increasingly threatened by the consequences of human activities. The growing number of users necessitates integrated and efficient management of this resource with a long-term perspective, requiring innovative solutions to meet the rising demand.

Agriculture is by far the largest consumer of water, with irrigation accounting for 70% of global water use. In many developing countries, irrigation constitutes up to 95% of all water usage and plays a vital role in food production and food security. Future agricultural development in these countries largely depends on the ability to maintain, improve, and expand irrigated agriculture.

At the same time, water resources face increasing pressure due to competition from other sectors and environmental concerns. Water can become a source of tension between countries sharing the same water sources, with irrigated agriculture being highly competitive, consuming 70-90% of water in some regions.

Irrigation can be defined as the artificial application of water to support the growth of crops, trees, and pastures. The methods vary: water can flow onto the land (surface irrigation), be sprayed under pressure (spray irrigation), or be delivered directly to plants (localized irrigation).

In the field of irrigation, the goal is to identify future projects by adopting techniques and

processes that ensure rational and efficient use of reserved water volumes. This modest course handout aims to provide an understanding of irrigation science, starting with a general introduction, followed by the determination of key factors, evaluation of plant water needs, water/soil relationships, and various irrigation techniques.

Chapter 1

General Information About Soil

Chapter 1: General Information About Soil

1.1. Introduction

Agricultural viability depends upon a healthy soil. A healthy soil is obtained through knowledge of the soil and the application of appropriate management practices. Poor management practices can lead to soil degradation, which can reduce productivity. Soil is not a renewable resource. The loss of 1 mm of topsoil can take 3000 years to replace.

Soil has a number of functions important for agricultural production, these being:

- A medium for plant growth supplying and retaining nutrients, oxygen and water.
- A medium for the decomposition of crop and pasture residues
- An anchor for plants
- A medium that should support machinery and animal traffic under most soil conditions without degradation.

Soil is essentially made up of four main fractions, but the fractions vary greatly in arrangement and form, hence soils can be physically and chemically quite different. Understanding why soil can be so varied, and how different soils require different management is important for an effective farming enterprise.

1.2. Definition

Soil is the uppermost layer of the Earth's crust, composed of minerals, organic matter, water, and air. It serves as the essential medium for plant growth by providing nutrients, water, and a substrate for roots. Soil also plays a crucial role in the water cycle and the maintenance of biodiversity.

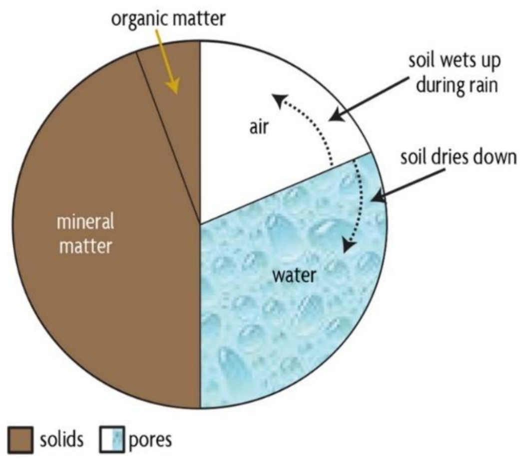

Figure 0.1 Proportions of the four soil fractions in typical soil

1.3. Characteristics and Physical Properties of Soils

Characteristics of soil

There are three characteristics of soil that are important for plant growth and productivity: physical, biological, and chemical. A change in one characteristic is likely to affect another.

Physical

The aspects of the soil that you can see and touch. Physical charactersitics include: soil texture, soil colour, soil depth, soil structure, porosity (spaces between particles) and stone content. The role physical properties play in soil health are:

● To supply water and air to plant roots and allow adequate water and air movement into and through the soil profile.

● To store water for plant growth.

● To support machine and animal traffic.

Chemical

The ability to supply nutrients for plant growth and store nutrients in the profile without loss by leaching. The ability to keep clay aggregates chemically stable which impacts on soil structure.

Biological

The ability to support a healthy microbial population for organic matter breakdown (faeces and crop and pasture residues), nutrient cycling and the growth of nitrogen fixing bacteria.

Physical characteristics

Soil texture

Soils are partially made up of a mineral fraction (gravel, sand, silt and clay particles) and an organic matter fraction. It is these two fractions combined (minus the gravel particles) that give the soil a characteristic known as texture. There are many different texture grades depending on which particles (sand, silt, clay or organic matter) are dominant (if any). Soil texture provides a good way of characterising soils and can be described through the behaviour of a moist lump of soil when rubbed between your thumb and forefinger.

The texture of the soil can change with depth. Obvious changes in texture through the soil profile can provide an easy way of assessing the different horizons (layers). Determining how the soil texture changes (if at all) at depth is important in understanding what plant roots have to contend with. In some cases the soil texture can differ markedly through the soil, ranging from a light texture (e.g. sandy loam) and changing abruptly into a heavy texture (e.g. clay). This is known as a texture contrast or duplex soil. This could be a problem for some plants. The ideal situation for plants is gradational soils, that is a soil texture that gradually becomes heavier down the profile. Some soils do not change textures, that is, they are the same texture throughout the soil (uniform soil). If the soil is clay all the way down, it will often drain quite slowly, so plants that can cope with wet roots will grow best in this soil type. Soil that is sandy all the way down will drain very quickly and plants that can deal with dry conditions will be suited to this soil type.

Soil structure: Soil structure refers to the arrangement of soil particles into aggregates or clumps.

Good soil structure allows for better aeration and proper drainage, facilitating root penetration and water infiltration. The solid category of soil, which consists of individual particles (sand, silt, clay and organic matter) can cement together to form aggregates (also referred to as peds). (Figure 1.2).

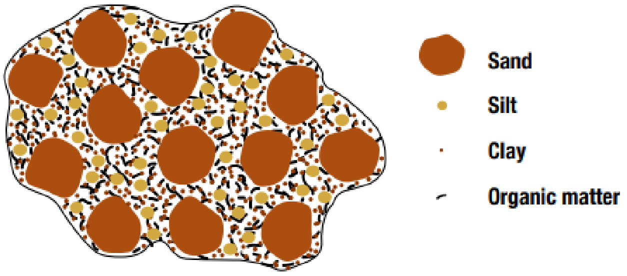

Figure 1.3 Soil aggregate

Sand, silt, clay and organic matter are cemented together by the clay particles and organic matter (due to electrical attraction). Organic matter is one of the major cementing agents for soil aggregates (particularly in topsoils) and one that is strongly affected by soil management.

Organic matter and clay also bind aggregates together. The arrangement of aggregates, along with their size and shape, gives soil a characteristic known as soil structure. (Figure 1.3)

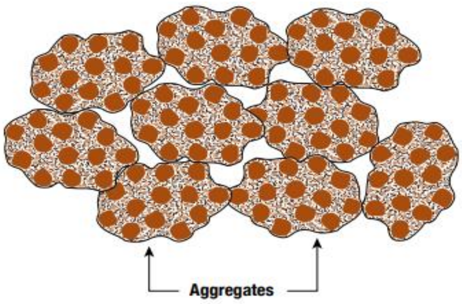

Figure 1.3 Aggregates join together to give the soil a characteristic known as structure.

Porosity:

Porosity Spaces or pores within and between aggregates can be either filled with air or water. The number, size and shape of the pores determines the amount and rate at which water and air can move into and through the soil, and also the amount of water held in the soil. Pores can be divided into two main classes based on the diameter.

Soils with good porosity have a high capacity to retain water and allow the movement of air and water through the soil.

***Macropores* -** Macropores occur between the soil aggregates. They are responsible for the rapid movement of air and water into and through the soil but are not filled with water at low to moderate soil moisture contents. Because of their size, roots grow through macropores. These pores are normally greater than 0.1 mm in diameter.

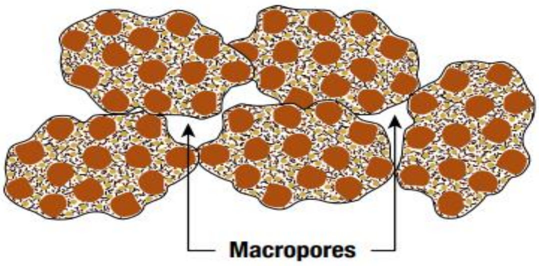

Figure 1.4 Macropores between soil aggregates.

Micropores –

Micropores occur within the soil aggregates. They are the spaces formed between the sand, silt, clay and organic matter particles. Micropores are responsible for the water holding capacity of the soil and are the principal site for water extraction by roots. These pores are normally less than 0.1 mm in diameter.

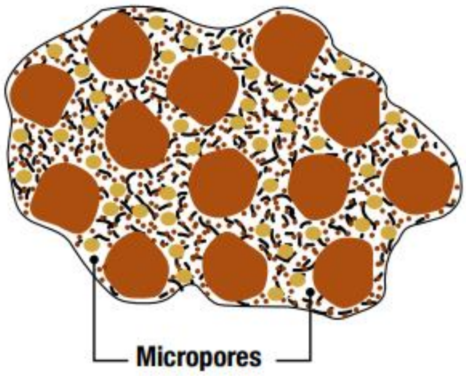

Figure 1.5 Micropores within a soil aggregate.

