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Agricultural irrigation equipment — Guideline on the implementation of pressurized irrigation systems —

Part 1: General principles of irrigation

Matériel agricole d'irrigation — Lignes directrices relatives à la mise en œuvre des systèmes d'irrigation sous pression —

Partie 1: Principes généraux d'irrigation

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Foreword

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This document was prepared by Technical Committee ISO/TC 23, *Tractors and machinery for agriculture and forestry*, Subcommittee SC 18, *Irrigation and drainage equipment and systems*.

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Agricultural irrigation equipment — Guideline on the implementation of pressurized irrigation systems —

Part 1: General principles of irrigation

1 Scope

This document provides a guideline for the implementation of pressurized irrigation systems.

It is applicable to small-scale family agriculture and large-scale commercial agriculture, in open fields or within enclosed growing structures (e.g. greenhouse, net house).

This document is intended for the use of agriculture ministries, agronomists, irrigation planners, farmers and end-users.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
wetting front
boundary between the wetted region and the drier region of soil during infiltration

[SOURCE: Glossary of Soil Science terms, modified — 'dry' substituted with 'drier'.]

4 Water management

4.1 Soil-water relationship

4.1.1 General

The soil is a three-phase system (mineral and organic solid particles, water and air). It is a reservoir of water used by plants. To design an irrigation system, the soil-water-plant relations, as described in Clause 4, should be considered. Examples of values of soil physical parameters are presented in Annex A.

4.1.2 Solid particles and porosity

The soil volume is made up of solid particles of different sizes (sand, silt and clay) and pores. The relative content of the three groups of particles defines the soil texture.

The volume not filled by the solid particles defines the soil pores. The total volume and size of pores depend on the soil texture. The higher the soil clay content, the higher the total porosity of the soil and lower pore size. The total porosity is between 35 % to 40 % in sandy soils, 50 % in medium soils and can reach 60 % for clay soils.

Under conditions of soil water saturation, all the pores of the soil are full of water and, as a consequence, do not contain air.

4.1.3 Soil water

The percentage of water relative to the mass of solids is the relation between the mass of the water and the mass of the particles [as shown in Formula (1)] and is commonly determined by the gravimetric method.

$$w = \frac{m_w}{m_s} \times 100 \qquad (1)$$

where

w is the gravimetric water content (%);

m_w is the mass of the water (g);

m_s is the mass of dry soil or mass of solids (g).

The gravimetric method is the most accurate method (i.e., the standard method) for determining the soil water, and it consists of drying samples of soil in an oven at 105 °C for 24 h (or until the sample reaches steady mass). The gravimetric water content (w) can be obtained using Formula (2):

$$w = \frac{m_{w+c} - m_{d+c}}{m_{d+c} - m_c} \times 100 \qquad (2)$$

where

m_c is the tare of the container;

m_{w+c} is the mass of wet soil + container;

m_{d+c} is the mass of dry soil + container.

The percentage of water relative to soil volume (i.e. the volumetric water content) is the relation between the volume of water and the total volume of soil. See Formula (3).

$$\theta = \frac{V_w}{V_t} \times 100 \qquad (3)$$

where

θ is the volumetric water content (%);

V_w is the volume of the water (cm^3);

V_t is the total volume of the soil (cm^3).

The gravimetric method can be used to determine the soil bulk density, the gravimetric water content and the volumetric water content. For that purpose, undeformed soil samples should be collected using the Uhland soil sampler or other similar device for extracting undeformed samples. The soil bulk density is obtained by Formula (4), in which the total volume of soil is equal to the volume of the container. Assuming the water density as a constant equal to 1 g cm^{-3}, the volumetric water content is obtained by Formula (5).

$$\rho_b = \frac{m_s}{V_t} \tag{4}$$

$$\theta = w \times \rho_b \tag{5}$$

where

θ	is the volumetric water content (%);
w	is the gravimetric water content (%);
ρ_b	is the soil bulk density (g · cm^{-3}).

4.1.4 Determination of amount of water in a soil layer

The amount of water in a soil layer can be expressed as water depth (mm). See Formula (6).

$$h = \frac{\theta}{100} \times n \tag{6}$$

where

h	is the water depth in a particular layer of soil (mm);
θ	is the volumetric water content (%);
n	is the thickness of the particular layer (mm).

NOTE

1 mm = 1 l m^{-2} = 10 m^3 ha^{-1}

1 ha = 10 000 m^2

4.1.5 Water retention in soils

Knowing the amount of water in the soil without knowing other soil characteristics is insufficient to determine the amount of water available for crops, in order to programme the irrigation regime.

The water held in the soil pores is a result of the surface tension of the water in contact with the air and the contact angle between the water and the soil particles. As a result, there is a retention force in the soil pores (capillarity) that increases with a decrease in the diameter of the soil pores.

Each soil has its own characteristic water retention curve (the water tension relative to the change in the moisture) according to its texture and structure that defines its pore size distribution.

According to the water retention curve, three water conditions in the soil can be defined.

