People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University of 8 May 1945 Guelma

Faculty of Science and Technology

Department of Civil Engineering & Hydraulics

Course handout

Irrigation

Conceived by: **Dr. DORBANI Meriem**

(Doctor of Civil Engineering – Hydraulic Option)

Designed for: **3 LMD Hydraulic**

Academic year 2023-2024

Acknowledgements

I would like to express my gratitude towards the people who contributed to the creation of this course material on irrigation.

First of all, I sincerely thank the faculty of the Genie civil and Hydraulics Department for their guidance and constant support in preparing this educational content. Their valuable feedback greatly enriched the substance of this course.

I am also grateful to my colleagues and industry professionals who agreed to proofread parts of the text and share their experiences, ensuring the relevance of this course.

Finally, I wish to address my appreciation to the students for their enthusiasm and eagerness to learn – it is a privilege to contribute to your educational journey. I hope you will find this course material useful as you build robust foundations in irrigation.

Thank you all, and enjoy the read!

Dr DORBANI Meriem

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Department of Civil and Hydraulic Engineering

SYLLABUS

Specialty: Hydraulic **Unit: UED 3.1,** **Subject: irrigation**

Semester: 5, **Academic Year: 2023/2024**

Credits: 1 **Coefficient: 1**

Teacher in charge of the subject: Dorbani Meriem, **Grade: M.C.B**

Number of teaching hours: **Course: 1.5 hours**

Teaching objectives:

The student will have to acquire, at the end of this semester, the basic knowledge of the operation of an irrigation system.

Prior knowledge recommended:

Basic notions of hydraulics.

Content of the material

Chapter 1: General introduction to irrigation

History; Definition of irrigation; Purpose of irrigation science; Improvement of the calculation of irrigation regime.

Chapter 2: Parameters and factors involved in irrigation

Thermal regime; Rainfall regime; Evaporation; Relative humidity; Wind speed and fluctuation; Relief and topography; Soil structure and texture……

Chapter 3: Crop Water Requirements

Evapotranspiration; the easily usable reserve; the reserve irrigation dose and the basic irrigation dose; the dates and number of watering for agricultural crops; Specific flows (hydro modules); Charts of regulated and unregulated hydro modules.

Chapter 4: Irrigation Techniques

Surface Irrigation (gravity); Spray Irrigation; Drip Irrigation.

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Evaluation mode:

- 100% exam.

Summary

Chapter III: Crop water requirements

Chapter IV: Irrigation techniques

Avant-propos

The teaching of this unit is scheduled for 3rd year Bachelor Hydraulic students. It is designed to complement the knowledge of programmed irrigation material for the benefit of students of the third year Bachelor's degree in urban hydraulics specialty.

The programme of this handout consists of four main chapters: a general introduction on irrigation, the factors involved in the latter, the calculation of crop needs and the various irrigation techniques.

This handout is the result of the lessons I taught for several years for the L3 level, Convinced that this document will facilitate the task for the learners, I would like to express my gratitude to all those who helped or encouraged me in its realization.

Introduction

Introduction

Water is an essential resource for life. It is used in many different ways by humans. Essential for agricultural, energy and industrial production.

Fragile and limited, water resources are increasingly threatened by the consequences of human activities. The growing number of users today means that this resource must be managed in an integrated and efficient manner, with a long-term perspective, and thus must find innovative solutions to meet demand. L'agriculture est, de loin, l'industrie ayant la plus grande consommation d'eau. L'irrigation des régions agricoles représente 70% de l'eau utilisée dans le monde entier.

In many developing countries, irrigation accounts for up to 95% of all water uses, and plays an important role in food production and food security. Future agricultural development strategies in most of these countries depend on the ability to maintain, improve and expand irrigated agriculture.

On the other hand, there is increasing pressure on water resources, amplified by competition from other water-using sectors and respect for the environment.

Water is a resource that can create tensions between different countries sharing the same water sources. Irrigated agriculture can be highly competitive, accounting for 70-90% of water use in some regions.

Irrigation can be defined as an artificial supply of water to facilitate the growth of crops, trees and pastures. The methods differ depending on whether water flows onto the land (surface irrigation), is sprayed under pressure (spray irrigation) or is brought directly to the plant (localized irrigation).

In the field of irrigation, the solution is to identify future projects by adopting irrigation techniques and processes that make rational and efficient use of reserved water volumes.

This modest polycopiy makes it possible to know the science of irrigation, passing first by a general introduction on irrigation then the determination of the factors intervening in the latter then the evaluation of the water needs in the plant, water/soil relations and the various irrigation techniques.

Chapter I

General introduction to irrigation

Chapter I: General introduction to irrigation

1.1. Introduction

Life, as we understand it, is not possible without water.

Water is one of the major challenges of the 21st century. Indeed, although global water supplies are theoretically sufficient for the needs of the whole planet, they are very unevenly distributed. Rainfall is also very imbalanced with the seasons in some parts of the world. Moreover, global warming is further increasing these inequalities.

In the nutrition and development of all living things, especially plants, the role of water is, in fact, fundamental in a double relation.

Water is first of all a constituent element of the plant, either simply in the form of water, called constitution, or after combination with the elements found in the soil and in the air: water is then the vehicle that brings the plant mineral elements of food: it is water called vegetation.

Agronomists have quantified the water requirements of plants, as they result from this double aspect.

In the field of irrigation, we first concern ourselves with the movement of water between plants and their environment.

According to FAO (United Nations Food and Agriculture Organization) statistics, 20% of arable land is irrigated but produces 40% of the crop. Irrigation is therefore an effective way to significantly improve productivity and therefore feed humanity.

1.2. History of irrigation

1.2.1. Antiquity:

All history shows us that, as it has just been defined, irrigation was a powerful factor of wealth, prosperity and, consequently, security.

Its origins are very distant, and very early one can see how some empires that had resorted on a large scale experienced prosperity, and how often arrived, when irrigation was abandoned, decadence and ruin.

- ***China***

It is the creation, from the blue and yellow rivers, of a vast irrigation network across the Chinese plains that increased its fertility and allowed the intensive cultivation of rice.

This work of the great Chinese emperors provided food for the inhabitants of the Celestial Empire.

- ***India***

Twenty centuries before our era the basin of the Indus was covered with reservoirs of irrigation that the world's longest-standing chronicles in Sanskrit prescribed to build as an imperative duty, given the extreme drought.

But, if irrigation knew in this country a certain development until the middle ages, the modern times saw the abandonment of the canals and it was necessary to wait the English domination for a new impulse was given in this field.

- ***Egypt***

Egypt has known, even before historical times, the practice of irrigation. Elsewhere, the pharaohs had dug a large number of artesian wells, some of which reached 100 meters deep. But, from the first centuries of our era, irrigations knew an abandonment that was to last fifteen centuries.

Around 3000 BCE, an irrigation system was created from the Nile to divert part of the water to a lake, Lake Moeris. The Moeris consisted of a reservoir (the lake), a flow channel, a group of regulators, water intakes, dams, etc…

Figure 1.1: Canals and dikes on the Nile: Ancient Egyptian Agriculture

It was used in certain seasons to supplement the lack of water and to regulate the level of an immense waterway parallel to the Nile intended for the circulation, in all seasons, of the heavy barges necessary for the construction of the pyramids. The hydraulic complex restored under the XII dynasty, used both for irrigation and communications, was extended to Lake Mariout. Used until the Arab era this canal was successively named: Memphis Canal, Bahire Canal, El Asara, Bahr el Lebeini.

The Arab countries

From **Yemen**, their country of origin, the Arabs had made an irrigated and fertile land. In the countries they conquered, they also sought to develop all aspects of irrigation. They were helped by an excellent knowledge of hydraulics and the art of construction. If, in Egypt, they partially restored the pharaonic works, their greatest work was carried out in Spain. The regions of Valencia, Granada and Andalusia experienced the peak of Arab irrigation.

In **Oman**, the «Aflaj» irrigation systems have also been listed as World Heritage by UNESCO. The oldest achievements date back to 500 AD but traces suggest that irrigation was practiced as early as 2500 BC. «Aflaj» is the plural of «Falaj» which means, in classical Arabic, «Divide into parts». This system channels water from groundwater sources, by gravity, to supply fields and inhabited areas. Watchtowers were built to defend the system.

In **Algeria**, the **Foggara** system: it is a traditional irrigation system «foggara» in the Algerian Sahara, allowed the transition from nomadism to sedentarization. This hydraulic organization made it possible to install and maintain here oases, whose essential role was to offer travelers and caravans the last stage before crossing the great south.

The ingenuity of the process lies in its design and its adaptation to the conditions of life and the Saharan climate: it eliminated the exhausting water chores, which took most of the time of the inhabitants, ensured a constant flow supply, without the risk of drying up the water table and limiting evaporation to a minimum.

In **Algeria**, foggara has developed in the south-western regions of the country, particularly in the regions of Adrar, Touat and Gourara, where the hydrogeological and topographical conditions of its regions consist of a string of sebkha, fed by natural executions of the continental interlayer layer flush to the ground surface.

This drainage system is known around the world under several names:

- Iran, Yemen, and Jordan: «Qanat».
- In Italy: «Ingruttati».
- In Spain: «Madjirat».
- In Sultanate Oman: «Falag».
- In Morocco: «Khattara».
- In Japan: «Manbo».
- In Latin America: «Hoyas».
- In China: «Jing-quen».
- In Algeria: «Foggara».
- In Tunisia: «Ain or Mkoula».