Bulk Density: Bulk density is the mass of soil per unit volume.

Compact soils have high bulk density, which reduces porosity and the soil's infiltration capacity.

Permeability: Permeability is the soil's ability to transmit water and air. Sandy soils have high permeability, while clayey soils have low permeability.

Water Retention Capacity: The water retention capacity of soil is the maximum amount of water the soil can hold after drainage.

It depends on the soil's texture, structure, and organic matter content.

1.4. Soil Water in Relation to Irrigation

Soil water is essential for plant growth, and its management is crucial in irrigation.

1.4.1. Soil Moisture

Water is held in the soil due to its natural attraction to soil particles, similar to its attraction to itself. Water is retained as a film around each soil particle.

1.4.1.1. States of Water in Soil

Soil is a functional system, characterized by its dynamic compartments. It preserves precipitation water to cover plant transpiration. In Mediterranean arid and semi-arid climates, precipitation is insufficient and poorly distributed to meet plant water needs.

Therefore, to improve yields, replenishing soil water reserves is recommended. The type of water that can be contained in the soil depends on its bonding:

Hygroscopic Water: This type of water is bound by adsorption to the surface of soil particles. It is present in very small amounts and is unavailable to plants.

Capillary Water: This relatively mobile water is retained in soil pores by capillary action after drainage.

This water is partially available to plants (see Figure 1.6).

Free Water or Gravitational Water: This water temporarily fills the larger voids in the soil. It is highly mobile and infiltrates deeper into well-drained soils due to gravity. Generally, it is not available to plants (see Figure 1.6).

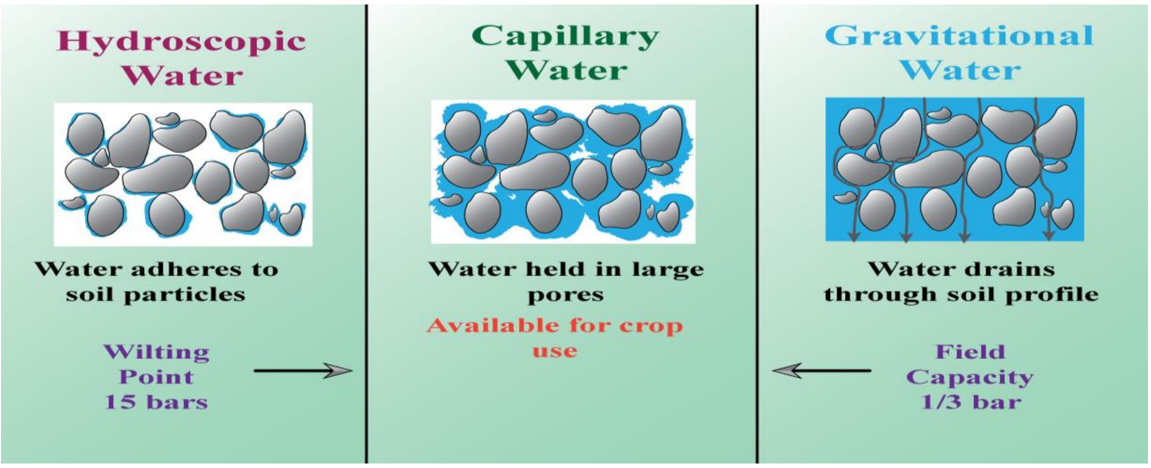

Figure 1.6 States of Water in the Soil

1.4.2. Characteristic Soil Moisture Levels

These moisture levels are considered notable moisture content rates (Figure 1.7)

1.4.2.1. Water Content at Saturation θs

At this level, all the soil pores are filled with water.

1.4.2.2. Water Content at Field Capacity θfc

This level corresponds to the soil moisture observed after gravitational water has drained away. Below this point, water is held by the solid matrix through capillary and adsorption forces.

1.4.2.3. Water Content at Permanent Wilting Point θpwp

This represents the soil moisture at which the plant's suction force equals the soil's water retention force. At this point, the remaining water in the soil is no longer available to plants, leading to irreversible wilting.

1.4.2.4. Water Content at Temporary Wilting Point θtwp

This level characterizes the soil moisture when plants show temporary wilting symptoms during periods of high evaporative demand.

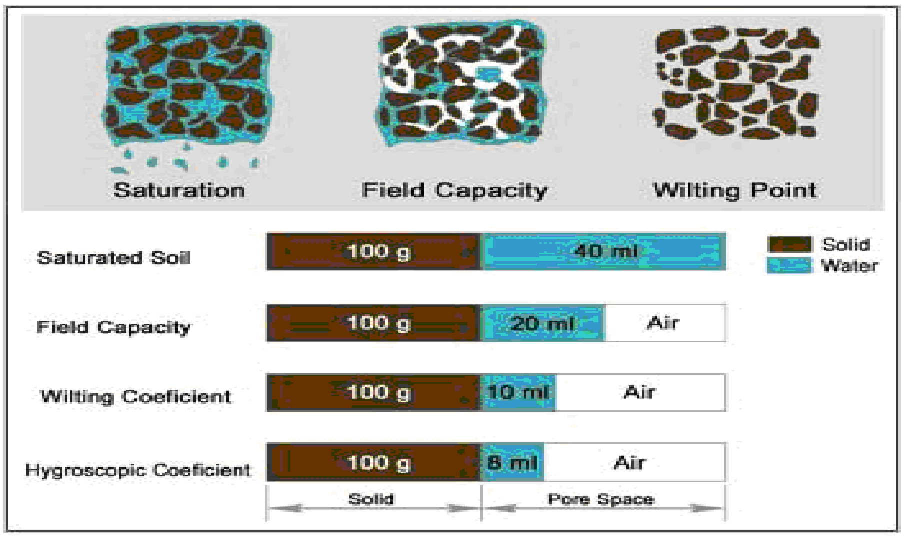

Figure 1.7 Characteristic Soil Moisture Levels

Soil is not a renewable resource on a human timescale, which is why it is crucial for humans to find solutions to expand cultivated areas while preserving soil health.

1.5. Physical Properties

Permeability and Soil Water Capacity: The greater the permeability, the lower the capacity to retain water. Additionally, soil saturation reduces cohesion by dispersing soil aggregates.

Heavy soils, which have a high degree of cohesion, can manage large amounts of water even on relatively steep slopes.

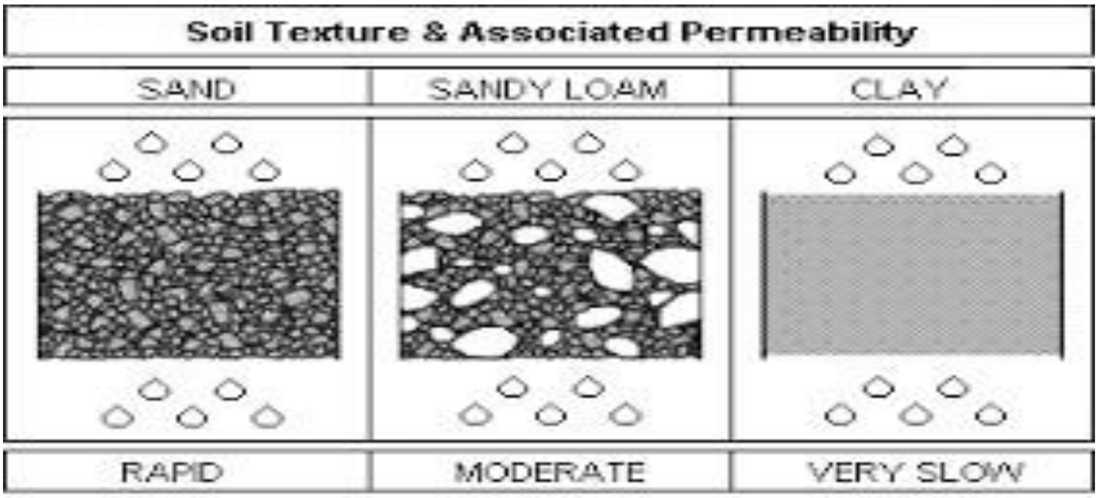

Figure 1.8 Soil Texture and Permeability

1.6. Chemical Properties

1.6.1. Organic Matter

The mineral fraction makes up about 95-99% of the solid category. It is comprised of the weathered remains of parent rocks that are broken down over many thousands of years. 3 Non-Solid Solid Organic Water Air Mineral Figure 1.1 Approximate proportions of the four soil fractions in a typical soil. As the mineral fraction is such a large percentage of the total soil volume, the characteristics of soil are generally determined by the type of parent rock (geology) from which it was formed.

The mineral fraction is made up of four main particles that are defined by the diameter of the particle:

Gravel > 2 mm

Sand 0.02-2 mm

Silt 0.002-0.02 mm

Clay < 0.002 mm

The proportion of these particles plays an important role in the fertility of the soil and its response to management.