— Saturation: after an excessive rainfall or irrigation, all the soil pores become full of water, and drainage downward immediately starts, faster in sandy soils and slower in soils with increasing clay content.

— Field capacity (θ_{FC}): the water content in the soil 1 to 3 days after saturation condition and drainage has largely ceased.

— Wilting point (θ_{WP}): as water is extracted from the soil through evapotranspiration (from plants and soils), the water tension is increased (up to 1,5 MPa) at a value whereby most plants can no longer extract water and wilt permanently.

The total available water of the soil can be calculated as the difference between the water content at field capacity and permanent wilting point, expressed in percentage. See Formula (7).

$$W_{TA} = \left(\frac{\theta_{FC} - \theta_{WP}}{100} \right) n \quad (7)$$

where

W_{TA}	is the total available water in a particular soil layer (mm);
θ_{FC}	is the volumetric water content at the field capacity (%);
θ_{WP}	is the volumetric water content at the wilting point (%);
n	is the thickness of the particular layer (mm).

4.1.6 Soil water potential and movement of water in the soil

The water in the soil is subject to a number of forces, which cause the potential of the soil water to differ from the potential of pure and free water. These forces result from the attraction of water to the solid matrix of the soil (clay particles and organic matter), as well as the presence of dissolved salts, and the influence of the force of gravity. The total water potential in the soil can be presented as the sum of the individual contribution of each of these forces, as expressed using Formula (8).

$$\Psi_t = \Psi_g + \Psi_m + \Psi_o + \ldots \quad (8)$$

where

Ψ_t	is the total water potential in the soil;
Ψ_g	is the gravitational potential;
Ψ_m	is the matrix potential;
Ψ_o	is the osmotic potential;
...	are expressions for other terms of the potential of water in the soil that exist theoretically.

The direction of water movement between two points in the soil is determined by the existence of a difference in the total water potential (Ψ_t). The movement occurs from the point of highest potential to the point of lower potential. In the movement of water between two points within the soil, the osmotic potential (Ψ_o) is negligible (in the absence of a semi-permeable membrane between the two points), so that the total potential is restricted to the sum of the gravitational potential (Ψ_g) and the matrix potential (Ψ_m) ($\Psi_t = \Psi_g + \Psi_m$).

The gravitational potential of water at a given point in the soil is determined by the relative elevation of the point in the soil (relative to the surface, for example).

The matrix potential is also called capillary potential. It results from capillarity (which depends on the size of the pores in the soil) and water adsorption forces (by attraction to solid soil particles, especially clay and organic matter).

4.1.7 Water distribution in the soil

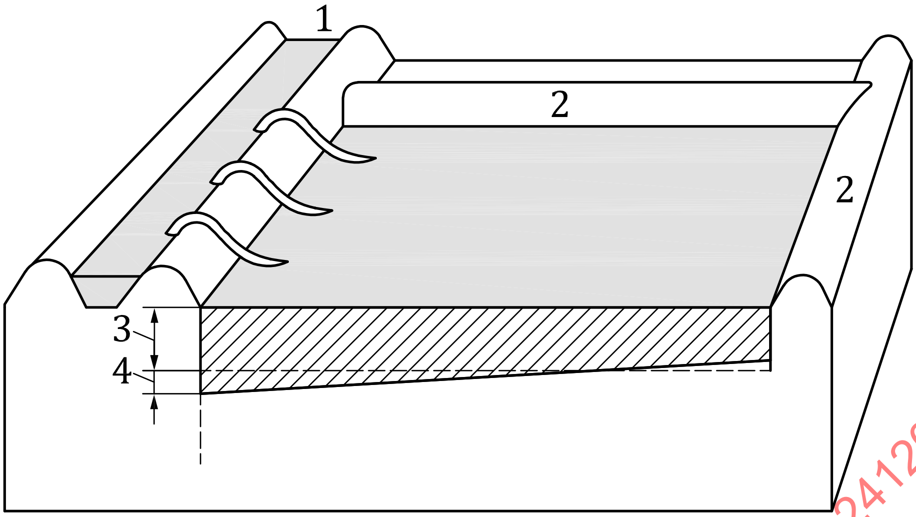
4.1.7.1 Methods with total surface wetting

Irrigation methods with total surface wetting (surface basin irrigation and some sprinkler irrigation) are designed to perform a uniform distribution of water over the entire surface of the soil, similar to natural rainfall. The driving force in the movement of water in the soil during irrigation is the force of gravity (the difference in the gravitational potential of soil water between the surface and the deeper layers of the soil) and the difference in the matrix potential of the soil between both sides of the wetting front.