1.2.2. Modern times

While in modern times the Spaniards had only to continue and develop the work of the Moors, in Italithe first major irrigation works were born in the free communes of Lombardy. Then the work of the communes was continued by the princes who came afterwards.

In France, it was in the Pyrenees that the first important canals were built around the same time, probably under the influence of the Moors.

Then it was the Italian influence that was felt, first with the popes who enriched the Vaucluse by watering, then with the French of Charles VIII and Louis XII who, back from Milan, practiced, according to the methods they had learned, watering in the South.

1.2.3. The contemporary era

If the modern times had seen some countries resume and restore the irrigations of antiquity and others to initiate watering, it was necessary everywhere to wait for the 19th century to realize again large irrigations.

- ***India and Egypt***

British engineers did a splendid work in these two countries, one of the most beautiful in the world. It was not without political purpose, for the English had understood that, if they held water, they held the country.

In India, the irrigated area is estimated at nearly 24 million hectares.

In **Egypt**, they modernized the old processes of the pharaohs and, thanks to a powerful system of dams reservoirs and canals, they succeeded not only in considerably extending the irrigated areas, but still to lengthen the period of watering thanks to the waters derived and put in reserve. Thus the general economy of this country received a vigorous impulse.

- ***Spain and Italy***

The contemporary era has seen in Spain a great development of the existing irrigation network, but it seems that too much attention has been paid to the construction of important works, such as dams and canals, while the fundamental problem of water distribution and its best use was somewhat neglected. The result was a considerable amount of capital which was not always profitable.

In **Italy**, the greatest abundance of rivers and the management by the state of the canals avoided the miscalculations known in Spain. A continuous expansion of the irrigation system brought the total area to 1,400,000 hectares by the end of the last century.

- ***France***

In **France** too, it was in the 19th century that structures multiplied in order to extend irrigation. But all the channels have been far from being used to the maximum of their possibilities, which often leads to an unfortunate deficit of their exploitation.

However, in addition to the large areas they irrigate, there are a large number of much smaller areas that growers water individually using streams, springs, etc.

In fact we can only estimate in a very approximate way the areas really irrigated.

According to old estimates, irrigation in France would extend to 2,500,000 ha, or 7% of the useful agricultural area.

1.3. Definition of irrigation

The man saw very early on the interest he had in bringing to the lands he was cultivating make-up water, without which some plants could not develop, or in any case reach their maximum growth: he applied irrigation.

Irrigationis the operation of artificially bringing water to cultivated plants to increase production, and allow their normal development in the event of water deficit induced by a rainfall deficit, excessive drainage or a drop in groundwater, especially in arid areas. According to the international glossary of hydrology.

Irrigation is the set of cultural techniques intended to provide plants through the soil all the water but only the water they need.

Irrigation **is probably the** oldest of human techniques; it reflects the supremacy of man over nature.

Irrigation management consists of answering the following questions:

- When to water? Taking into account:
  - Water needs of plants;
  - Water reserves from the ground.

- How much water to bring? To determine the irrigation doses that must be provided in addition.

- How to bring it? Based on:
  - The mode of irrigation;
  - The type of soil;
  - The nature of cultures.

The implementation of an irrigation system is not improvised. There are a number of considerations, from project design to the long-term facility management process.

Irrigation is a key component of vegetable production. Even if it is not essential every year, it is an investment that reduces the risks related to climatic hazards in vegetable production.

The definition of irrigation seems very simple, but it hides a very difficult overall problem: it is first of all to find in a relatively small radius available water; it will then be necessary to bring it to the places of cultivation, then the distribution enters all the plants in well defined quantities.

1.4. The purpose of irrigation science

Irrigation is food security and therefore a better life. It changes the human environment; ecology and economics.

Why irrigate?

Irrigation must make it possible to fill this water deficit (It is called water deficit, for a given period, the difference between the rains fallen and the need for water defined according to the climatic and physiological characteristics of the plant).

When the rain satisfies most of these needs, this is called make-up irrigation. In this case, irrigation helps to secure production, by regulating and improving yields.

Today, it still makes it possible to compensate for a lack of water but it also allows to increase production thanks to the contribution of fertilizing elements and to fight against frost by sprinkling water.

Modern irrigation techniques seek to save water. They are chosen according to the terrain and culture and take into account technical considerations, the need for water for crops, the reserves of soil water, and irrigation equipment. The purposes of irrigation are:

- Increase in agricultural production.
- Improving water quality for irrigation
- Improvement of production quality.
- Contribution to the stabilization of agricultural products.
- Reinforce the mechanization.
- To combat the fragmentation of the agricultural sector by grouping together small holdings through the creation of large holdings.
- The implementation of technology and technicality.
- Contribution to the development of agricultural land.
- Water assessment through efficient and rational management.
- Fight against water waste.
- Contribution to food security.
- Fight against poverty.
- Positive impact on health (healthy and clean food).
- Compensate for the lack of rainfall.
- Leaching of the soil.
- Fight against the risk of frost.
- Possibility of fertilization. (Amendment).

1.5. Improvement of the calculation of the irrigation system

The calculation of irrigation scheduling depends of many factors, such as the type of crop, soil, climate, and the water needs of the plant.

Here are some general steps to refine the calculation of irrigation scheduling:

- Know the water needs of the crop: it’s essential to understand the specific water requirements of the crop you are growing. This can vary significantly from one crop to another.
- Study the soil: the soil’s water-holding capacity, drainage rate, and other soil characteristics play a crucial role in calculating irrigation scheduling. Well-draining soil requires less water than clayey soil.
- Measure precipitation: take into account natural precipitation levels in your area to adjust your irrigation water needs. A rain gauge can help you track precipitation levels.

- Use efficient irrigation tools: choose efficient irrigation methods, such as drip irrigation or sprinkler irrigation, to minimize water losses.
- Monitor the weather: regularly check weather forecasts to adjust your irrigation schedule based on future conditions.
- Collect data: use soil moisture sensors or other devices to monitor real-time soil moisture and adjust your irrigation accordingly.
- Conduct trials: perform trials to determine the necessary water flow rate for each zone or crop. This may require some adjustments over time.
- Save water: ensure you do not over-irrigate, as it waster precious resources. Use water management technique such as scheduling irrigation times and regular system maintenance.
- Adapt to changing conditions: be prepared to adjust your irrigation schedule based on seasonal variations and the specific needs of your crops.

Ultimately, refining irrigation scheduling is an ongoing process that requires monitoring, experience, and adjustment based on local conditions and the specific needs of your farm or garden.

Chapter II

Parameters and factors involved in irrigation

Chapter II: Parameters and factors involved in irrigation

2.1. The basics of irrigation

It is obvious that the data collected relate to the conditions of the environment in which crop production evolves.

In this section, data on soil, water, plants, and of course climate are collected. Therefore:

- Soil: It has many properties that play a fundamental role in the cultural process of irrigation.
- Water: In case of drought, it is important to know where you can get water to irrigate and knowledge of the origin of the water must provide valuable elements regarding its quality for irrigation.
- The plant: It consumes water according to its needs which are variable according to the type of plant and its stage of development.
- Climate: It determines the importance of needs and when they are most important.

From a technical point of view, irrigation relies on the knowledge of three fundamental elements that react closely to each other: Plant-Water-Soil.

2.1.1. The Soil

2.1.1.1. Definition

Soil is a porous mixture of inorganic or mineral particles, organic matter, air and water. The term soil, will be defined as the top layer of soil that can be dug and shovelled. The nature of the bedrock (granite or limestone, for example), therefore influences the type of soil formed.

The soil is a support and a reservoir of water storage for the plant, the capacity and the modalities of emptying this reservoir require the knowledge of certain elements for each type of soil: Texture, Structure, Permeability and capacity of the soil.

The soil has two essential criteria for irrigation characteristics:

- Physical characteristics;
- Chemical characteristics.

The science that studies soil and its evolution over time is called pedology. It leads to a classification of soils and an analysis of their vocation to avoid any degradation and preserve their fertility.

Agricultural soil includes:

- Of mineral elements
- Organic elements
- Water and air

What qualities does the farmer expect from the soil?

The plant grows partly in the soil (germination-growth of the roots). It must therefore, at any time, meet the needs of the crop.

- **The needs of plants**

- The plant is anchored in the ground;
- Seeds and roots breathe: the presence of oxygen is essential;
- The plant absorbs water and nutrients from its roots in order to build its plant matter.

Water allows the transport of nutrients to other organs and their use (especially at the leaf level in synthesis reactions (photosynthesis). Some is rejected by perspiration.

- Roots (and other organs such as seeds) grow and develop in the soil and require some heat.

- **Search for roles and qualities to identify.**

The soil therefore has:

- A supporting role: it must be sufficiently loose, without obstacles, favourable to root growth;
- A nourishing role: water-filled soil, aerated, warming quickly and rich in nutrients.

How to improve the soil?

(Or preserve its fertility). To be able to act on the qualities (or defects) of the soil, it is already necessary to carry out a diagnosis on potentialities. This is the role of laboratory analyses but also of numerous field observations (for example: crop profiles).

The techniques to be used are very varied. Depending on the case:

- Water control in soil (drainage-irrigation);
- Adapted tillage;
- Chemical fertilisation (fertiliser);
- Calcium or organic amendments.

Priority orders are to be respected in each situation.

2.1.1.2. Physical Soil Characteristics

The observation of an existing soil shows that it consists of:

- A liquid fraction (the soil is wet). This fraction consists of water containing dissolved substances (especially nutrients), the roots draw this liquid to meet the nutrient needs (water and elements) of the plant.