Clay particles are the smallest particles of the mineral fraction. They are an important component of soil as they have a negative electrical charge. This enables them to hold and exchange nutrients (which also have an electrical charge). Clay particles in soil provide an exchange site for plant nutrients. Clay soils are normally more fertile than sandy soils.

The type and quantity of clay in the soil can affect the amount of nutrients held for plant use and the ease at which these nutrients are released to the plant. The electrical charge on clay particles enables them to stick to other clay particles and also to sand and silt particles (this is the reason why clays are so sticky). This can be good and bad in terms of soil management as will be explained in Section 1.5 of this booklet: Soil Management and Land Degradation.

Gravel, sand and silt particles do not have an electrical charge and have minimal ability to hold and exchange plant nutrients. They do, however, have other important roles such as aeration of the soil. Gravel and coarse sand particles are larger than clay, silt and fine sand particles, and they have bigger gaps between them. Therefore, more space is available for movement of water and air through the soil.

A good mix of sand, silt and clay particles will allow the soil to hold sufficient nutrients as well as allowing adequate exchange of air and water essential for plant growth.

1.6.2. Mineral Matter

Organic matter is the other part of the solid soil category. It consists of the remains of living organisms in various stages of decomposition as well as living micro-organisms. In agricultural soils in Victoria, organic matter can comprise up to 6% of the solid soil fraction however it is more common for agricultural soils to have between 0.5 and 3% organic matter. In forest soils, organic matter can comprise up to 20%.

Organic matter occurs in various forms from undecomposed to completely decomposed (humus), and all forms provide benefits for the soil. Like clay particles, humus is also electrically charged and is able to store and release nutrients. Humus is also able to increase the water holding capacity of the soil. This is particularly important for sandy soils which have a low water holding capacity.

Micro-organisms form the living component of the organic fraction. They feed on organic matter decomposing it to humus. Micro-organisms also live on products of living plants, some providing benefits to the plant, others creating disease. Most soil organisms decompose organic matter and release nutrients for plant growth as well as improving soil structure. Micro-organisms in the soil are important for soil health.

Exercise

In the exercise, follow these steps:

- Take a small handful of soil from the bag or from each depth if conducting the test at the hole. If you are using samples collected earlier remember to do this for each depth.
- Remove any coarse organic matter i.e. roots and any stony material (larger than 2 mm diameter). Crumble the soil in your hand, especially if it is clayey.
- Wet the soil until it is moist enough to mould into a ball. Stop adding water when the ball starts to stick to your hand.
- To determine the texture class you need to manipulate the ball and feel whether the soil is: sandy - feels and sounds very gritty silty - feels very smooth and silky clayey - feels like plasticine and is sticky.
- The texture class is also determined by ribboning the soil. Roll the ball into a sausage shape and then press the sausage out between your thumb and forefinger. Measure the length of the ribbon.
- Use the table below to determine the texture.

Table 1.1 Determining soil texture

Ball	Ribbon	Feel	Texture
Will not form ball		Single grains of sand stick to fingers, note whether it is coarse or fine sand; coarse sand can be seen with the eye	sand (S)
Ball only just holds together	0.5 cm	Gritty	loamy sand (S)
Ball just holds together	0.5-1.3 cm	Sticky, sand grains stick to fingers	clayey sand (S)
Ball just holds together	1.3-2.5 cm	Very sandy to touch, visible sand grains	sandy loam (SL)
Ball holds together	1.3-2.5 cm	Fine sand can be felt	fine sandy loam(SL)
Ball holds strongly together	2-2.5 cm	Sandy to tough, sand grains visible	light sandy clay loam (SL)
Ball holds together	2.5 cm	Spongy, smooth but not gritty or silky	loam (L)
Ball holds together	2.5 cm	Slightly spongy, fine sand can be felt	loam, fine sandy (L)
Ball holds together	2.5 cm	Very smooth to silky	silty loam (L)
Ball holds strongly together	2.5-3.8 cm	Sandy to touch, medium sand grains visible	sandy clay loam (CL)
Ball holds together	3.8-5 cm	Plastic, smooth to manipulate	clay loam (CL)
Ball holds strongly together	>5 cm	Plastic, smooth, handles like plasticine and can be moulded into rods	clay (C) *

- Record the texture group at each depth in the Texture column on the recording sheet.

Figure 1.9 Ribboning between thumb and forefinger

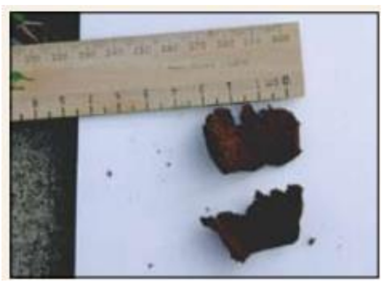

Figure 1.10 Measuring the length of the ribbon

Chapter 2

Principles of Irrigation

Chapter 2: Principles of Irrigation

2.1. Introduction

In the field of irrigation, our primary concern is the movement of water between plants and their environment. According to statistics from the FAO (Food and Agriculture Organization of the United Nations), 20% of arable land is irrigated but produces 40% of the crops. Therefore, irrigation is an effective means of significantly improving productivity and thus being able to feed humanity.

2.2. Definition of Irrigation

Irrigation has several definitions, the most commonly used being:

- It is the art of intentionally supplying water to soil, usually to prevent the effects of drought.
- It essentially consists of restoring to the soil, at the opportune moment, the water consumed by the crop.
- It is providing plants with the necessary amounts of water, in addition to natural inputs, at opportune times, through an irrigation network.
- It is a set of cultural techniques aimed at providing plants through the soil with all the water, but only the water, they need to develop.

2.3.Supplementary Irrigation

Supplementary irrigation differs from perennial irrigation in that it involves providing a small amount of water to crops to compensate for insufficient rainfall, with the aim of stabilizing yields. It alone cannot bring crops to maturity but complements rainfall and conventional irrigation. The effect of supplementary irrigation is maximized when applied at a critical stage of crop development (such as flowering, maturation, etc.).

2.4.Water in the Plant

The user must consider the source of the water, its quality, and its flow rate. Since domestic water needs are a priority, and given the central role of water in many other sectors (tourism, industry, hydroelectricity, cooling of nuclear power plants), irrigated agriculture, although it remains the main user of freshwater (70% of withdrawn volumes), must adhere to regulatory controls for water access and balance the different uses.

However, the match between the growing demand for water and the availability of water resources is not always controlled.

2.4.1. Physical Quality

The dominant physical quality of water is its temperature. The optimal temperature is around 25°C for most plants during the active growing season. Hot water can damage roots or cause thermal shock, and it can cause plants to wilt even if they are otherwise healthy.

Watering with cold water can send your plants into "winter mode." They won't necessarily die, but they will stop growing or flowering. In general, keep cold water away from flowering plants. Outdoor plants can usually tolerate any temperature. Vegetables grown in an outdoor garden can handle the water you get from a hose.

2.4.2. Chemical Quality

The chemical quality of water is primarily determined by the dissolved salts it contains. Some ions are beneficial, even at relatively high concentrations. Others are useful only in very low doses and quickly become harmful as the water's concentration increases; magnesium is an example of this. Just as physiological tests are used to determine a soil's fertilizer needs, it is also important to apply irrigation water to test plants using the soil to be irrigated. This approach helps to avoid errors since water and soil interact and influence each other

2.5. Secondary Effects of Irrigation

While irrigation is essential for meeting the water needs of crops, it can have adverse environmental consequences. The secondary effects of irrigation can vary depending on irrigation practices, soil types, and environmental conditions. Here are some common secondary effects of irrigation:

- **Soil Salinization**: Excessive irrigation can lead to the accumulation of salts in the soil, rendering the land unsuitable for cultivation.
- **Soil Erosion**: Poorly managed irrigation can cause soil erosion, resulting in a loss of fertility and a decline in the quality of agricultural land.
- **Water Quality Degradation**: Irrigation practices can contribute to water pollution by transporting nutrients, pesticides, and other chemicals from agricultural land to waterways and groundwater.

- **Deforestation**: In some regions, intensive irrigation can lead to deforestation to clear additional agricultural land, negatively impacting biodiversity and ecosystems.
- **Loss of Biodiversity**: Converting natural land into irrigated agricultural land can lead to the loss of natural habitats and the disappearance of plant and animal species.
- **Decline in Water Resources**: Excessive use of water for irrigation can lower groundwater levels and reservoir volumes, compromising the future availability of water for irrigation and other uses.
- **Human Health Issues**: Irrigation can contribute to the spread of waterborne diseases by encouraging the breeding of mosquitoes and other disease vectors in wet areas.

2.6. Classification of Irrigation

There are various methods of irrigation, each suited to specific conditions and different types of crops:

Manual Irrigation (watering can, bucket, etc.): Reserved for very small areas.

Surface Irrigation: Utilizes gravity flow through canals and furrows, also known as gravity irrigation or surface irrigation, and includes furrow irrigation.

Sprinkler Irrigation: A technique that simulates natural rainfall.