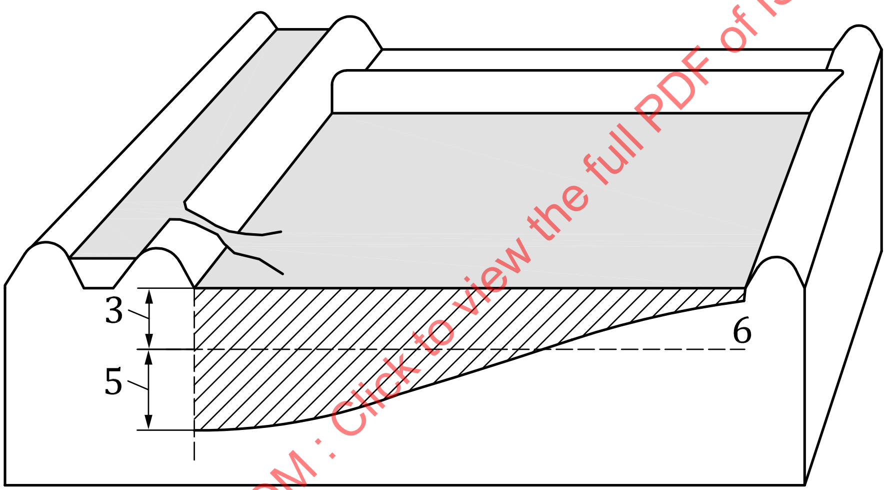
In general, the wetting front is a plane that advances in parallel to the soil surface. The horizontal movement of water occurs when there is a difference in soil moisture, that is, a difference in the matrix potential between two points at the same depth in the soil. In methods with total surface wetting, this difference exists only within the boundaries of the irrigated plot in which the contact plane between the wet zone and the dry zone (the wetting front in the plot boundaries) represents a very small area in relation to the surface of the area and the wetting front in the vertical direction. This is why the lateral movement is very small in relation to vertical movement, and the volume wetted by the movement of water in the horizontal direction is minimal in relation to the total volume of soil irrigated. The water pattern in basin is shown in Figure 1 and in sprinkler irrigation in Figure 2.

In basin irrigation, at the ideal wetting pattern, there are small percolation losses close to the field channel, and in consequence a low depth of percolation at the opposite end. When the inflow rate is not enough, percolation is high near the canal, and the depth of percolation towards the end is lower than in optimal conditions (see Figure 1).

In sprinkler irrigation, the uniform water distribution on the soil surface is obtained by establishing a sufficient overlap of distribution patterns from adjacent sprinklers. The degree of overlap depends on the characteristic distribution pattern of the individual sprinkler, which in turn is a function of the sprinkler type, height of sprinklers above crop, nozzles, pressure head and wind conditions. The degree of overlap and uniformity is also dependent on the speed of movement and whether a 30 s, 60 s, 120 s (or other) setting is used for the percent timer.



a) Ideal wetting pattern

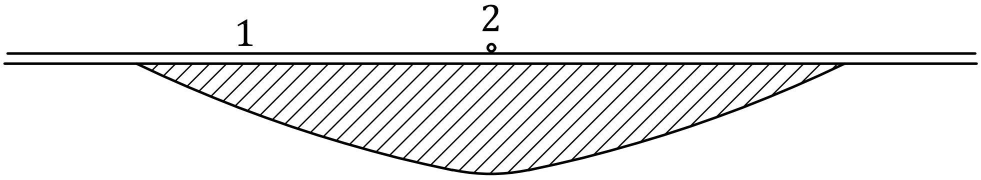


b) Wetting pattern with insufficient flow rate

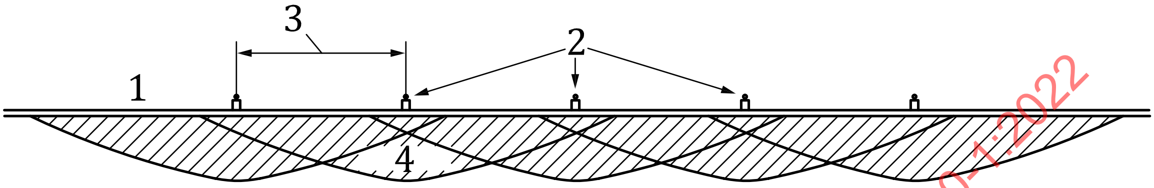
Key

1 field channel
2 bund
3 root zone
4 low percolation losses
5 high percolation losses
6 too dry

Figure 1 — Basin irrigation water distribution[1]



a) Wetting pattern for a single sprinkler



b) Wetting pattern of several sprinklers with superposition between wetting zones

Key

1 lateral

2 sprinkler

3 spacing

4 wetted zone

Figure 2 — Sprinkler irrigation[1]