- A gaseous fraction (presence of voids). This fraction consists of air mixed with gases from the life of soil organisms (including root respiration) and their activity. The roots must find enough oxygen.

- Of a solid fraction. According to their nature and origin, mineral constituents (origin = rocks) and organic constituents (origin = living beings) are distinguished.

The knowledge of the characteristics for a given soil will make it possible to appreciate its behavior vis-à-vis the needs of the crops and its ease of work.

The main physical properties affecting irrigation are:

- The texture;
- Structure and porosity;
- Permeability and soil capacity for water;
- Topography;

The texture

The texture indicates the relative abundance in the soil of particles of various sizes: sand, silt or clay.

Particle size analysis consists in separating and precisely fixing the percentages of the various components of the soil, defining the different textures. The granulometry itself concerns the fine earth.

- Sands: > 50 µm
- Silt: 50 µm to 2 µm
- Clays: < 2 µm1

Structure and porosity

Structure is the mode of assembly of solid components, at a given time. These constituents are more or less welded, giving rise to aggregates that will allow air, water, etc.

The porous space of the soil contains the liquid (microporosity) and gaseous phase of the soil (macroporosity).

The porosity of soils depends on the particle size, their distribution and therefore the porous volume of the soil.

$$\mathbf{P = V_t - V_s}$$

With :

P: Porosity

Vt: Total volume

Vs: Solid Volume

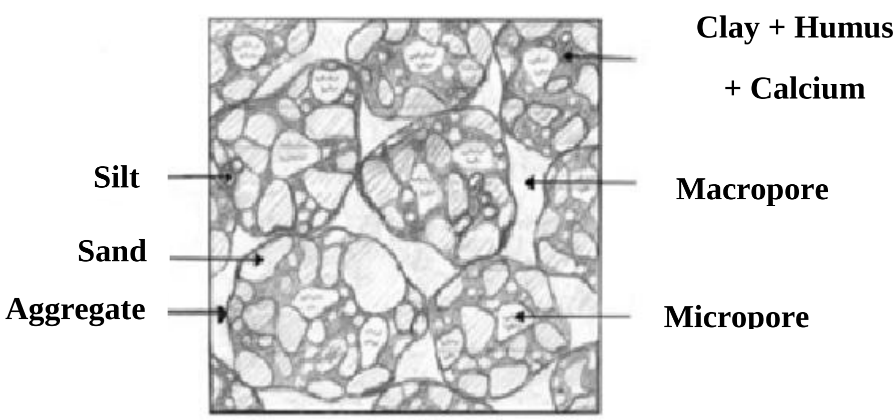

Figure 2.1: Soil structure

Permeability and soil capacity for water

Permeability or hydraulic conductivity is the property that translates the ease of water flow into the soil. The permeability of soils depends mainly on their porosity.

The permeability is large, the lower the capacity. In addition the imbibition of the soil reduces by itself the cohesion force by dispersing the aggregates. Heavy land, with a high degree of cohesion, can therefore use large bodies of water on relatively steep slopes.

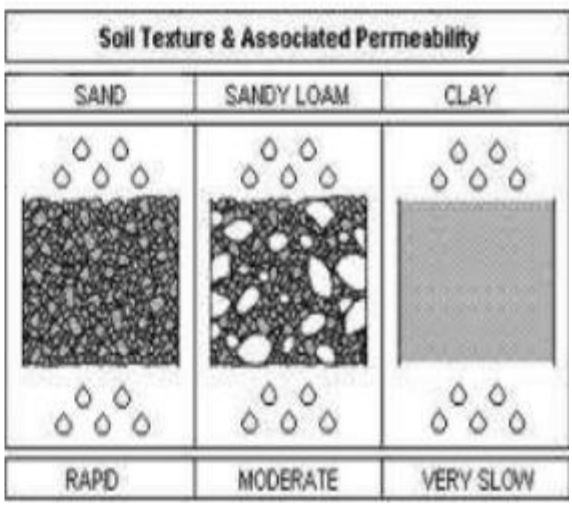

Figure 2.2: Soil texture and permeability

Topography

Examine the slope (capital factor of irrigation) which determines the velocity of water circulation on the surface, as well as the rate of circulation. Plots with uniform slopes and low amplitude (areas served by large dams, are well suited for irrigation because they reduce costly earthworks.

2.1.1.3 Chemical characteristics

- Salinity: This is the mass of salts (ionic compounds) dissolved in 1 L of water. It is expressed in g per kg of water.

- Alkalinity: It measures the ability of water to neutralize acids. This is called the buffering power of water or the ability of water to withstand a change in pH when adding acid.

- Organic matter: Soil contains a small percentage mass of organic matter, usually between 1 and 5%. This small amount of organic matter, about half of which is organic carbon, is very important for the functioning of the soil and the entire ecosystem.

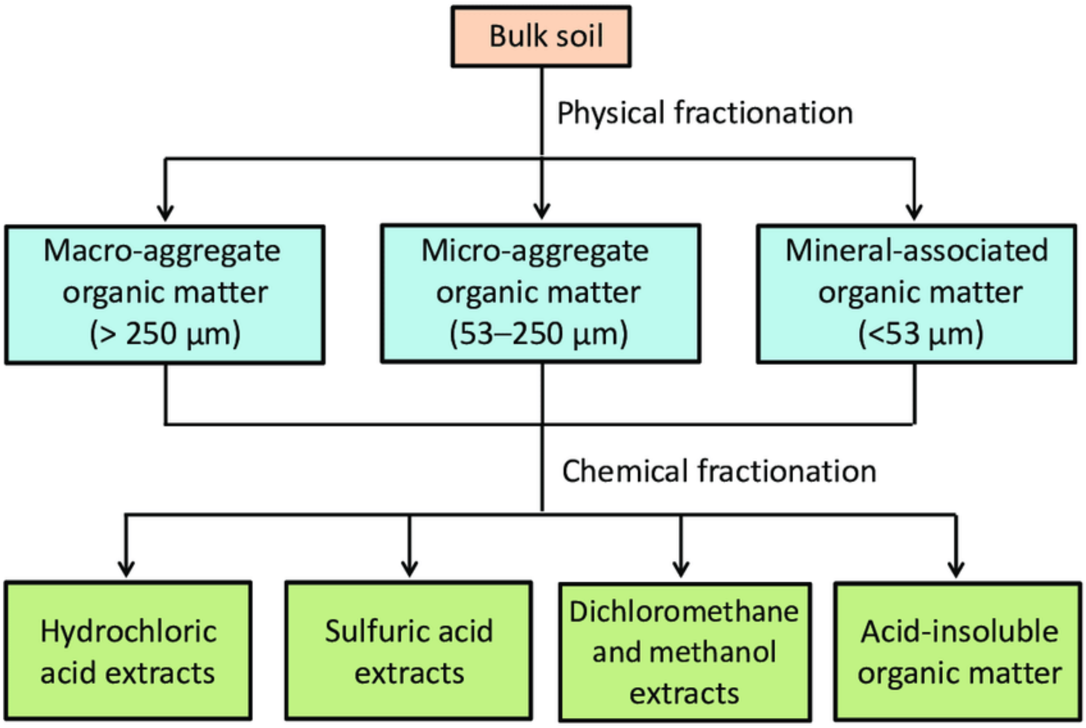

Figure 2.3: the different fractions of organic matter: stages and dynamics in the soil.

2.1.1.4. Soil humidity

Water is retained in the soil because of its natural attraction to soil particles in the same way as to its own particles. Water is retained in the form of a film around one each soil particle.

Soil moisture is the amount of water it contains. It depends on the type of soil (texture and structure) and its ability to retain water.

- **The equivalent humidity «He»**

This is the water moisture in the soil corresponding to a 1 Pf (Potential). It is measured in the laboratory using a centrifuge. It is a reliable, easy and fast method. Following numerous measurements carried out on different types of soil, the results obtained by the researchers are:

- For clay soil: He = 0.35 or a rate of 35%
- For silty soil: He = 0.18 or a rate of 18%
- For sandy-loamy soil: He = 0.13 or a rate of 13%
- For sandy soil: He = 0.06 or a rate of 06%

Based on AUBERT: **He = 10 + 0.55 ta**

With **ta:** Clay content (%)

- **Humidity to retention capacity Hr or Cr**

It is the moisture of a resurfaced soil, that is to say after disappearance of gravity water.

$$H_r = \frac{bound\ water}{dry\ soil\ weight}$$

- **Saturated humidity**

It is soil moisture when water occupies all the porosity (empty space) the soil no longer contains air.

Humidity at withering point

This is the moisture below which the plant suffers irreversible damage due to drought.

The permanent wilt point corresponds to the threshold above which the soil moisture no longer allows the plant to draw the water it needs, because the useful water reserve of the soil has been fully consumed. The plant then wilts and then dies if this moisture content lasts.

The wilt point "Hf" is related to the equivalent humidity by the following relationship:

$$H_f = \frac{H_e}{1.84}$$

Hygroscopicity point H_h

Hygroscopic water is water absorbed from the atmosphere and retained very tightly by soil particles, so it is not available to plants. Its value depends on the humidity and temperature of the atmosphere. According to VAGELER, the hygroscopicity point corresponds to natural desiccation.