Micro-Sprinkler Irrigation: Similar to sprinkler irrigation but more localized, thus more water-efficient.

Micro-Irrigation or Drip Irrigation: A water-efficient technique that prevents runoff but can lead to soil salinization over time, altering soil characteristics.

Subsurface Irrigation: Involves buried porous pipes, a variant of drip irrigation.

Flood or Submersion Irrigation: Used in rice paddies and historically in Egypt, fertilizing the land through Nile floods.

2.7. Conditions for Rational Irrigation

The conditions for rational irrigation include several essential elements for effective and sustainable water management in agriculture. Here are a few key points:

- **Understanding Crop Water Requirements**: It's important to know the specific water needs of each crop at different growth stages. This helps determine the necessary amount of water for efficient irrigation.

- **Soil Characteristics Analysis**: Understanding the soil's texture, structure, and water retention capacity is crucial for adapting irrigation practices to each soil type and avoiding water waste.
- **Water Management**: Utilizing techniques such as drip irrigation, micro-irrigation, and soil moisture management to optimize water use and reduce losses from evaporation and runoff.
- **Use of Appropriate Technologies**: Modern technologies like soil moisture sensors, automated irrigation systems, and data-driven water management models enable more precise and efficient irrigation management.
- **Water Conservation**: Encouraging water conservation practices such as the reuse of wastewater, rainwater harvesting, and the construction of retention basins to recharge groundwater supplies.

Chapter 3

Irrigation Network

Chapter 3: Irrigation Network

3.1. Introduction

An irrigation network is a structured system of channels, pipes, pumps, and other infrastructure designed to transport water from a source to cultivated areas. Irrigation networks can be gravity-based, where water is conveyed through open channels using gravity, or pressurized, where water is transported through pressurized pipelines. These networks are essential for ensuring uniform and controlled water distribution, tailored to the specific needs of crops. Irrigation networks are man-made facilities for water conveyance, distribution and application.

The network includes storage/diversion headwork, conveyance system, distribution system and structures. Three management levels are available in irrigation networks:

The main components of an irrigation network include:

Water Source: Can be a reservoir, river, lake, or well.

Main Channels: Transport water from the source to secondary channels or distribution pipes.

Secondary Channels: Convey water from the main channels to agricultural plots.

Regulation Devices: Valves, pressure regulators, and meters to control the flow and distribution of water.

Distribution Equipment: Sprinklers, drippers, distribution ramps, etc.

3.2. Definition

Irrigation distribution network… the network of irrigation canals including the diversion and the flow regulatory structures.

3.2.1. Irrigation Water Conveyance System

In irrigation, water is transported from the source to the command area by either in

- **Open canals:** common in surface/canal irrigation system
- **Pipes:** common in pressurized system (sprinkler/drip)

Table3.1: Flow Characteristics in Open Canals and Pipes

Open canals	Pipes
Has free surface Hydraulics of flow difficult	No free surface Hydraulic analysis of flow relatively simple

3.2.2 Irrigation Canal Alignment

Canal Networks: the network of irrigation canals used to convey water from the source to the command areas.

Main components of canal networks include:

- Main canal: from a diversion headwork deliver water to secondary canals.
- Branch canal/Secondaries: takes water from the main canal and delivers it to the tertiary canals.
- Distributaries/tertiaries: take off from a branch canal and supplies water to field channels.
- Field channels: from the outlets of the distributaries, cultivators supply water to their own lands.

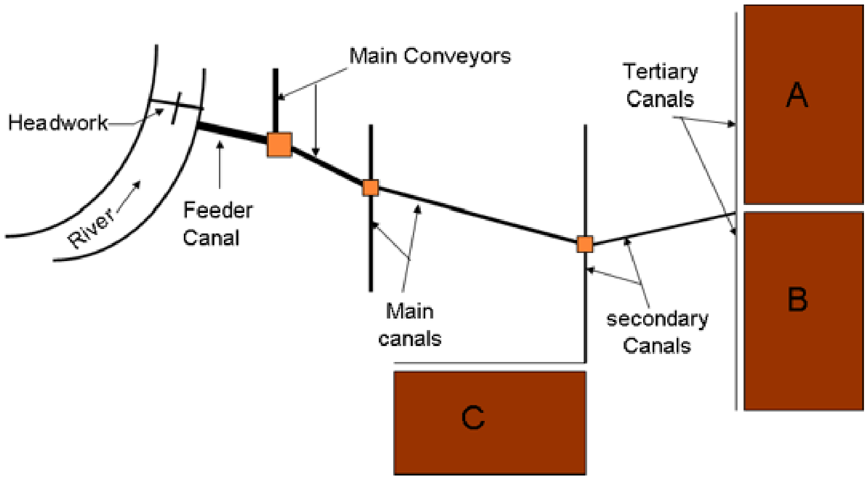

Figure3.1: Irrigation Canal Alignment

3.3. Determination of Canal Capacity

The capacity of a canal is its ability to transport a certain volume of water, usually expressed in cubic meters per second (m^3/s). The capacity is determined by several factors, including the slope of the canal, its cross-sectional area, and the roughness of its walls.

Calculating Canal Capacity

To calculate the capacity of a canal, the Manning formula is often used:

$$Q = \frac{1}{n} \times A \times R^{\frac{2}{3}} \times \sqrt{I} \dots\dots\dots\dots\dots\dots\dots\dots Eq3.1$$

Where:

Q = flow rate (m^3/s)

n = Manning's roughness coefficient

A = cross-sectional area of the flow (m^2)

R = hydraulic radius (m) (cross-sectional area divided by the wetted perimeter)

S = slope of the energy grade line (slope of the channel)

This formula helps in estimating the volume of water that can be transported through the canal, considering its physical characteristics and the influence of gravity.

Exercise:

Rectangular Cross-Section:

If a canal has a width of 2 m and a depth of 1 m, the cross-sectional area A is 2 m^2. If the wetted perimeter P is 4 m (2 m width + 2 times 1 m depth), and if the slope S is 0.001, with a Manning coefficient n of 0.03 (typical for earth canals).

Solution:

Calculate the hydraulic radius R

$$R = \frac{A}{(P)} = \frac{2}{(4)} = 0.5\ m$$

Using the Manning formula:

$$Q = \frac{1}{n} \times A \times R^{\frac{2}{3}} \times \sqrt{I}$$

$Q = \frac{1}{0.03} \times 2 \times (0.5)^{\frac{2}{3}} \times \sqrt{0.001}$

$Q \approx 1.41 m^3/s$

Therefore, the estimated flow rate of the canal is approximately 1.41 cubic meters per second.

3.4. Canal Losses

Water losses in irrigation canals can be classified into two major categories: losses due to evaporation and losses due to infiltration.

3.4.1. Evaporation Losses

Evaporation losses occur when surface water evaporates due to solar heat and climatic conditions. These losses depend on temperature, humidity, wind speed, and the exposed surface area of the water.

3.4.2. Infiltration Losses

Infiltration losses occur when water seeps into the soil through the bed and walls of the canal. These losses depend on the nature of the soil, canal design and maintenance, as well as the groundwater level.

3.5. Reduction of Losses

- **Canal Lining:** Use impermeable materials (such as concrete, geomembranes) to line the canals and reduce infiltration losses.
- **Floating Covers:** Utilize floating covers or covered canals to minimize evaporation losses.
- **Optimal Irrigation Management:** Adopt optimal management techniques to reduce water losses and increase irrigation efficiency.

Chapter 4

Irrigation Techniques

Chapter 4: Irrigation Techniques

4.1. Introduction

Regardless of the water, source (natural watercourse, groundwater, and runoff) and its mode of transport (channels, pressurized pipelines), a fundamental issue arises for the farmer: how to distribute this water on the soil so that plants derive maximum benefit from it?

However, the means of water distribution on the soil do not always have to meet this criterion of maximum production; the farmer must primarily consider the final profitability of the operation. Therefore, the installation and equipment costs on the one hand (soil development, equipment, etc.) and the operating costs on the other hand (energy, labor, etc.) must largely influence the choice of the irrigation technique to be adopted.

4.2. Definition of an Irrigation Technique

An irrigation technique refers to a specific method used to deliver water to agricultural crops in a controlled and efficient manner. There are several irrigation techniques, each adapted to specific conditions and different types of crops. The three main methods used today to irrigate fields are:

- Surface irrigation (by flooding, runoff, or furrow),
- Sprinkler irrigation,
- Micro-irrigation or drip irrigation.