4.1.7.2 Methods with partial surface wetting

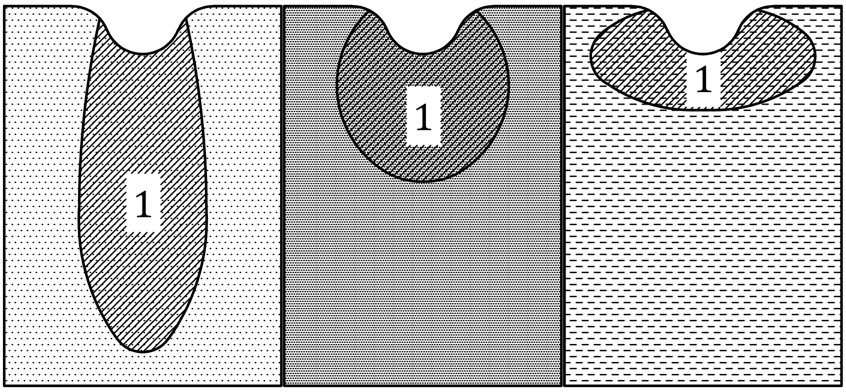
4.1.7.2.1 General

In irrigation methods with partial soil wetting (furrows, drip irrigation, micro-sprinklers and some cases of irrigation on moving equipment such as LEPA – low energy precision application), the wetting zone is characterized by having a special shape due to the forces that act on the water during its infiltration and its movement in the soil. Water is moved by the difference in the total potential of water in the soil [see Formula (8)]. In the vertical movement, the differences in the gravitational potential act as well as in the matrix potential. In the horizontal movement there are only differences in the matrix potential.

The general tendency is that the vertical movement (gradient in the matrix potential and the gravitational potential) is greater than the horizontal movement (result of the gradient in the matrix potential only). The difference between the two directions of movement will be greater as the content of clay in the soil becomes lower. This is because the difference in the potential matrix between the wet zone of the soil and the dry zone is greater in higher clay content, while there is no difference in the gravitational component between the soils, whatever their texture.

4.1.7.2.2 Furrow irrigation

The water flows in the furrow and infiltrates down and to the sides of an individual furrow (see Figure 3).



Key

A sandy soil

B loam soil

C clayey soil

1 wetted zone

Figure 3 — Movement of water in irrigation by furrows in soils of different texture[1]

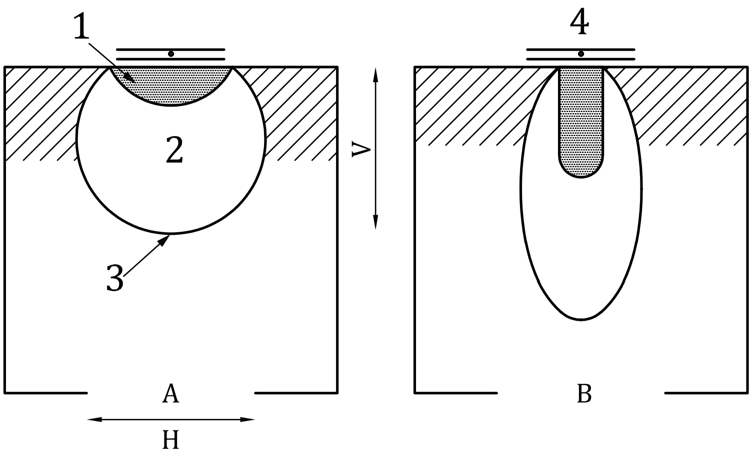
4.1.7.2.3 Drip irrigation

Below and around the dripper, where the water drops drop by drop, a wetted soil zone is formed, within it three zones can be distinguished (see Figure 4):

— Saturated zone: immediately below and around the dripper a saturated zone is formed, from which the water moves towards the interior of the soil. In this area there is excess water and lack of air. Especially in soils of medium or clayey texture there is a small accumulation of water on the surface, from which the water infiltrates into the saturated zone.

— Equilibrium zone: it is an intermediate zone, in which the moisture content is close to field capacity, so there is an optimal ratio between the water and air content.

— Wetting front: it is the boundary between the intermediate zone and the dry zone or with moisture content similar to that existing at the time of beginning of irrigation. In this area there is a deficit of humidity and the aeration of the soil is maximal.



Key

A clayey soil

B sandy soil

H horizontal dimension

V vertical dimension

1 saturated zone

2 equilibrium zone

3 dry zone (wetting front)

4 dripper

Figure 4 — Wetting bulb in the drip irrigation in two soils of different texture

The shape and dimensions of the wetting zone (bulb) depend on five factors:

— Soil: when a certain amount of water is applied, the bulb that forms on a clayey soil (with a low hydraulic conductivity in saturated soil) will be shallower and wider compared to a sandy soil (with a high saturated hydraulic conductivity). In the latter, the vertical dimension will be more developed, while the horizontal dimension will be narrow.

— Dripper discharge: for a given soil, an increase in the dripper discharge means an increase in the radius of the saturated zone, i.e. a wider and more superficial bulb. For the same dripper discharge, the higher the soil clay content, the greater the radius of the saturated zone.

— Duration of irrigation: the horizontal dimension increases from the irrigation beginning and as long as it continues, up to a certain limit that also depends on the texture of the soil and the discharge of the dripper. Above this limit the movement of water will be mainly in the vertical direction, thus decreasing the irrigation efficiency due to the loss of water by drainage below the root zone.