The hygroscopicity point "Hh" is related to the equivalent humidity by the following relationship:

$$H_h = \frac{H_e}{4.55}$$

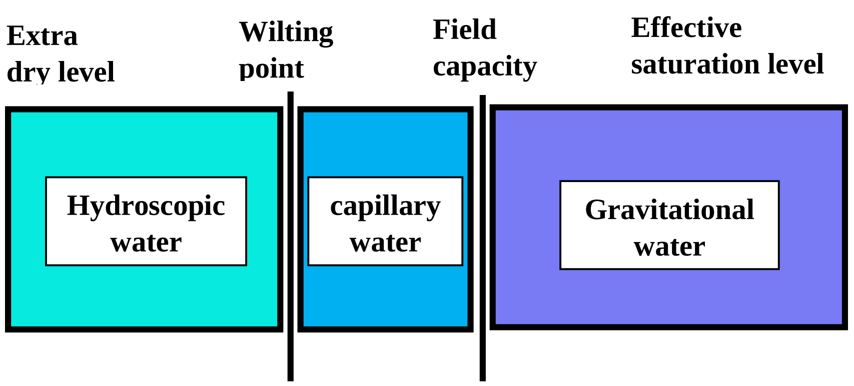

Figure 2.4: Retention capacity.

2.1.2. Water

Water is the essential element for plant development. It is used to transport nutrients by participating in the constitution of tissues and thermally regulating the plant.

The user must be concerned about the origin of the water, its qualities and its flow. Domestic water needs being a priority, and given the central role of water for many other sectors of activity (tourism, industry, hydroelectricity, cooling of nuclear power plants), irrigated agriculture, even if it remains the main user of fresh water (70% of the volumes collected) must respect the control devices for access to water and the trade-offs between the different uses.

But the balance between increasing demands for water and the availability of water resources is not always controlled.

2.1.2.1. The different water states in the soil

The floor is a functional system, so that stands out from energized by its compartments. Thus, the soil preserves the precipitation water to cover the transpiration of the plant. Under arid and semi-arid Mediterranean climates, rainfall is insufficient and poorly distributed to meet the water requirements of plants. However, to improve yields, replenishment of soil water reserves is recommended. The water likely to be contained in the soil is a function of the bond.

- **Retention water**

- **Hygroscopicity water**

When the soil is very dry, water is retained very intensively by the soil. It takes very energetic means to separate them (artificial desiccation), it is a water that is very bound to soil particles, and it is unusable by plants.

- **Capillary water**

When the moisture level increases at ground level, the water that binds to it essentially in the interstices, will be subjected to capillary forces. This water is easily usable by the plant.

Gravity or saturation water

It is water that is not retained by the soil, flowing under the action of gravity in well-drained soils. It is water that is unusable by the plant, contained beyond the retention capacity.

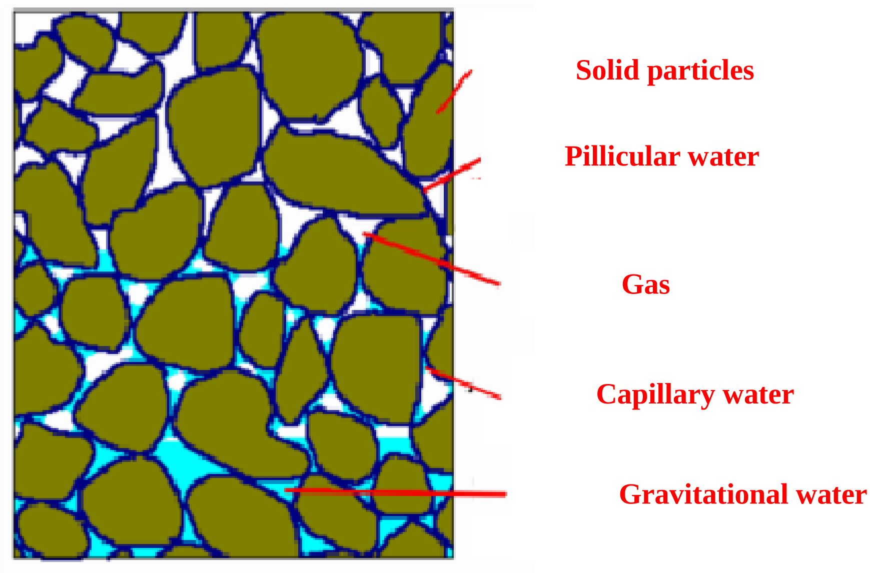

Figure 2.5: Soil water states

2.1.2.2. Physical quality

The dominant physical quality is temperature. The optimum temperature can be around 25° for most plants during the active growing season. A water supply on very dry land can give rise to hydration phenomena that can dangerously raise the temperature of the soil. That is why it is recommended not to water in full heat. Cold water coming into contact with overheated foliage can also cause accidents.

2.1.2.3. The chemical quality

Water derives mainly from the salts it contains in dissolution. Some ions are useful, even at relatively high doses Calcium, which thus compensates for the lime losses discussed above. Others are useful at very low doses, and then quickly become harmful when the water content increases, such as magnesium. In the same way that physiological tests are now used to determine the fertilizer requirements of a soil, one should not hesitate to apply irrigation water to control plants, using the land to be irrigated, since we cannot separate without fear of error these two elements that react on each other: water and soil.

2.1.2.4. The flow rate

It is the amount of water available in a given time, by watering a property, expressed in litres per second, liters per minute or cubic meters per hour.

The total flow, or general module for a property, is calculated based on the peak needs of crops in the course of a year. Losses along the way, if any, should be taken into account and a small margin of safety should be provided in the event of an accident. The volume of water distributed in each element, or per hectare, takes the name of dose, so we have:

Dose = flow rate x flow time

2.1.2.5. Energy status of water in soil

The energy state of water in the soil is defined by two parameters:

- Kinetic energy;
- potential energy.

The flow (water transfer) depends on the potential difference (pressure).

2.1.2.6. Soil Water Potential

Water is linked to the solid phase of the soil by a system of forces defined by the following relationship

$$\boldsymbol{\Psi_t = \Psi_w + \Psi_e + \Psi_c + \Psi_o + \Psi_g}$$

With:

Ψt: Total potential

Ψw: Adsorption potential

Ψe: Electrochemical potential

Ψc: Capillary potential

Ψo: Osmotic potential

Ψg: Gravity potential

- In saturated soil: Gravitational potential dominates (Ψg);
- In field-capable soil: Capillary potential dominates (Ψc);
- In dry soil: Electrochemical potential dominates (Ψe).

2.1.2.7. Useful Water (Useful Reserve) “rated Hu or Ru”

The useful reserve (RU) is the amount of water that the plant can theoretically use in its optimal conditions. This amount is always < to the retention capacity and depends on the plants. The amount of water that remains in the soil but cannot be used by plants defines the wilt point.

It is equal to the difference between the retention capacity (field capacity) and the wilt point.

$$\mathbf{Hu = Hr - Hf}$$

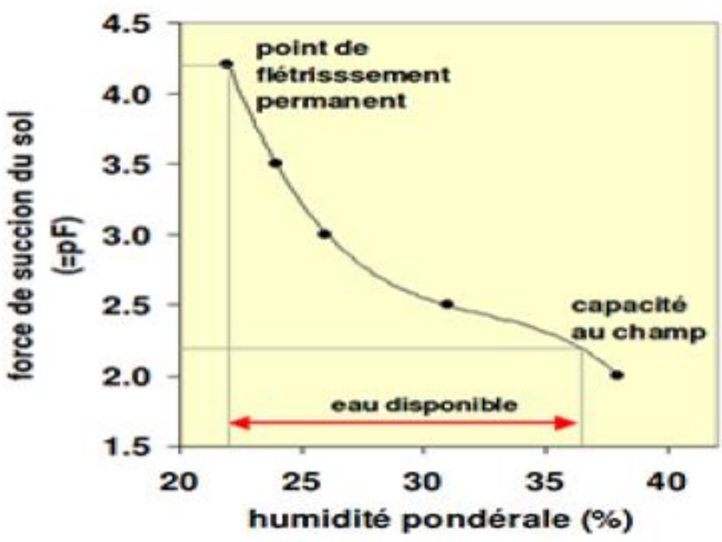

Figure 2.6: Useful Water (Useful Reserve)

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

$$\mathbf{Hu = (Hr - Hf) .da .h}$$

With:

da: bulk density

h: root depth

Hu: Useful water corresponding to the maximum irrigation dose

2.1.2.8. Readily Usable Reserve "Rated RFU"

The easily usable reserve (RFU) is limited practically to 2/3 of the useful reserve.

For irrigators, RFU is the most important parameter. It corresponds to the practical irrigation dose that must be brought during irrigation.

$$\mathbf{RFU = 2/3\ RU = 2/3\ (H\ r\text{-}\ Hf)\ \ x\ da\ x\ h}$$

The root volume varies according to the plants.

Vegetable plants can be divided into 3 groups according to their rooting:

- Low rooting: about 15 cm, radishes, salad…
- Medium rooting: about 20 cm, onion, potato, cabbage,
- Powerful rooting: over 30 cm, turnip, carrot, tomato, eggplant, zucchini, spinach…

The RFU in water of a soil is expressed in millimeters of water, it corresponds to the upper fraction of the useful reserve (RU) It is difficult to assess, and can be estimated at 60% of the RU.

2.1.3. Crops

Affect the mode of irrigation either by nature that does not combine with all systems, or by their water needs that can change the rotation of watering.

2.1.3.1. Nature of Crops

Imposes an irrigation system. Obviously, the natural conditions must be suitable for both the plant and its watering system. If the environment requires irrigation, the choice of crops is restricted. Thus a slope greater than 10% requires furrows or watering in rain. In order that these changes do not surprise the grower, they must be planned before the establishment of the watering system, so that it is arranged accordingly.