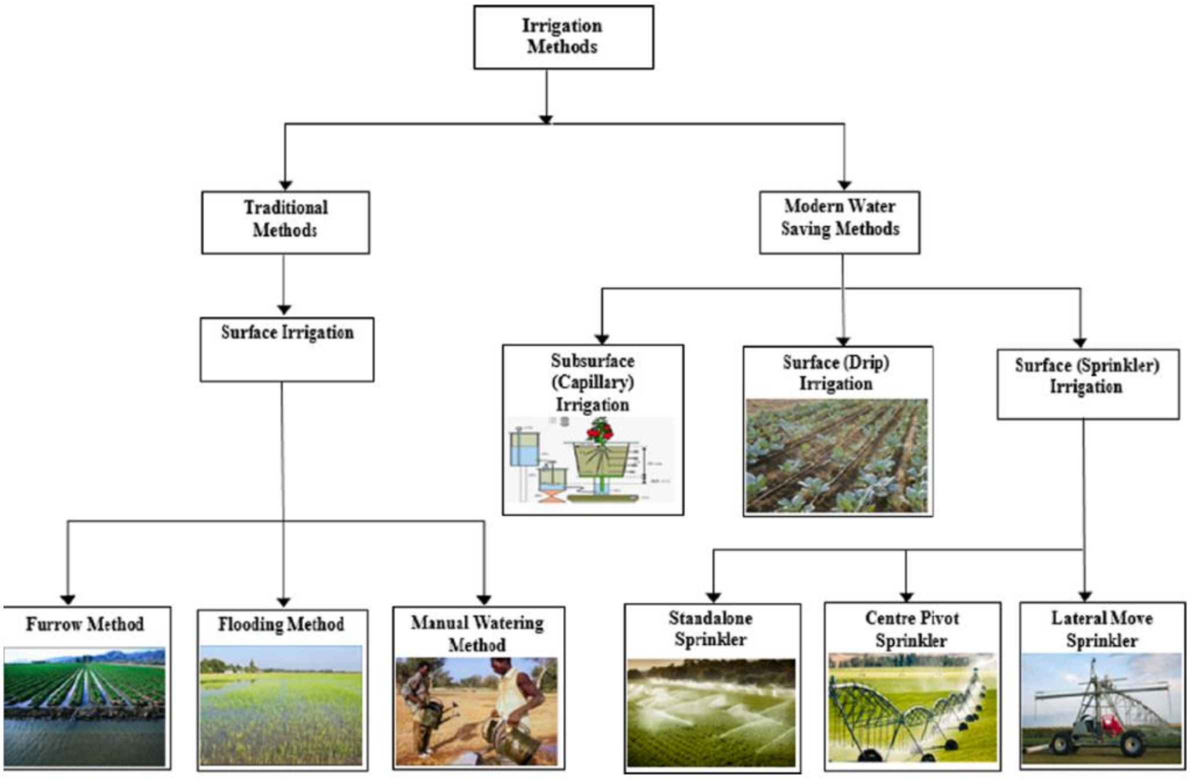

Figure 4.1 : Différentes méthodes d'irrigation.

4.3. Choosing the irrigation system

The choice of the irrigation system is based on a set of criteria and constraints:

- Topography (slope, terrain, parcel geometry).
- Water resources (quantity, quality, flow rate, availability).
- Soil type (permeability).
- Economic factors.
- Labor requirements.
- The crop under consideration.

4.3.1: Surface Irrigation

Surface irrigation is a method that uses gravity to transport water along cultivated surfaces, typically on gently sloping terrain. In this technique, water is applied to the soil surface, where it naturally flows over the agricultural plots, following the contour of the land.

4.3.1.1: Flood Irrigation:

The principle of this technique involves creating a thin layer on long and narrow boards on a gentle slope. The water that flows and infiltrates during its journey along the board reaches this time from one of its small sides. Therefore, the boards are long and narrow.

But for the water to reach the downstream end of each board, the flow rate must be greater than in the case of "overflow" described above. The slope is typically between 0.15 to 0.60% for row crops and exceeds 5% for alfalfa and other forage crops. The water that emerges on the board through one or more gates in the supply channel, and guided along the board by low and wide lateral ridges to avoid obstructing the passage of machinery, in dry periods. A drainage ditch collects excess water at the bottom of the board.

Figure 4.2: flood irrigation

4.3.1.2: Submersion Irrigation

Submersion irrigation is used for densely seeded crops such as rice, where the terrain is flat, surrounded by dikes, and water is abundant. A water blade brought by furrows covers the field for a variable time depending on the crop, soil porosity, and drying rate. Submersion irrigation of basins is used in orchards where trees are surrounded by a depression that is filled with water. Surface irrigation is practiced in sloping terrain.

4.3.1.3: Furrow Irrigation

Furrow irrigation is reserved for row-planted crops such as cotton and vegetables. Parallel furrows allow irrigating fields with surfaces too irregular to be submerged.

Figure 4.3: Furrow Irrigation

4.3.1.4: Infiltration Irrigation:

Infiltration irrigation is a method that involves applying water directly to the soil surface, where it slowly infiltrates into the soil to reach the plant roots. This technique is particularly effective for permeable soils that allow rapid water infiltration.

This is the most widely used system in Algeria; in this case, the water does not run off but rather stagnates as it infiltrates laterally to moisten the surface between two furrows. This technique accounts for 90% of irrigated areas in Algeria.

4.3.2. Sprinkler Irrigation:

Sprinkler irrigation rapidly developed after World War II, particularly in Europe and the United States. Water is transported through pressurized pipeline networks and delivered at the plot level through outlets that regulate pressure and flow rate. Downstream from the outlet, pipes (carrying ramps and ramps) under pressure feed rotary sprinklers that spread water like rain.

This technique requires less water and allows for better management. The sprinklers positioned along a pipe each send water droplets in a circular pattern until the moisture reaches the root level. It is practiced in three modes:

- by moving a mobile ramp along the plot,
- by total coverage of the plot by the ramps

- by full coverage of the plot.

Originally reserved for vegetable irrigation, sprinkler irrigation has seen considerable growth in large-scale farming thanks to metallic and plastic materials. This technique mimics rainfall without runoff, and the irrigation flow rate must always be less than the infiltration rate, requiring extensive calculations.

It requires significant resources and is mainly used for irrigation of large areas.

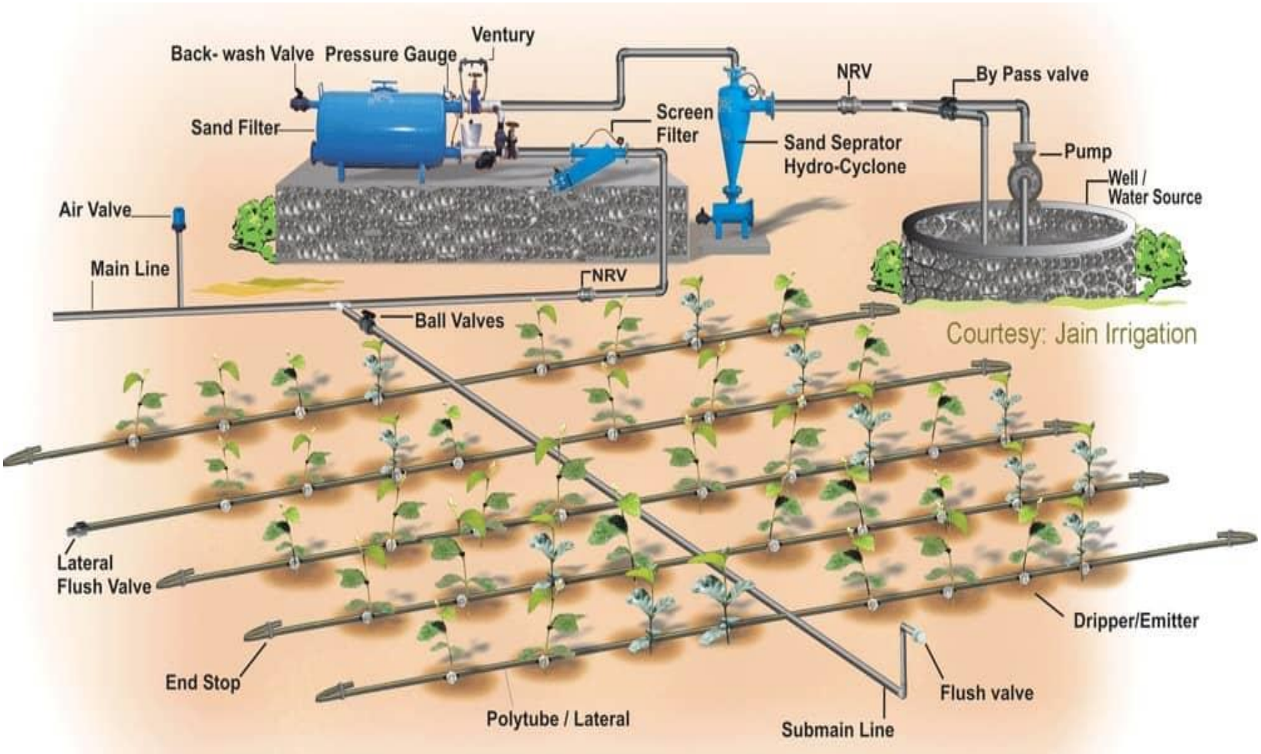

Figure 4.5: Sprinkler Irrigation System

In some cases, the sprinklers are arranged along an axis that rotates around a central pivot, resembling the minute hand of a clock. Over time, to irrigate larger areas, the sprinklers have evolved into irrigation guns, which are large rotating sprinklers similar to reels.