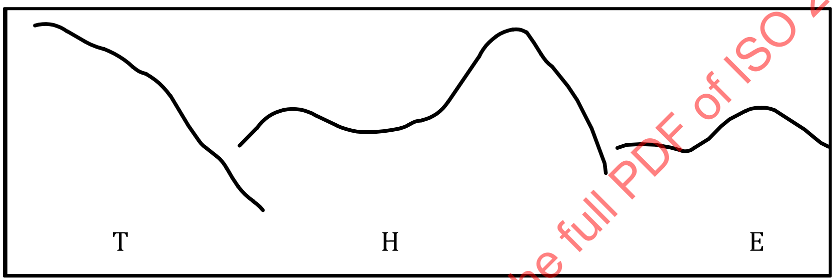
— Irrigation frequency: as the water content in the soil decreases, the water tension in the soil increases. The hydraulic conductivity of soil has a wide influence on the behaviour of the water in the soil wetting from a dripper. The hydraulic conductivity decreases exponentially with an increase in the water tension in the soil (decrease in water content), and the movement of the water is slower. Under these conditions, the relative importance of the matrix potential is greater than the gravitational potential, resulting in a more accentuated horizontal movement.

— Calculation of the bulb dimensions and drippers spacing: the dripper spacing is the spacing (distance) between drippers along a lateral line. The optimum distance between drippers is that which represents 80 % of the diameter wetted by an individual dripper, which was calculated or estimated in the field. With this spacing, an overlapping will be obtained between the wetted areas of neighbouring drippers. At the same time, a wet strip will be received along the drippers lateral.

Examples of some means of estimating the wetted area dimensions are presented in Annex B. Manufacturers of drip irrigation systems present in their catalogues the recommended spacing data, according to their experience, for different soils and crops.

4.1.7.2.4 Micro-sprinkler irrigation

Similar to drip irrigation, the wetting of the soil in this method of irrigation is partial. There are different types of micro-sprinklers with different water distribution patterns over the soil surface (see Figure 5). Thus, the distribution of water in the soil in micro sprinkler irrigation depends on the water distribution pattern on the surface and the radius achieved by the water distributed by the micro-sprinkler. The pattern of water movement in the soil differs from that of a point source (dripper), and is similar to the pattern in sprinkler irrigation. In cases in which an individual emitter is placed, i.e. an emitter per tree in a plantation, there will be movement of water to the sides due to the difference in the potential of the water between the wetted and dry areas (see Figure 6). In many cases, the emitters are located in such a way that there is an overlap between wetted zones of adjacent emitters, and there will be a continuous wetted strip along the row of trees. In this case, the lateral movement of the water will be towards the area between the rows of trees.



Key

T triangle

H hump

E even graph

Figure 5 — Schematic description of water distribution from individual micro-sprinklers

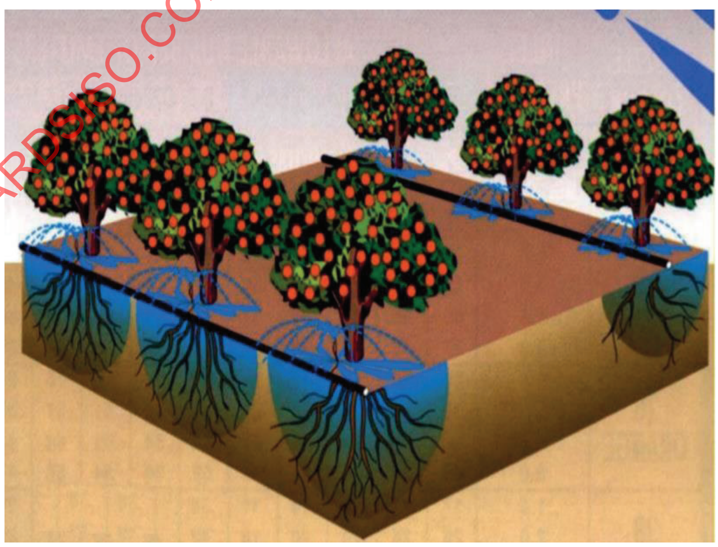


Figure 6 — Wetting pattern in individual micro-sprinklers

4.1.7.2.5 Moving equipment — Centre pivots and linears — Subset of sprinkler irrigation

Below and around the distribution device, where the water is delivered, a wetted soil zone is formed. Within it three zones can be distinguished:

— Saturated zone: immediately below and in the direction of movement in the path of the application device a saturated zone is formed from which the water moves into the soil. The saturated zone in the wetted soil under micro-sprinkler is bigger than in dripper irrigated soils. In this area there is excess water and lack of air. Especially in soils of medium or clayey texture, there is a small accumulation of water on the surface, from which the water infiltrates into the saturated zone.

— Equilibrium zone: it is an intermediate zone, in which the moisture content is close to field capacity, so there is an optimal ratio between the water and air content.

— Wetting front: it is the boundary between the intermediate zone and the dry zone or with moisture content similar to that existing at the time of beginning irrigation. In this area there is a deficit of humidity and the aeration of the soil is maximal.

The shape and dimensions of the wetting zone depend on five factors:

— Soil: when a certain amount of water is applied, the bulb that forms on a clayey soil (with a low hydraulic conductivity in saturated soil) will be shallower and wider compared to a sandy soil (with a high saturated hydraulic conductivity). In the latter, the vertical dimension will be more developed, while the horizontal dimension will be narrow.