2.1.3.2. Plant Requirements

Vary with climate and species and the degree of vegetation change. Changes due to climatic factors are essentially variable from one year to the next depending on the temperature, rainfall, winds, etc. The needs vary according to the species, mainly because of the length of vegetation in the summer period, certain speculations such as vegetable crops, of primeur requiring only some watering in the spring, while others, such as the date palm claim water for most of the year. Some fruit species can be satisfied with watering from far away (apricot, olive), while some require continuous irrigation (citrus).

- **Evapotranspiration «ET»**

Evapotranspiration (scientific abbreviation ET) is the biophysical process of transferring a quantity of water to the atmosphere, through evaporation at ground level and through plant transpiration. It depends on:

- The climate that provides the energy needed for ET (Heat, Wind, Radiation);
- Water available in the soil or atmosphere;
- The development of vegetation.

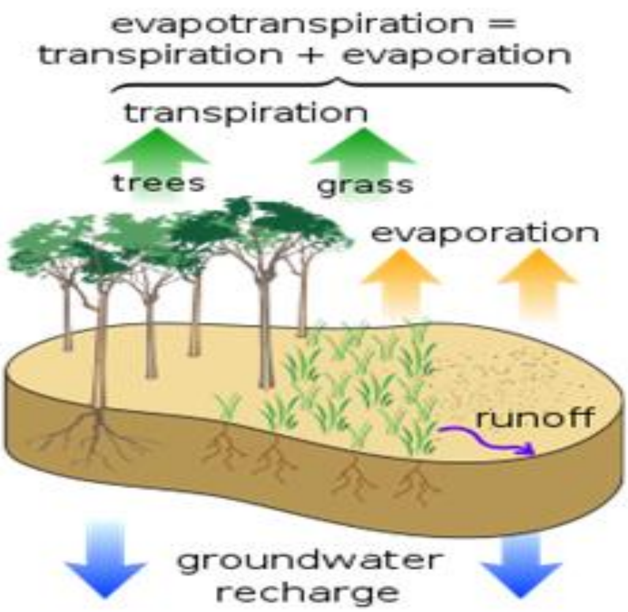

Figure 2.7: L'Evapotranspiration

- **Potential Evapotranspiration «ETP»**

A potential ETP evapotranspiration is the maximum amount of water evaporated under a climate given by a continuous vegetation cover well supplied with water. It therefore includes the evaporation of the soil/substrate and the transpiration of the vegetation of a given region during the time considered. It is expressed in water height (mm).

ETP is considered as a water demand by the climate to the soil-plant system. When the soil-plant system is able to meet this demand, the amount of water lost by it corresponds to the FTE.

When the soil-plant system is unable (drought) to have a supply equal to climate demand, only REE (reduced evapotranspiration) will occur.

Maximum evapotranspiration «E.T.M»

The maximum amount of water that the crop needs for optimal growth is defined by the product of ETP and Kc. This need is called Maximum Evapotranspiration (ETM), expressed in mm.

$$ETM = Kc * ETP$$

With **Kc**: cultural coefficient

The plant does not always have enough water to meet its needs.

In this case, the plant is unable to provide all the water required. It then decreases its activity and therefore its growth. The transpiration activity of the plant is then limited to what is called Real Evapotranspiration (ETR), expressed in mm.

ETM = ETR if there is enough water available (optimal growth).

ETR < ETM in case of lack of water (reduced growth).

Reduced evapotranspiration «ETR»

This is the amount of water actually lost by the soil-plant system. It may be lower than the ETM (maximum evapotranspiration), because in addition to the factors that determine it, it is influenced by the possible deficit of soil moisture and excess heat causing defensive reactions against water loss (closure of stomata).

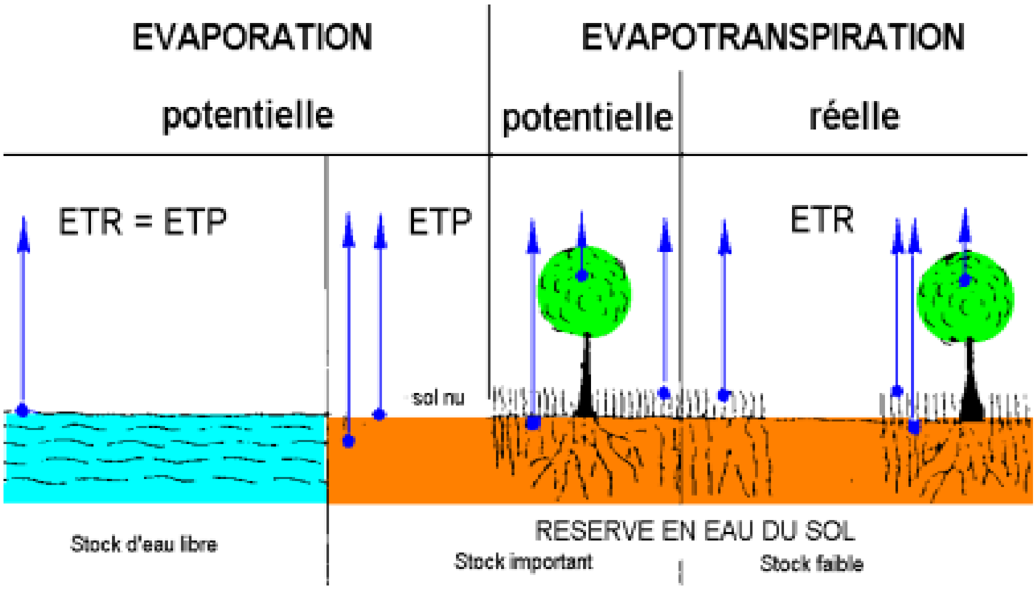

Figure 2.8: ETP and ETR

2.1.4. The climate

It determines the importance of needs and when they are most important. It is described by measuring and analysing its various elements:

- Temperatures;
- Elements related to light: radiation, insolation, cloudiness;
- Water-related elements: precipitation, evaporation, humidity (= humidity);
- Wind and atmospheric pressure (which, without being really an element of the climate, can explain the circulation of air).

2.1.4.1. Why study climate

Climate indirectly affects plant yields (in quantity and quality), by:

- On the surrounding environment of the crops (soil, biological environment = enemies of crops and auxiliaries, etc.) and on the possibilities of intervention of the farmer.
- It is also a factor of production by its direct action on the growth and development of crops, from sowing to harvest (growth = increase in weight and dimensions – development = appearance of new organs).

2.1.4.2. Action of climate factors on crops

For each climatic factor, there is an action on the growth and development of the plant that defines the interest of its measurement and the use that can be made of it.

- **Light:** it is a source of energy for the plant.

  - **Absorption:** One part is absorbed by the plant (another is «lost» by reflection of radiation and air circulation).
  - **Transpiration:** The plant «opposes» a very large increase in its temperature by perspiration (application: radiation will be taken into account in formulas to calculate the evaporating and sweating power of air, or ETP).

- **Temperature:** The plant requires some heat for its growth and development. Some of this development takes place in the soil (germination, root growth), so air and soil temperature will be measured.

- **Wind:** It is mainly its harmful effects that are taken into account when it is important:
  - It can lacerate foliage, cause crops to pour, deform trees but also erode and damage buildings (greenhouses, sheds).
  - It cools the ground, buildings...
  - It increases the ETP and dries the atmosphere: the plant, by closing its stomata, decreases its perspiration but even more its photosynthesis (=decrease in dry matter production and the efficiency of the water consumed).
  - It carries pollen but also the seeds of «weeds»

The only way to fight the wind is to install or maintain (artificial) wind breakers.

Chapter III

Crop water requirements

Chapter III: Crop water requirements

3.1. Introduction

To grow, all field crops need the soil, water, air and energy of the sun. The soil ensures the stability of the plant, it stores water and nutrients that plants absorb through their roots.

The sun provides the energy needed to grow the plant. The air allows the plants to breathe. Plants can no longer grow without water, but too much water is also harmful to many. Except for rice, very few plants grow in the water. The most famous source of water for plant growth is rainwater.

First, the determination of the water needs of a crop requires knowledge of various parameters concerning both the plant itself and the climatic or soil data of the region.

According to Doorenbos and Pruitt (1975) climate is one of the factors that most influences the volume of water that the crop loses through evapotranspiration. Agronomic practices, irrigation techniques, fertilizers, insect and disease infestations can also influence the rate of evapotranspiration.

The concept of evapotranspiration combines the two processes mentioned above, namely direct evaporation of soil water and transpiration by plants. On soil with even partial vegetative cover, transpiration exchanges are quantitatively more important than direct evaporation exchanges.

3.2. Process of water transfer in the plant

- Root absorption
- Fluid circulation in the vascular system of the roots, trunk, branches, leaves
- Transpiration through leaf stomata pores (=90% of total transpiration)
    - Perspiration is a direct product of photosynthesis, which depends on solar radiation.
    - Sweating also regulates the T°C of the plant (by evaporating the water carries away some of the heat of the plant)
    - Perspiration is influenced by:
        - Climatic factors
        - Nature, age and development of plant foliage
        - Soil moisture
- If soil moisture content < min content (“wilt point “) then roots fail to draw water from the soil => transpiration ceases, foliage wilts, plant dies.

3.3. Crop water requirements

According to Doorenbos and Pruitt (1976): The water requirement of a crop is the height of water, in mm, necessary to compensate for the evapotranspiration of a crop in good sanitary condition, established in a field of large area, under soil conditions that are 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 needs, because this concept is the basis of the irrigation project.