The reel thus performs strip irrigation without intervention. During irrigation, the winding speed is automatically adjusted to deliver the chosen water dose. At the end of the run, the winding stops automatically, and the entire system is moved using a tractor to irrigate the next strip.

Sprinkler ramp

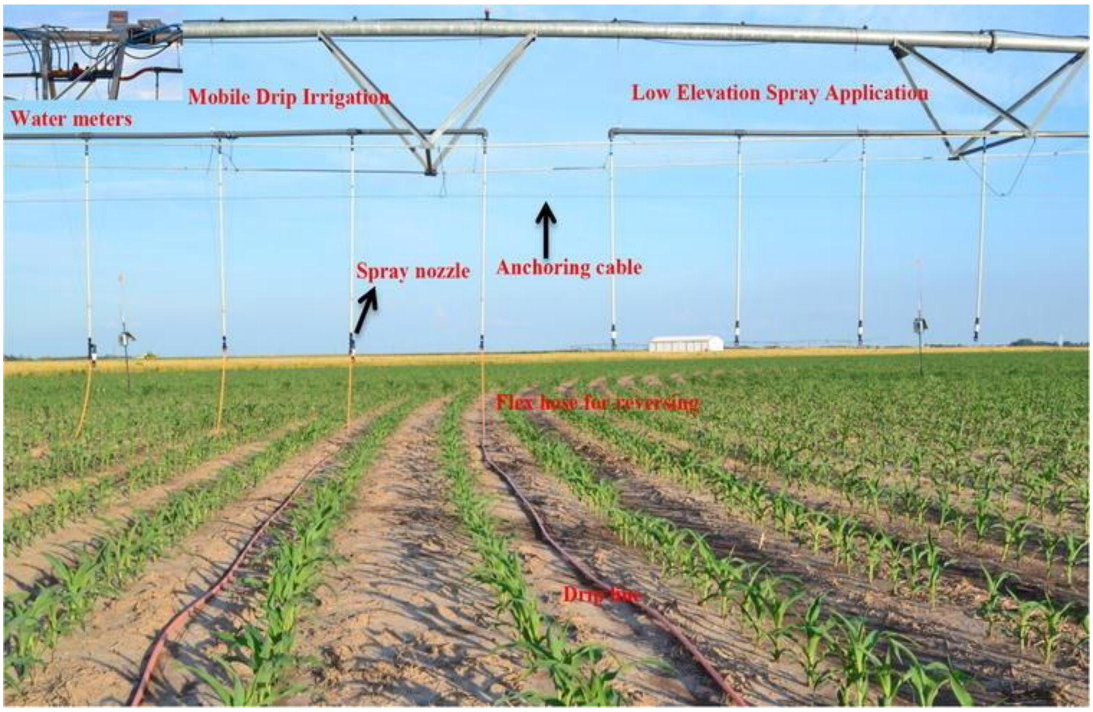

Figure 4.6: Arrangement of irrigation posts and movement of mobile ramps

Figure 4.7: Layout of irrigation stations and movement of mobile ramps in the field

4.3.3. Drip Irrigation

Drip irrigation involves delivering water to only a portion of the soil through small, frequent doses. At the limit, compensation for evapotranspiration occurs daily, and water is supplied through emitters, creating wet zones in the soil called "watering bulbs."

These installations are entirely fixed, equipped with semi-automatic valves, and are generally made of plastic. Water is supplied at low pressure and low flow rate. Precautions must be taken to filter the water used, as the emitters easily clog.

Several techniques have been developed:

- Localized irrigation by drippers
- Localized irrigation by fixed perforated ramps
- Localized irrigation by diffusion (micro-jet, micro-diffuser).

It is theoretically the most water-efficient technique. It helps limit the contact between air and water, thus reducing evaporation. Although evaporation remains low under our climates, it allows positioning the water near the plant where it can be absorbed by the roots. Most installations are coupled with fertigation devices. It is used in open-field vegetable crops as well as in greenhouses.

Given the investment that these systems represent (€1,500 to €3,000/ha), farmers are concerned about their sustainability, often challenged by clogging issues. This is one of the reasons why disposable systems are developing. Their technical interest is understandable, but one may wonder about their impact in terms of CO_2 production, even though they are constructed from recyclable materials.

Figure 4.8: Drip Irrigation

In drip or trickle irrigation, water is delivered to the plant in small doses, leading to the moistening of a fraction of the soil. This helps to limit losses due to evaporation and percolation. It also reduces weed growth.

Chapter 5

Study of a Sprinkler and Drip Irrigation Project

Chapter 5: Study of a Sprinkler and Drip Irrigation Project

5.1. Introduction

To grow, all field crops need soil, water, air, and sunlight. The soil provides plant stability, storing water and nutrients that plants absorb through their roots. The sun provides the energy necessary for plant growth. Air allows plants to breathe. Plants cannot grow without water, but excess water is also harmful to many of them. Except for rice, very few plants grow in water. The most well-known source of water for plant growth is rainwater.

The water needs of plants are essential resources for their growth. Water is a major constituent of plant material, but also a source of hydrogen and oxygen for photosynthesis: hydrolysis. Most of the water consumed by plants is not used for the formation of plant material but for transpiration.

The amount of water that a plant transpires to synthesize one gram of dry matter, the transpiration coefficient, varies according to the plants. It ranges from 300 to 700 grams of water per gram of dry matter for cultivated plants (about 336 grams for maize, 700 for zucchini).

Plant transpiration regulates their temperature and is the main driver of the circulation of raw and elaborated sap. The transpiration rate depends on climatic conditions (temperature, solar radiation, air humidity deficit, wind), plant type, vegetative stage, growth, and soil water availability.

If the plant's water resource is not limited (the soil is saturated with water), the transpiration rate is maximal: this is referred to as actual maximum evapotranspiration. Otherwise, the plant will suffer from water stress. The plant will reduce its biological and photosynthetic activity, and therefore its water consumption.

5.2. Estimation of water requirements for crops:

According to Doorenbos and Pruitt (1976): "The water requirement of a crop is the depth of water, in mm, needed to compensate for the evapotranspiration of a crop in good health, established in a large field, under soil conditions not limiting in terms of water availability and fertility, and leading to potential crop yield under given climatic conditions." It is necessary to choose a good definition of water requirements, as this concept is fundamental to irrigation projects. The two main factors determining the amount of irrigation needed are:

- the total water requirement of different crops;
- the amount of rainfall available for the crops.

In other words, the irrigation water requirement is the difference between the total water requirement of the crops and the amount of rainfall available for the crops.

5.2.1. *Definitions of potential (ETP), maximum (ETM), and actual (ETR) evapotranspiration:*

This is the ideal consumption of a plant, covering the soil well, optimally supplied, and in full vegetation. The roots of plants absorb or extract water from the soil to live and grow.

The majority of this water does not remain in the plant but dissipates into water vapor in the atmosphere through the leaves and stems. This process is called transpiration; it mainly occurs during the day.

The soil, under the influence of heat, evaporates the water it contains. This is evaporation. Evaporation is defined as the transition from the liquid phase to the vapor phase; it is physical evaporation.

ETM can be defined as the maximum water consumption of a well-watered vegetation cover. It is maximal in the sense that it does not take into account the actual water available to the plant in the soil for evapotranspiration. The water is considered to be in an ideal quantity here (water reserve = easily usable reserve). As long as the water is not present in the soil under conditions that do not generate either water stress or asphyxiation, the evapotranspiration of the crop will be lower than its maximum evapotranspiration. We then speak of actual evapotranspiration ETR. ETR is the actual water consumption of the crop**.**

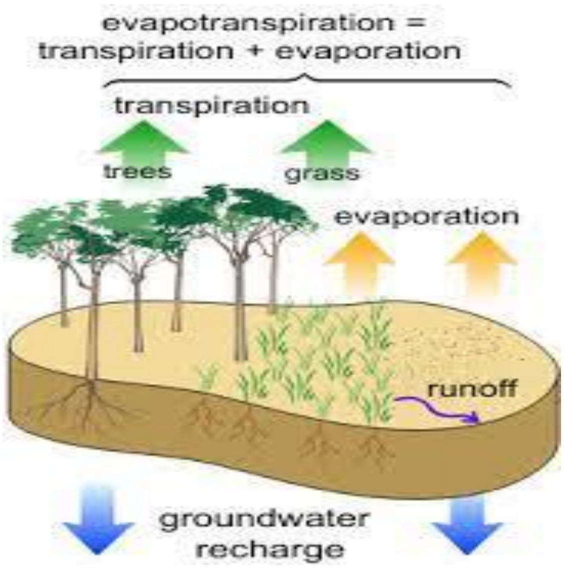

Figure 5.1: Schematic representation of the evapotranspiration/groundwater recharge/runoff balance

5.3. Determination of crop evapotranspiration

Estimating the evapotranspiration of soil covered by vegetation is challenging. Researchers have devised a method to determine the water requirements of crops, equivalent to the reference evapotranspiration (**ET_0),** by adjusting the potential evapotranspiration (**ET_0**) of a reference crop, typically grass, using a coefficient called the "crop coefficient" (**kc**) using the following formula:

$$ETM\ (crop) = K_C\ ET_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.Eq5.1$$

ETM: maximum evapotranspiration of a crop (mm),

Kc: cultural coefficient,

ETP: potential evapotranspiration (mm).