— Moving application device: for a given soil, an increase in the application means an increase in the width of the saturated zone. For the application device discharge, the higher the soil clay content, the greater the width of the saturated zone, which may lead to water moving ahead of the application device. This will depend on the speed of movement of the moving application device.

— The duration of the irrigation: the horizontal dimension increases from the irrigation beginning and as long as it continues, up to a certain limit that also depends on the texture of the soil and the movement of the water application device. Above this limit, the movement of water will be mainly in the vertical direction, thus decreasing the irrigation efficiency due to the loss of water by drainage below the root zone.

— The irrigation frequency: as the water content in the soil decreases, the water tension in the soil increases. The hydraulic conductivity of soil has a wide influence on the behaviour of the water in the soil wetting from the application device. Due to this, it is important to note that the hydraulic conductivity decreases exponentially with an increase in the water tension in the soil (decrease in water content), the movement of the water is slower. Under these conditions the relative importance of the matrix potential is greater than the gravitational potential, resulting in a more accentuated horizontal movement.

— Calculation of the bulb dimensions: the spacing is the spacing (distance) between water application devices along the pipeline and speed of movement of the pipeline. Distance between the wetted areas of water application devices along the pipeline is dependent on the soil and crop. The movement is how overlap will be obtained in the direction of movement.

4.1.8 Distribution of salts in the irrigated volume

4.1.8.1 General

All sources of irrigation contain dissolved salts. The concentration and composition depend on the source. Dissolved salts accumulate in the root zone when water evaporates from the soil surface and by transpiration from the crops. Soil salinity is uneven in width and depth, while roots develop and absorb water and nutrients mainly from those soil volumes where salinity is relatively low and moisture is relatively high. The main root zone volume is determined by a number of major factors:

— water salt content;

— irrigation management;

— fertilization management;

— irrigation method;

— water evapotranspiration;

— type of soil;

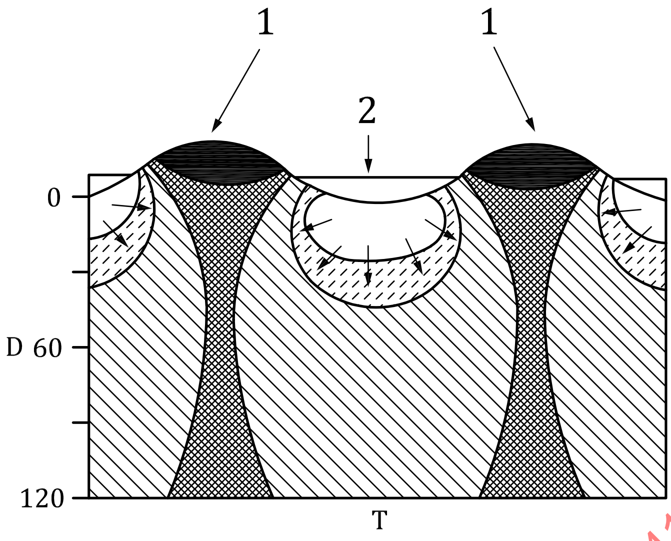
— rainwater.

Soil is salinized when the soil concentration in the root zone reaches a level higher than the plant sensitivity for optimum plant growth and yield. Plants differ in this sensitivity between very sensitive to very resistant.

Dissolved salts move along the soil with water, the distribution of salts is determined by the water flow patterns in the soil. Salts have a maximum concentration in the wetting front of infiltrating water. Accordingly, the distribution of salts in the soil is correlated with the distribution of water previously presented.

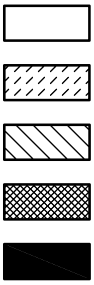
4.1.8.2 Salt distribution under furrow irrigation

Furrow irrigation is considered a good method to prevent salt accumulation due to large, deep percolation that can leach salts away from the root zone. However, furrow irrigation can promote salt accumulation on the furrows' edge and ridge between two furrows (see Figure 7). Furthermore, salt can accumulate on the edges at the wetting front in the soil profile, right above the root zone.



Key

D depth in cm
T total salt present in soil profile
1 zone of salt accumulation
2 water in furrow