The two main factors that determine the amount of irrigation required are:

- The total water requirement of different crops;
- The amount of rainwater available for crops.

In other words: the need for irrigation water is the difference between the total need for crops and the amount of rainwater available for crops.

3.4. Why determine crop water requirements?

Knowing the value of crop water requirements is the basis for:

- **Irrigation project:** design of irrigation networks (calculation of the design flow of structures),
- **Irrigation network management:** short-term forecasting (water supply planning), irrigation management,
- **Planning the use of water resources:** volume of water needed for irrigation, irrigable areas in view of resources, etc.

3.5. How to determine crop water requirements?

According to Doorenbos and Pruitt (1975) the estimation of evapotranspiration for irrigation programming should be based on the calculation of maximum evapotranspiration and effective rain (Pe).

- **Need for irrigation water**

Noted (BI) is the total amount of water, per unit area, that a crop needs to develop normally under field conditions. The need for irrigation water is divided into:

The need for irrigation water is further divided into:

- **Net need for irrigation water**

Quantity that must be actually consumed by the plant. It is expressed in mm/d, mm/month or any unit of time. It is calculated by the following formula:

$$\mathbf{Bn = ETM - Pe - R}$$

Pe: fraction of precipitation stored in the root zone (effective rain)

R: rainwater runoff

- **Gross irrigation water requirement**

Volume of water that must be delivered from the system or taken from the water resource. This is a net requirement increase to account for:

$$\mathbf{Gross\ BI = BI / eff}$$

BI: need for irrigation water

eff: irrigation efficiency, expresses the dimensionless ratio between the height of irrigation water actually required by the crop.

In order to calculate irrigation needs, it is necessary to first know the maximum water needs of crops (ETM).

3.5.1. Crop Water Requirement (ETM)

In terms of irrigation, we try to place the plants in optimal production conditions and we base the irrigation on the value of the maximum evapotranspiration **ETM** which is a point value linked to the **ETP** which is relative to a region by a cultural coefficient.

ETM is the maximum amount of water that the crop needs for optimal growth, it is defined by the product of **ETP** and **Kc** expressed in mm.

$$\mathbf{ETM = kc \cdot ETP}$$

ETM: maximum evapotranspiration of a crop (mm),
Kc: cultural coefficient,
ETP: potential evapotranspiration (mm).

Evapotranspiration is determined by the following methods:

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

The considered flow studies, the water consumption of plants is systematically based on potential evapotranspiration, crop coefficients. These are therefore indirect methods, consisting of:

- Determine the **ETP** in the climatic conditions of the crop studied,
- Determine the cultural coefficient **Kc**,
- Deduce the **ETM**, then assume that the **ETR** equals the **ETM** assuming that net irrigation needs are met at all times (no water stress).

3.5.2. Calculation of Potential Evapotranspiration

Potential evapotranspiration (**ETP**) is defined as «the maximum evapotranspiration of a grass covering completely the ground, well supplied with water, in active phase of growth and located within a sufficiently extensive plot». Grass is one of the densest plants (20,000 viable seeds per square meter) and caught in the development phase that requires the most water supply. This definition implies a stage of development for which physiological regulations do not undergo significant changes and has been designed so that the calculation can be made from only meteorological data and therefore physical measurements.

The **ETP** can be calculated from more or less complex formulas depending on the amount of climate data available. It is important to have a critical eye in particular regarding the validity criteria of semi-empirical formulas that depend on the conditions of the measurement series that constitute the basis.

ETP is determined by two approaches:

- Direct method;
- Indirect method by empirical formulas.

❖ **Direct method**

It can be made from the evapotranspirometer or lysimetric tank. Lysimeter is a sealed tank (case) buried with vertical walls open on the surface and filled by the soil to be tested. The surface of the lysimetry soil receives precipitation (rainfall), while the bottom allows the water to percolate so that it can be harvested.

$$\mathbf{ETP = P - D - R}$$

With:

P: Precipitation

D: Drainage

A: Reserve

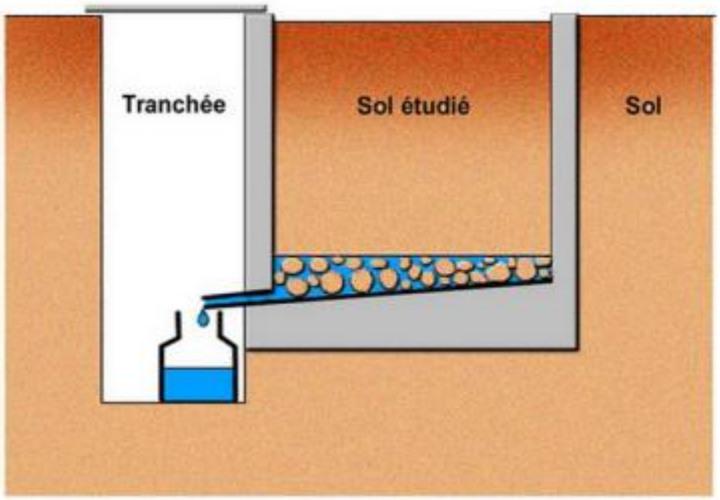

Figure 3.1: Lysimetric vessel

- **Indirect method**

This consistency in the value of potential evapotranspiration, demonstrated by a considerable number of systematic experiments, prompted researchers to establish models linking **ETP** to climate elements.

Some of the proposed formulae are the result of static adjustments (Thornthwaite, 1948; Blaney and Criddle, 1950; Turkish, 1961, etc.), while others are the result of physical reasoning based on the energy balance (Penman, 1949; Bouchet, 1964; Gerbier, 1974).

Some Algerian authors in 1983, using measurements made in Ain Baida, came to the following conclusions:

- Blaney and Criddle's formula estimates **ETP** values during the cold months;
- The Penman formula during the spring and summer, gives a higher **ETP** estimate than other formulas.

From a series of measures conducted for a panel of cultures and in a type of climate, laws of behavior could be identified.

- **TURC Formula**

If the relative humidity of the air is greater than 50 %, the potential evapotranspiration is given by:

$$\mathbf{E.T.P} = \mathbf{0.40}.\frac{T}{T+15}.(Ig+50) \quad \text{en (mm/month)}$$

E.T.P: potential evaporation in mm/month

T: average monthly temperature in °C

Ig: global solar radiation of the month considered in (cal/ cm^2/ day).

According to TURKISH, the coefficient **0.40** is reduced to **0.37** for the month of February.

If the global radiation **Ig** is not measured, it can be evaluated from the duration of exposure h by the formula:

$$\mathbf{Ig = lo\ (0.18 + 0.62\ h/H)}$$

h: duration of actual insolation, in hours

lo: theoretical maximum radiation ($cal/cm^2/day$)

H: maximum exposure time Theoretical, in hour provided

lo and **H** are given by tables according to latitude.

Thornthwaite Formula

THORNTHWAITE also proposed a formula based mainly on air temperatures, which is valid in semi-arid and semi-rainy regions:

$$ETP = 16 \times \left(10 \times \frac{t}{I}\right)^{a} \times K \quad \text{(en mm)}$$

t: monthly average temperature of the month in question (°C);

ETP: the potential evapotranspiration of the month in question (in mm of water);

K: is a monthly adjustment coefficient.

a: simplification brought by Serra

K: monthly adjustment coefficient

Mois	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

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

I: annual thermal index

i: monthly thermal index

$$a = \frac{1.6}{100} \times I + 0.5$$

Modified Permann Formula

$$E.T.P = c[WR_n + (1 - W)f(u)(e_a - e_b)]$$

E.T.P: (mm/ day)

W: temperature weighting factor.

Rn: equivalent evaporative radiation, (mm/day)

f(u): wind-related factor

$$f(u) = 0.27\left(1 + \frac{U2}{100}\right)$$

C: correction factor for daytime (day) and night (night) weather.

ea and eb: respectively the saturated vapour pressure and the actual air pressure at the same height (kPa)

U2: average daily wind speed measured at 2 metres (m/s)

Bouchet Formula

It is the estimation of the potential evapotranspiration from the measured values of the evaporation by the Piche evaporometer which is installed under shelter. The estimate is based on the following formula:

$$ETP\ (mm) = K.EV_P.a$$

K : Correction coefficient calculated as a function of **ϴ**, which is a coefficient which depends on the average temperature of the period under consideration.

$$\Theta = (3\,t + T)/\,4$$

t: T° minimum of the period considered.

T: Maximum T° of the period considered

EVp: evaporation measured under cover with the Piche evaporometer (mm) in 24 h (10 yars).

a = 0.37 (standard shelter), Coefficient depending on the type of shelter.

3.5.3. Cultural Coefficient Kc

By definition, the cultural coefficient (**Kc**) is the ratio between culture evapotranspiration (**ETC**) and potential evapotranspiration (**ETP**), it incorporates the effects of the 4 primary characteristics that distinguish a culture from the reference culture which are: crop height, soil surface resistance - vegetation, albedo, soil evaporation.