The determination of evapotranspiration at the system level will always start with its measurement or estimation at the plot scale for a given crop, which will then be regionalized to the system.

Evapotranspiration can be determined using the following methods:

- **Water balance methods (lysimeter)**
- **Thermal balance method (evaporimeter)**
- **Empirical formulas**

5.3.1. Direct method

Evapotranspiration can also be measured experimentally using lysimeters.

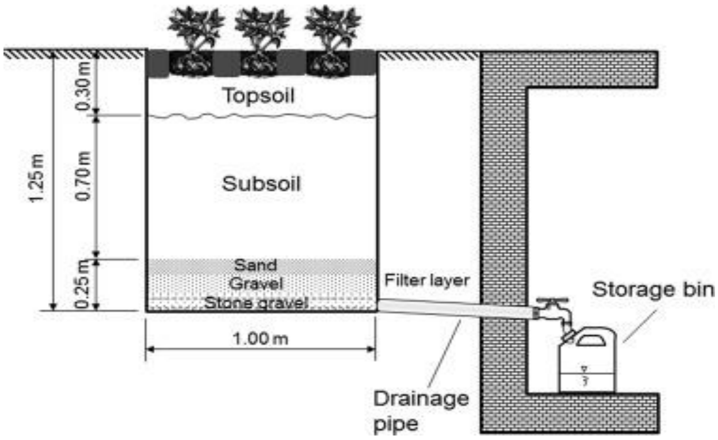

Figure 5. 2: Measuring actual evapotranspiration with weighing lysimeters

These are outdoor bins containing soil covered with a certain type of vegetation or left bare, where the amount of infiltrated and drained water is evaluated relative to that brought by precipitation. While these direct measurements are indeed very accurate, the result of their regionalization at the perimeter scale is rarely reliable because it encounters the heterogeneity of agro-pedo-climatic conditions. Moreover, these direct measurement methods are difficult to implement and relatively expensive. That's why in the considered flux studies, plant water consumption is systematically based on potential evapotranspiration, cultural coefficients. These are indirect methods, which consist of:

a- determining the potential evapotranspiration (ETP) under the climatic conditions of the studied culture,

b- determining the cultural coefficient (kc),

c- deducing the potential evapotranspiration (ETM), and then assuming that the actual evapotranspiration (ETR) equals the ETM by assuming that net irrigation needs are satisfied at every instant (no water stress).

5.3.2. Indirect method

Evapotranspiration can also be indirectly estimated using empirical and theoretical formulas that combine climatic variables.

5.3.2.1. Turc formula

The Turc formula, derived by simplifying the Penman formula, only requires knowledge of air temperatures and global radiation or sunshine duration. This formula is as follows:

$$\boldsymbol{Etp = 0.013 \times (T + 17.8) \times Ig \times K \ldots\ldots\ldots\ldots.. Eq5.2}$$

Where:

Etp is the potential evapotranspiration (in mm/day).

T is the mean daily temperature in Celsius.

Ig is the mean daily global radiation received at the ground (in calorie/cm2/day).

K is a coefficient, which is equal to 1 if the relative humidity is greater than 50%.

5.3.2.2. Thornthwaite formula

The Thornthwaite formula, applicable in semi-arid and semi-humid regions, is also based primarily on-air temperatures.

$$\boldsymbol{ETP = 16 \times \left(10 \times \frac{t}{I}\right)^{a} \times K \ldots\ldots\ldots\ldots\ldots\ldots Eq\ 5.3}$$

$$\boldsymbol{i = \left(\frac{t}{5}\right) \times 1.5\ et\ I = \sum_{1}^{12} i \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Eq\ 5.4}$$

$$\boldsymbol{a = \frac{1.6}{100} \times I + 0.5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots. Eq5.5}$$

t: is the average monthly temperature of the month considered;

Etp: is the potential evapotranspiration of the month considered (in mm of water);

K: is a monthly adjustment coefficient.

Table 5.1: monthly adjustment coefficient.

Month	J	F	M	A	M	J	J	A	S	O	N	D
K	0.73	0.78	1.02	1.15	1.32	1.33	1.33	1.24	1.05	0.91	0.75	0.70

5.4. Cultural coefficient KC

The crop coefficient (Kc) is defined as the ratio of crop evapotranspiration (ETc) to potential evapotranspiration (ETp). It reflects the combined effects of four key factors that differentiate a specific crop from the reference crop: crop height, surface resistance of the soil-vegetation interface, albedo, and soil evaporation.

A plant's water consumption primarily depends on its growth stage (vegetative phase) and variety. These factors determine the Kc value for each crop. This coefficient represents the growth dynamics of the plant throughout its vegetative cycle. For example, in sugarcane, the Kc starts at 0.2 during the initial stages of growth and progressively increases, peaking at a value of 1. The coefficient also varies based on factors such as altitude and the crop's planting date.

Factors affecting the value of KC are:

- The characteristic of the culture,
- Dates of planting or sowing,
- The rhythm of its development and the duration of its vegetation cycle,

Climatic conditions, especially at the beginning of growth and the frequency of rainfall or irrigation.

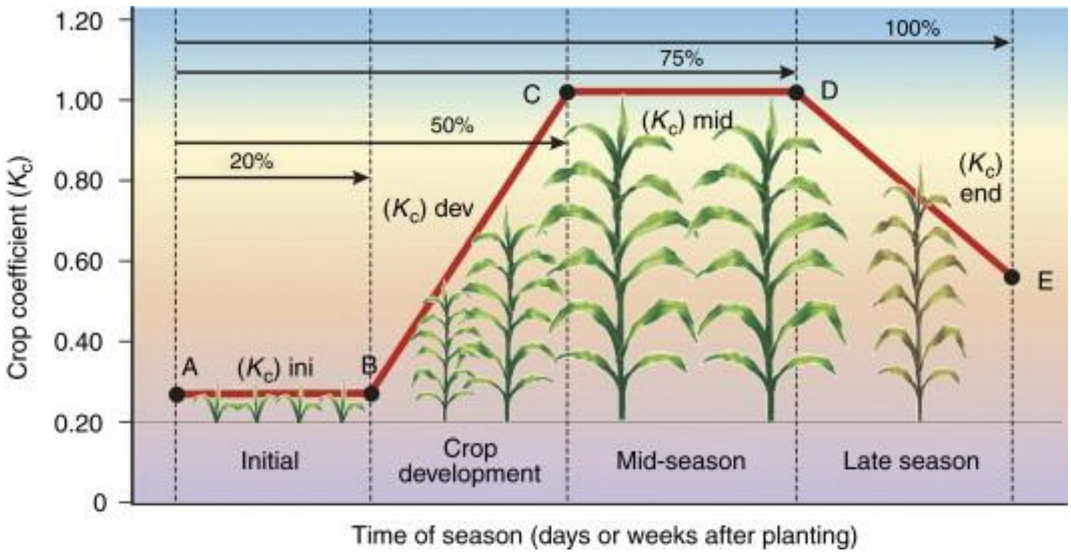

Figure 5.3: Crop coefficient curve and stage definitions

The Kc curve over the whole growth period was initially presented by Doorenbos and Pruitt (1975). It allows to distinguish the 3 values of kc (initial, mid-season, and late season). The highest values of kc are observed in spring and autumn, when the soil is still wet. The lowest values are noted in summer.

When choosing the appropriate Kc for a given crop and for each month of the vegetative cycle, it is necessary to take into account the rhythm of its development, the time of planting or sowing, climatic conditions including wind and humidity, and also the particularity of the formula used to calculate the ETP.

Table 5.2: Cultural Coefficient of Some Crops

Crops	Total Amplitude	Peak Period
Grains (wheat, oats, barley, corn, millet, sorghum)	02-1.2	1.05-1.02
Alfalfa, Clover	0.2-1.2	1.05-1.25
Rice	0.2-1.25	1.05-1.35
Cotton	0.2-1.25	1.05-1.25
Sugar beets	0.2-1.2	1.05-1.2
Carrots, Potatoes	0.2-1.15	1.0-1.15
Melon, Spinach	0.2-1.05	0.55-1.05
Onions	0.2-1.1	0.95-1.1
Tomatoes	2-1.25	1.05-1.25

Crop water requirements depend on several parameters that can be grouped into three categories, each represented by a global parameter:

Table 5.3: Summary table of parameters affecting crop water requirements calculation

Parameters	**Components**	**Represented by**
Climatic	Temperature and humidity of the air, wind, sunlight.	L'ETP
Pedological	Texture, structure (infiltrability), physicochemical properties of the soil, availability of water in the soil (available water capacity)	Water potential
Biological	Characteristics specific to the plant	Crop coefficient

5.5. Effective rainfall

Effective rainfall (P_{eff}) refers to the portion of precipitation that is effectively utilized by crops after accounting for losses due to surface runoff and deep percolation. Selecting an appropriate method to calculate effective precipitation requires careful evaluation. Various methods have been developed, each tailored to consider the climatic conditions specific to the region where the measurements are conducted.