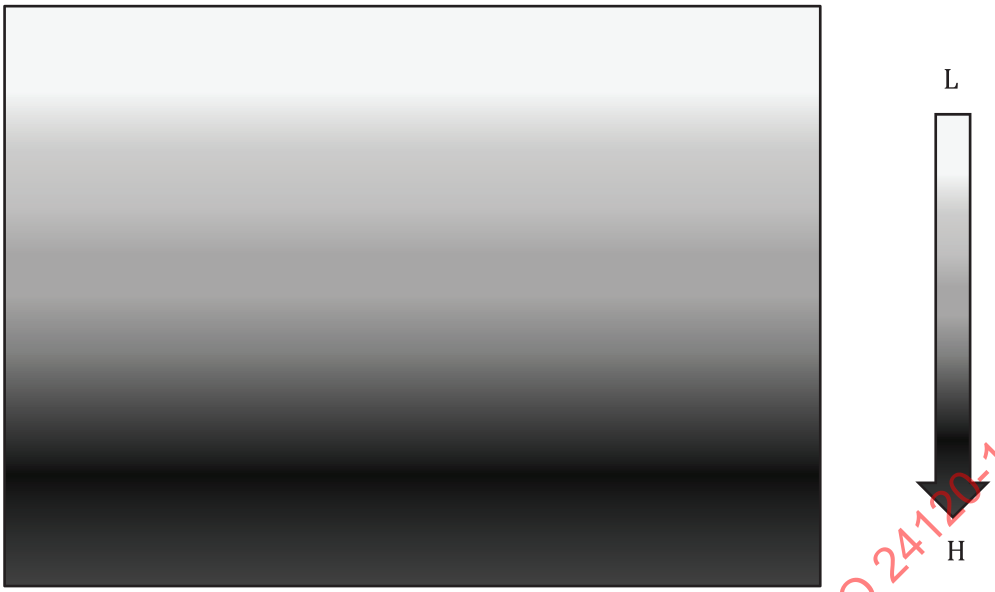


0,01-0,02
0,02-0,1
0,1-0,2
0,2-0,5
0,5-2,0

Figure 7 — Salt accumulation in soil profile in furrow irrigated field[4]

4.1.8.3 Salt distribution under sprinkler irrigation

In sprinkler irrigation, because water is applied to all of the soil surface and water flows downward, salt concentrations are relatively uniform at each depth across the soil. Sprinkler irrigation systems that wet the entire soil surface create a profile that steadily increases in salinity with soil depth to the bottom of the root zone (see Figure 8).



Key

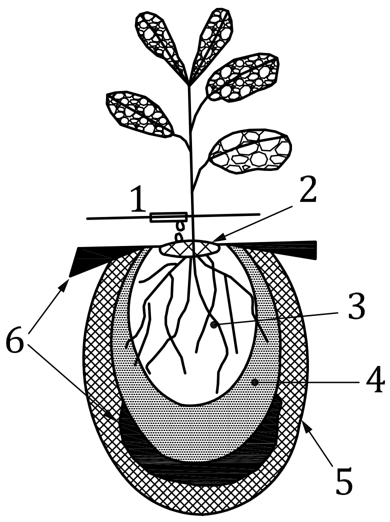
L low salinity

H high salinity

Figure 8 — Salt accumulation in soil profile in sprinkler irrigated field

4.1.8.4 Salt distribution under the drip irrigation

During drip irrigation, a large amount of salts are transported within the wetted volume. After several irrigation cycles, water evapotranspiration and salt transport, large differences in the salinity concentration of the soil solution are created within the wetted volume, margins, and soil (see Figure 9). Under the ponded area, the lowest soil salinity is in a leached volume. From this area and towards the perimeter of the wetted area, the concentration of salts increases gradually. The increase is smallest in the vertical direction and largest in the horizontal direction. Very high salinity can be observed in the bottom of the wetted zone and in the top (because water evaporation from the soil surface).



Key

1 dripper
2 ponded area
3 leached volume
4 salt accumulation
5 high salinity
6 extreme high salinity

Figure 9 — Salt distribution pattern under an individual dripper[6]

4.1.8.5 Salt distribution under micro-sprinkler irrigation

The distribution of dissolved salts in micro-sprinklers wetting patterns may differ from that of sprinkler irrigation. For a micro-spray system that sprays a relatively large wetted zone around each plant, salt may accumulate within each zone in a pattern not unlike that of an individual sprinkler. In contrast, for an irrigation system employing bubblers, salt tends to accumulate mainly in the outer fringes of the wetted zone (see Figure 10)[7].

Key

A micro-spray;
B bubbler

Figure 10 — Salt distribution pattern under an individual micro-sprinkler[7]

4.1.9 Salt concentration as a function of soil water content

Salt accumulation in the soil occurs also with relatively low salinity water sources. After irrigation, and a subsequent drainage of water excess, the soil reaches the field water content capacity. The water content is high and therefore the salts are at a relatively lower concentration. Between two irrigation operations, the soil water content decreases due to evaporation from the soil surface and water consumption by the plant. This decrease in water content means that salts in the soil are dissolved in less water and, therefore, the concentration of salts in the soil solution increases. Thus, with the gradual reduction in water content, there is a gradual increase in the concentration of salts. The salinity effect on crops is reduced by maintaining a high moisture level in the soil. The way to do this is by applying frequent irrigation that keeps the soil in moisture at a value close to the field capacity.

With furrow irrigation, maintaining high moisture levels can be done only if irrigation is applied every day. This requires a high water and energy investment, which is not practical. With drip irrigation, daily application is common practice. Therefore, drip irrigation systems can reduce the salinity effect, and can be used in saline soils or with saline irrigation water. The other irrigation methods may also have the effect of frequent irrigation on salinity while practically allowing this irrigation management. Micro-sprinklers fixedly located in the plots can apply daily irrigation and up to several irrigations per day such as drip irrigation. One of the disadvantages in sprinkler and micro-sprinkler irrigation of increasing the frequency of irrigation is to increase water losses through evaporation during irrigation or from the irrigation surface. In saline conditions, leaching accumulated salts can overcome the salinity effect. However, in non-saline conditions, high irrigation frequency is not necessarily required, and all irrigation systems may be used to grow crops successfully.