Factors affecting the value of **Kc** are:

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

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

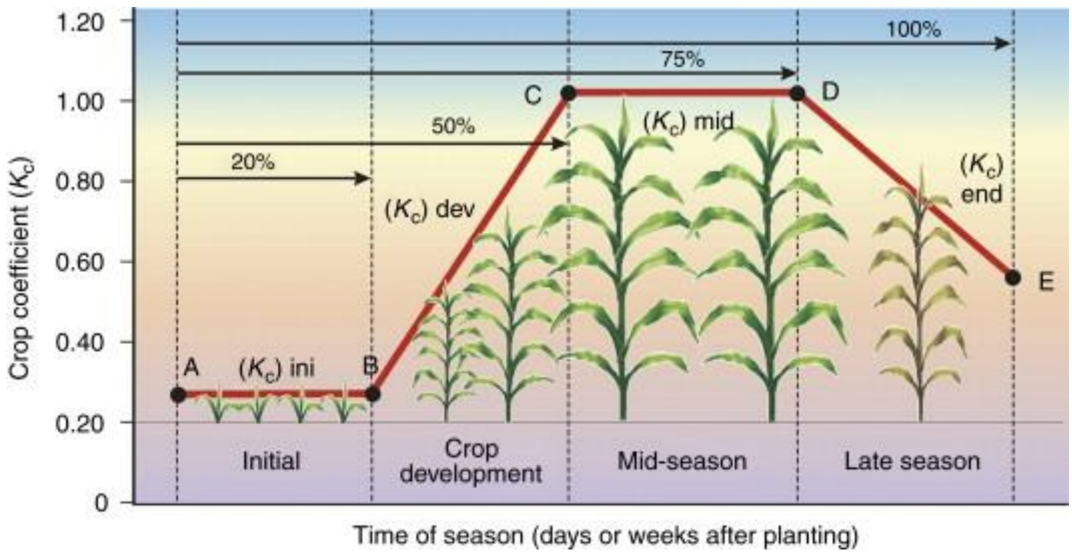

Figure 3.2: Crop coefficients curve and phase definition

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.

Kc varies mainly with the characteristics of the crop and only slightly with the climate. This allows the transfer of standard kc values from one place to another between climatic zones. But to have more precision in the determination of the ETC, it is always better to use the values of kc determined experimentally in the region elle-même.

3.5.4. effective rainfall

Effective rain, Peff, represents the fraction of precipitation that is actually used by the crop after deducting losses from surface runoff and deep percolation. The choice of the appropriate method for calculating effective precipitation requires serious consideration. Different methods have been developed, each taking into account the climate of the region where the measurements must be made.

If **P < 20** mm equals **P =Peff**

P ≥ 20mm equivalent to **Peff = P- [0.15 (P-20)]**

For a finished floor **Peff = 0.9 P**

3.6. Water balance

The continuous phenomenon of the water cycle can be schematized into three phases:

- Rainfall,
- Surface runoff and groundwater flow,
- The evapotranspiration.

It is interesting to note that in each phase there is respectively a water transport, a temporary storage and sometimes a change of state. It follows that the estimation of the quantities of water passing through each of the stages of the hydrological cycle can be done using an equation called "hydrological" which is the balance of the quantities of water entering and leaving a system defined in space and time. The temporal introduces the notion of the hydrological year.

In principle, this period of a year is chosen according to climatic conditions. Thus, depending on the meteorological situation of the regions, the hydrological year may begin on dates different from that of the ordinary calendar. In terms of space, it is customary to work at the scale of a watershed but it is possible to reason at another level (administrative area, regional entity, etc.).

The water balance equation is based on the continuity equation and can be expressed as follows, for a given period and basin:

$$\mathbf{P + S = R + FTE + (S + \Delta S)}$$

With:

P: precipitation [mm],

S: resources (accumulation) from previous period (groundwater, soil moisture, snow, ice) [mm],

R: surface runoff and underground runoff [mm],

E: evapotranspiration [mm],

S + DS: resources accumulated at the end of the period [mm].

The calculation of the water balance estimates the flow and evapotranspiration over a period of time or monthly depending on the soil and weather.

Soil has a significant impact on the balance sheet because it has a storage capacity that can be exhausted which leads to wilting of plants and thus a decrease in evapotranspiration.

Soil porosity (20 to 30% in general) can be considered storage capacity. When the soil is filled with water, porosity is almost completely occupied by water, the soil is said to be saturated.

3.6.1. Water Deficit

Water deficit is the comparison between the monthly needs of plants with the amount of water available from the soil during the growing period

3.6.2. Rainfall deficit (climatic)

Rainfall or climate deficit is the difference between the ETP and the corresponding rainfall module:

$$\mathbf{dp = ETP - P}$$

P is rainfall, expressed in millimeters.

ETP is the potential evapotranspiration in millimeters,

It is important to note that the excess precipitation is lost by infiltration and runoff and does not come from compensating the deficits of the other months, and it results that the annual rainfall deficit evaluated month by month.

3.6.3. agricultural deficit

It is not necessary to provide the soil each month with the entire rainfall deficit if the soil can provide the plant with a certain amount of water taken from its usable reserve

$$\mathbf{da = ETP - P - Kc.\ RFU}$$

$$\mathbf{da = dp - Kc\ .\ RFU}$$

- 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]

3.7. Principle of watering

The purpose of watering is to compensate for water losses in a green space, so that plants do not have to suffer from drought. The reasoning is done in stages:

- **1st step:** how much water is needed?
- **2nd step:** how much water can store the soil?
- **3rd step:** was there rain?
- **4th step:** given the storage capacity of the soil and the contributions by the rains, what is the stock available, and how many days leave between two waterings?
- **5th step:** set the watering time, according to the flow rate of the installation

3.8. Performance and refinement of irrigation regime calculation

The calculation for the improvement of the irrigation system is based on:

- ETM Crop Needs Assessment

It is the amount of water to be given during the entire growing season or the water needs of crops or time of deficit.

- The characteristic flow rate

This is the maximum flow among the monthly flows of the growing period

- Watering regimes

The irrigation dose is ensured by the watering doses during the vegetation period within a period determined according to the water needs of the plants, the watering regime is based on:

- **Watering dose:** This is the amount of water that must be discharged during watering on 1 ha for soil saturation, expressed in m3/ha or mm. It represents the reserve easily usable by the plant (RFU). It is given by the following formula:

$$RFU = \alpha \, RU$$

With:

$$\mathbf{RU = (H_{cr} - H_{pf})\, D_a \times Z}$$

α: equal fraction 1/2 for sandy soil or 2/3 for clay soil

RU: useful reserve in (mm).

Hcc: field capacity in (%)

Hence: **Hcc = CR** (holding capacity**)** = **Heq (**equivalent humidity**)**

Hpf: Moisture at wilt point in (%).

Da: bulk density in (%).

Z: Root depth in (mm)

- **The practical watering dose Dpr:** is the amount of water that must be given to the ground to avoid reaching the danger point

$$D_{pr} = \frac{RFU}{Efficience}$$

- **The actual irrigation dose dr:** The actual irrigation dose is the amount of water in the soil between the wilting point and the holding capacity.

- **Number of watering:**

$$\mathbf{N = A / dr}$$

- **Watering spacing T**

$$T = N/ \text{Day nbr of the self}$$

- **Watering module m:** Or practical flow is the flow of water that the irrigation has to pour it on the soil of the plot to irrigate.

$$m = (dr.s)/ t$$

- **Irrigation plot unit S:** The plot size is based on:
  - the method of watering.
  - the permeability of the soil corresponding to the filtration rate

$$S= \quad m/k \quad = \quad (\text{watering module } m^3/s)/ \text{ filtration rate } (m/s)$$

- **Number of parcel units n**

$$n = Sm/S \quad Sm = m / Qc$$

- **The theoretical duration of watering t:** The theoretical duration of watering is the infiltration time of the height dr

$$t= dr / k$$

3.9. Irrigation Schedule

A schedule can be established for any irrigation system; however, the frequency of watering and the amount of water used vary from system to system.

Scheduling is the process by which:

- Timing of irrigation; and
- The water requirements of the crop;
- The frequency of watering;

Chapter IV

Irrigation techniques

Chapter IV: Irrigation techniques

4.1. Introduction

The choice of one or the other of these processes cannot be made randomly, but on the basis of a well detailed analysis of these different modes and their degree of compatibility with the constraints of the region considered from the agronomic point of view, natural, technical and socio-economic.

Depending on how water is brought into the field and then distributed, irrigation systems are grouped into two categories: gravity and pressure systems:

- **Gravity systems**
  - By "plank"
  - In the line or "by furrows"
  - By basins
  - By tablecloth control
- Pressure systems
  - Sprinkler irrigation
  - Localized irrigation

4.2. Gravity irrigation

Surface irrigation or gravity irrigation consists of returning water directly to the plot cultivated by runoff on the ground in furrows (line irrigation method), by groundwater (we speak of irrigation by board or calant) or by controlled submersion (irrigation by basin). It is the oldest irrigation method (and therefore quite rudimentary) but it is inexpensive in investment and it is the most used method worldwide (it represents for example 80% of the area of large irrigated areas of Morocco). It is therefore essential to take an interest in this project.

Traditionally for these methods, water is brought to the level of the plot and then distributed in channels of land that feeds the lines, boards or basins. Infiltration losses and the difficulty of controlling the flows delivered lead to water waste and heterogeneous watering.

It takes place in four main forms:

4.2.1. Plank irrigation

The principle of this technique is to create a thin tablecloth on long, narrow boards on a low slope.

The plots are flooded from above from a supply channel that runs along the ridge. The water flows downwards and the excess is harvested by a colature ditch (which is often used as feeding for a row of plots located at a lower level. In Europe, and in the USA, the plots are often rectangular and elongated, hence the name "plank".