- If P < 20 mm equals P =P_{eff}
- P ≥ 20mm equivalent to Peff = P- [0.15 (P-20)]
- For a finished floor Peff = 0.9 P

5.6. Rainfall deficit

Knowing the evapotranspiration ETP (mm) and the precipitation module P (mm), it is possible to define the precipitation deficit DP (mm) for a given period:

$$DP = ETP - P \dots\dots\dots\dots\dots\dots\dots\dots\dots..Eq5.6$$

P is rainfall, expressed in millimeters.

ETP is the potential evapotranspiration in millimeters.

Monthly values allow for the determination of the annual precipitation deficit. In the case of a negative deficit, there is a precipitation surplus. However, it should be noted that this term does not account for excess or water losses through runoff and infiltration at the soil level.

5.10. Usable Water (Useful Reserve) "noted as Hu or Ru"

Usable water for the plant is the maximum quantity of water it can draw from the soil reservoir. It's equal to the difference between the retention capacity (field capacity) and the wilting point.

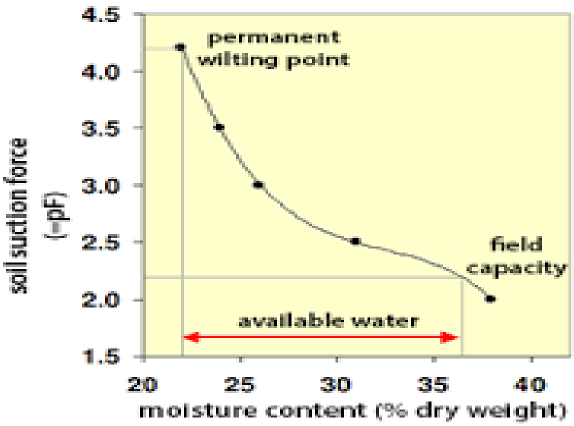

Figure 5. 4: Soil water reserve

It can be evaluated in weight (expressed as % by weight) or in volume (Hu + da), taking into account the root depth (h).

$$H_u = (H_r - H_f) \times da \times h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Eq5.7$$

Where:

da: bulk density

h: root depth

Hu: Usable water corresponding to the maximum irrigation dose

5.7. Easily usable reserve (RFU)

Easily usable reserve (RFU) is practically limited to 2/3 of the usable reserve. For irrigators, RFU is the most important parameter. It corresponds to the practical irrigation dose that needs to be applied during an irrigation session.

$$RFU = \frac{2}{3} RU = \frac{2}{3}\left(H_r - H_f\right) \times da \times h \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. Eq\ 5.8$$

5.8. The agricultural deficit

Theoretically, to compensate for the rainfall deficit, an equal volume of water should be applied at the soil level. However, in reality, this is not always the case because the usable reserve (RU) of the soil can store water. Therefore, water is applied to fill a fraction of RU. This is the easily usable reserve (RFU), which varies greatly due to soil type, root depth, crop type and growth stage, and winter water surplus. Thus, instead, we consider k RFU, where k is a value between 0 and 1.

Consequently, the soil-climate deficit, often referred to as agricultural deficit (Da), or pedo-agro-climatic deficit,

$$Da\ (mm) = ETP - P - k\ RFU \ldots\ldots\ldots\ldots\ldots\ldots\ldots.Eq\ 5.9$$

$$da = d_p - K_c \times RFU \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq } 5.10$$

RFU is the readily usable reserve, that is, the reserve of water in the soil available for plants, expressed in millimeters. It is worth 2/3 of the UK which is equal to the moisture rate multiplied by the depth reached by the roots.
Kc cultural coefficient [0.1]

Note that when RFU is depleted, the soil no longer contributes to watering the crops. The agricultural deficit equals the rainfall deficit.

5.9. The Characteristic Flow Rate

The characteristic flow rate is a fundamental measure in irrigation, especially in sprinkler and drip irrigation systems. It represents the volume of water delivered per unit of time to a specific point in the irrigation system. This parameter is crucial to ensure uniform water distribution and to ensure that the water needs of crops are optimally met.

5.9.1. Calculation of the Characteristic Flow Rate

The characteristic flow rate (Q) is typically expressed in liters per hour (L/h) or cubic meters per hour (m^3/h) and can be calculated using basic hydraulic formulas:

$$Q = \frac{V}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 5.10$$

where:

Q is the flow rate (in L/h or m^3/h),

V is the volume of water delivered (in liters or cubic meters),

t is the time (in hours).

For a drip irrigation system, the characteristic flow rate of an emitter is often specified by the manufacturer and is influenced by the water pressure in the system.

5.10. Definition of Equipment Calculation in Irrigation

Equipment sizing is a crucial step in the design and implementation of both sprinkler and drip irrigation systems. This process involves determining and sizing the various components of the system to ensure uniform and efficient distribution of water to the crops. Equipment includes pumps, pipes, sprinklers, drippers, filters, pressure regulators, and other necessary accessories.

5.10.1. Steps of Equipment Calculation

Crop Water Requirements: Calculate the amount of water needed per type of crop, considering specific requirements and climatic conditions.

Flow Rate and Pressure: Calculate the total flow rate required to irrigate the entire cultivated area and determine the necessary pressure for each type of equipment (sprinklers, drippers).

Selection of Sprinklers and Drippers: Choose suitable sprinklers and drippers based on the flow rate and pressure. Characteristics such as the coverage radius of sprinklers and the flow rate of drippers should match the project's requirements.

Pipe Sizing: Calculate the diameter of main and secondary pipes to ensure uniform water distribution with minimal head losses.

Pump Selection: Size the pumps according to the total flow rate and required pressure. Characteristics of the water source (depth, available flow) must be taken into account.

Filters and Pressure Regulators: Select filters to prevent clogging of drippers and sprinklers, and pressure regulators to maintain a constant and adequate pressure in the system.

Valve and Controller Planning: Install valves and controllers to manage different irrigation zones, allowing sequential and programmable irrigation.

Exercise

You have a 1-hectare plot that requires irrigation using a drip system. The system includes drippers with a flow rate of 1.5 L/h each.

Calculate the following:

1. **Water requirement**: Determine the daily water needed for the plot based on crop requirements.
2. **Total flow rate needed**: Calculate the total flow rate required to irrigate the plot effectively.
3. **Selection of drippers**: Decide the number and placement of drippers based on crop spacing.
4. **Pipe sizing**: Choose appropriate pipe diameters to maintain adequate water flow and pressure.
5. **Pump selection**: Identify a pump that meets the system's flow rate and pressure needs.

Additional Assumptions:

- Assume the crop requires a daily water application rate of 6 mm.
- Irrigation is planned for a 10-hour period each day.

Solution

1. Water Requirement

To determine the total daily water requirement for the plot, we use the crop's daily water need, which is 6 mm (or 6 liters per square meter, as 1 mm of water depth per m^2 = 1 L).

Daily water requirement = Plot area × Water depth requirement

$=10{,}000\ m^2 \times 6\ L/m^2 = 60{,}000\ L/day$

So, the plot needs 60,000 liters of water per day.

2. ***Total Flow Rate Needed***

To find the required flow rate, divide the daily water requirement by the number of hours the system will operate per day (10 hours).

Total flow rate = Daily water requirement / Irrigation hours

$= 60{,}000\ L/10\ h = 6{,}000\ L/h$

The system requires a total flow rate of 6,000 L/h.

3. Selection of Drippers

With drippers rated at 1.5 L/h, calculate how many drippers are needed to meet the total flow rate.

Number of drippers = Total flow rate / Dripper flow rate =6,000 L/h/1.5 L/h per dripper=4,000 drippers

Thus, 4,000 drippers are required to achieve the necessary flow rate.

Dripper placement: Dripper spacing should be set according to the crop's root zone and spacing requirements. For example, place them every 50 cm along rows that are 1 m apart if suitable for the crop.

4. Pipe Sizing

Pipe sizing is important to ensure water is distributed evenly across the plot.

Mainline pipe: Choose a diameter that can handle the total flow rate of 6,000 L/h.

Lateral pipes: Choose a diameter appropriate for the dripper distribution on each lateral line.

For example:

A 2-inch diameter mainline pipe can handle approximately 6,000 L/h.

Use 1-inch lateral pipes if each lateral line serves around 25–30 drippers.

Note: For an accurate pipe size, consider the hydraulic design, including factors like pipe length, elevation, and permissible pressure drop.

5. Pump Selection

Select a pump that can meet the required flow rate (6,000 L/h) and provide adequate pressure for the drip system.

Flow rate: 6,000 L/h

Pressure requirement: Typically, drip systems operate at 1–2 bars, depending on layout and pipe characteristics.

Choose a pump that provides 6,000 L/h at a pressure of around 1.5–2 bars. This will ensure sufficient flow and pressure to deliver water uniformly across the plot.

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