Figure 4.1: Plank Irrigation

4.2.2. Line or "furrow" irrigation

Row irrigation is reserved for row crops such as cotton and vegetables. Parallel grooves allow irrigating fields with a surface too irregular to be submerged.

Instead of flooding the entire field to saturate the soil and ensure the progression of the water front to the bottom of the plot, it is now preferred to lower the water in small furrows regularly spaced from 0.60 m to a few meters, the "rays", from which water seeps laterally.

At the bottom of the plot a colature ditch collects excess water. The stingrays are fed either from small siphons drawing from the supply channel, or by a flexible duct pipe carrying baskets or cuffs.

Figure 4.2: Line irrigation

4.2.3. Basin Irrigation

The basins are made up of earthen basins, with a flat bottom, surrounded by dikes of low height or raised. These surveys are designed to prevent the passage of water to adjacent fields. This technique is generally used for irrigation of flat rice fields or hillside terraces. In general, this irrigation technique applies to all crops that can tolerate water flooding for a long time.

Figure 4.3: Basin Irrigation

4.2.4. Groundwater Control Irrigation

It is a special variant, used in areas already drained by ditches. The control of the water level in the ditch makes it possible to raise the level of the water table and to supply water to the upper layers whose reserves are exhausted.

Gravity systems are most often fed directly by channels that gradually branch into smaller channels of decreasing order. Water usually comes from a river, the catch being located sufficiently upstream that, the channel having a less steep slope, it ends up being in a dominant position compared to the irrigated area.

The most frequent distribution system is the "water tower". Every farmer is warned that he has the right to draw from the canal, on a given day, at a given hour, for a fixed period. Days and hours change gradually during the season so that everyone has a balanced number of night hours.

Water is paid by subscription according to the number of hours of use.

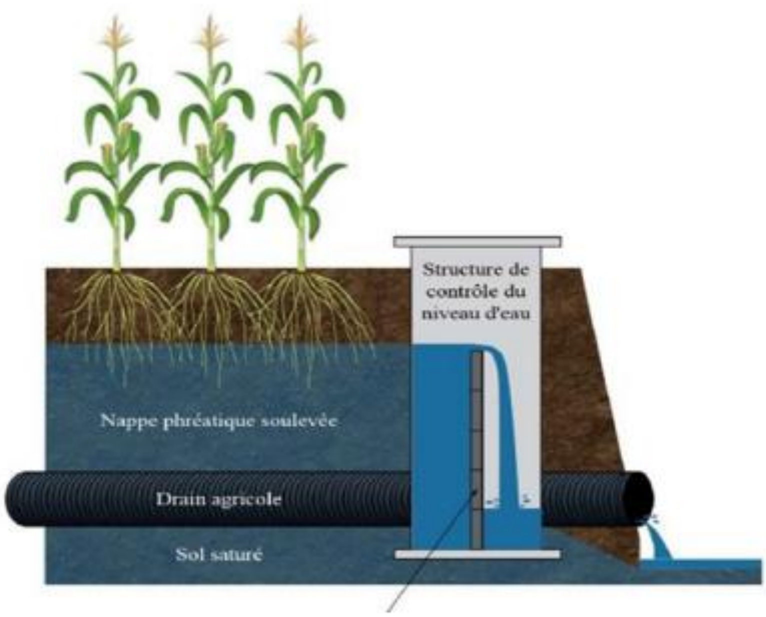

Figure 4.4: Irrigation by groundwater control.

4.3. Pressure Irrigation

4.3.1. Sprinkler irrigation

- **Microsprinkling**

Irrigation with micropulverizers waters only a fraction of the soil surface. The water is ejected in fine jets by a series of sprinklers from which it rains. Each sprinkler can water several square meters. The micro-sprinkling system therefore makes it possible to increase the volume of wet soil in which plant roots absorb water and nutrients, which is particularly interesting for large trees.

Microsprinkling has another big advantage. Because the nozzle holes are wider and the flow rate is higher, the risk of obstruction is reduced. The required pressure is of the order of 1 to 2 bar. This requires the installation of a pumping system or raising the supply tank by at least 10 m.

In other respects, micro-irrigation allows the frequent application of a small volume of water and the injection of fertilizers into the water. In addition, it is easy to adapt micro-irrigation systems to the conditions of developing countries, reducing their size, to make it more consistent with the plots to be irrigated, usually small.

On the other hand, microsprinkling also has disadvantages. The evaporation component of the water balance is increased, both because the wet surface is larger, water is sprayed into the dry air and the lower leaves are wet. As the foliage is wet, the use of brackish water and the incidence of fungal diseases are more problematic.

- **Sprinkling**

Spray irrigation developed rapidly after the Second World War, particularly in Europe and the United States. With technical improvements in yield and lower cost, it gradually developed in arid and semi-arid regions. The water is transported in pressure piping networks and then delivered to the plot by terminals that regulate pressure and flow. The water is then directed into other pipes that supply pressurized sprinklers that spread rain water.

There are two types of sprinkler irrigation. Traditional and mechanized.

Traditional sprinkling

In agriculture, sprinklers are slow rotation. This is obtained by the back and forth of a lever arm that carries a single blade and oscillates thanks to the impact of a jet that escapes from a nozzle. The small sprinklers are arranged along a mobile ramp that is moved from post to post, to irrigate the entire plot.

Figure 4.5: Traditional sprinkler irrigation

Large sprinklers have high hourly rainfall and this leads to large droplets. This can be problematic. Indeed, the size of the droplets should not cause any damage to the soil or the crop. And the bigger the sprinkler, the bigger the droplets.

Drops can cause problems with soil compaction (formation of surface crust) on loamy or fine soils. It is therefore necessary to size our sprinkler according to the soil (silt, sand, etc.) and the type of plant.

Mechanized spraying

Mechanized spraying is very often used in large operations. Systems of swivel and front ramps are used. The swivel boom system consists of a pipe with sprinklers, supported at one end by a central pivot tower from where the water arrives, a series of towers with wheels and an electric or hydraulic motor.

The pipe can measure between 100 and 500 m and can irrigate up to 100 ha. 1l should be noted that the rainfall necessary to provide a homogeneous dose to each rotation, grows as one moves away from the center. At the end of the ramp, maximum rainfall can reach 80 to 100 mm/h, which is incompatible with the permeability of most soils. I1 is advised not to exceed a radius of about 400 m except on sandy soil very permeable. But mechanized sprinkling requires high investment capital but low labor. If the operating pressure is around 6 bar, the flow rates will vary between 250 and 850 m3/h. For the front ramps, all the towers are mobile and the movement is lateral. To supply the system with water, the supply is made either by a ditch dug in the middle or at the edge of the field, or by a flexible pipe.

On the other hand, the investment must be very important and the energy consumption very high.

Figure 4.6: Pivot irrigation

Another type of mechanized sprinkler irrigation is reel irrigation. This type of irrigation is the most widespread in the world. The reels are drum and hose hose irrigation machines. The reel consists of a drum, on which a flexible polyethylene pipe is wound. The winding of the hose causes the movement of a wheeled sprinkler gun at the end of the hose. The reel thus performs a band watering, without intervention. At the end of the journey the winding stops automatically and the whole is moved by means of a tractor to water the next strip. The length of the hose obviously varies according to the length of the field and can reach 600 m. Its diameter can go from 50 to 140 mm. Finally the flow can reach 50 m3/ h and the range is about 100m.

Figure 4.7 : Reel irrigation

4.3.2. Surface micro irrigation

The methods described in this section are based on continuous or regular watering of a fraction of the soil surface. To do this, water is usually distributed in closed pipes (such as plastic tubes) at specific points, the location and spacing of which depend on the configuration of the crop. At these points, water is allowed to come out to the surface, ensuring that the flow is not greater than the ability to seep from the ground, so that all water enters the rhizosphere without stagnating or flowing to the surface.

Irrigation systems in which water is distributed through closed pipes (pipes) generally save water because they increase the uniformity of applications and avoid losses in quantity (due to percolation and evaporation) and quality (due to contamination of water in open pipes). But since they require a pressurization device and expensive installations, this saving often generates an increase in energy consumption and capital investments. This is why methods minimizing these capital and energy expenditures are necessary.

- **Complete drip system**

Drip irrigation is the slow and localized application of water, literally drip irrigation, at a point or grid of points on the soil surface. If the water is flowing at a rate that is less than the absorption or infiltration capacity of the soil, the soil is not saturated and there is no stagnant water or runoff at the surface.

Water is brought to the dripping holes by an assembly of plastic pipes, usually made of opaque polyethylene or weather-resistant PVC. Lateral pipes, fed by a master pipe, are laid on the ground. These pipes, usually with a diameter of 10 to 25 mm, are perforated or equipped with special drippers. Each dripper must drip water onto the ground at a predetermined flow rate of 1 to 10 litres per hour.

Water pressure in pipes is usually between 0.5 and 2.5 atmospheres. This pressure is reduced by friction when water flows through the narrow passages or orifices of the dripper, so that the water comes out at an atmospheric pressure in the form of drops and not in spray or spray.

The drippers marketed are either internal (fixed inside the side supply pipes) or external (plugged into the pipes through perforated holes in the wall of the supply pipe). They are designed to drain water at a constant flow of 2, 4 or 8 liters per hour. The output flow is always affected by pressure variations, but to a lesser extent if the transmitters are equipped with a pressure regulator. The frequency and duration of each irrigation is controlled by a manually operated valve or by a series of programmable automatic valves. Metering valves automatically interrupt flow once a predetermined volume has been applied.

Figure 4.8 : Drip irrigation

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