4.1.10 Nutrients distribution

Distribution of nutrients in the soil, applied through fertilization on the soil surface and incorporation in the soil profile, or via fertigation, depends on the interaction between the nutritional elements and the soil components.

Nitrogen as nitrate is mobile, and is distributed in the wetted zone similarly as described for the soluble salts, for the various irrigation methods, in 4.1.8. When nitrogen fertilizers containing ammonium nitrogen are applied, initially the ammonium cation is adsorbed on clay particles and the movement in the soil is limited. Ammonium passes gradually through the nitrification process, transforming into nitrate that moves in the soil as soluble salt.

Phosphorus mobility in soil is limited. In alkaline and neutral soils, phosphorous precipitates from the soil solution with calcium and magnesium as insoluble salts. In acid soils, it precipitates with iron and aluminium and remains in the upper soil layer.

Potassium cations are adsorbed on clay minerals and their movement in clay and medium texture soils is limited. Most applied potassium remains in the upper soil layer[8].

If potassium and phosphorous are applied on the soil surface, these nutrients are left in the upper centimetres of the soil and do not penetrate into the root zone, including after rain or sprinkler irrigation. Only after tillage are these nutrients incorporated into the root zone. It is different in drip irrigation and partially in micro-sprinkler irrigation, in which these nutrients are added by fertigation, and have greater mobility and deepen within the root zone[9].

Strongly adsorbed nutrients have reduced mobility in soils, compared with un-adsorbed ions. For a given concentration, the buffer capacity of a clayey soil exceeds that of a sandy soil, therefore, the mobility of adsorbed ions in fine-textured soils is less than in coarse textured soils[9]. For example, phosphorous concentration, after application via a point source, was restricted to distances of 12 cm and 7 cm from the emitter in sandy and clayey soils, respectively. Phosphate applied via trickle irrigation moved to a much greater distance than when it is applied on the soils surface by sprinkler irrigation. At point source application all the phosphorous is applied over a small surface area, so that soil adsorption sites are saturated and the P migration is greater.

Similarly, the soil adsorption affects the potassium movement in soil under the different water application methods.

4.1.11 Root distribution

Water application regime and water distribution pattern in the soil affect root system and distribution. Each plant family has a typical root pattern stemming from the growing conditions. Root systems can be shallow or deep, dense, branched or sparse, and are not related to the shape of the plant's canopy. Frequent and small water applications with drip irrigation lead to a shallow and compact root systems in comparison to sprinkler irrigation (see Figure 11). On the other hand, due to improved aeration and nutrition in drip irrigated soil volume, the density of the active fine roots is significantly higher than the density of root systems growing under sprinkler irrigation (see Figure 11)[8]. However, moving water application devices can overcome shortcomings of fixed sprinklers by improved timing of delivery and volume.

Source: Netafim

Figure 11 — Root system in drip irrigation (right) in comparison to root system in sprinkler irrigation (left)

4.2 Water sources

4.2.1 Sources

The water needed to supply an irrigation scheme is taken from a water source. The most common sources of water for irrigation include rivers, reservoirs and lakes, and groundwater. In the last decades, the use of treated wastewater (TWW) has increased. The same can be said about the use of seawater and desalinated saline water in some countries. The quality of irrigation water is connected to its source. Quality parameters can be classified as chemical and physical. The effects of these parameters can be on the soil and crops and the potential clogging of filters and irrigation emitters.

4.2.2 Effects on soil and crops main parameters in relation to chemical/biological quality of the irrigation water

— Salinity hazard – total soluble salt content

— Sodium hazard – relative proportion of sodium, calcium and magnesium ions (Sodium adsorption Ratio – SAR)

— pH

— Alkalinity – carbonate and bicarbonate

— Specific ions – chloride, sulfate, sodium and boron

— Inorganic micro pollutants - heavy metals (mainly in TWW)

— Organic micro pollutants – pharmaceuticals and personal care products (in TWW)

— Microbial pathogens (in TWW).

4.2.3 Effects on filters and irrigation emitters in relation to chemical and physical parameters

— Major inorganic salts with low solubility

— Hardness

— Suspended solids

— Total dissolved salts (TDS)

— Biological Oxygen Demand (BOD)

— Chemical Oxygen Demand (COD)

— Iron and Manganese and bacteria

— Hydrogen Sulphide and Sulphate reducing bacteria.

4.3 Water distribution network: main, sub-main, distribution pipes

Pipelines carry water through the entire irrigation system, from the pump through the filters, valves, and distribution devices.

All pipelines and fittings should be properly sized to withstand maximum operating pressures and convey water without excessive pressure loss or gain.

PVC piping may be used throughout the system or combined with steel piping at the pump station. Polyethylene (PE) or flexible pipes may be used for sub-mains and distribution pipes. Alternatively, aluminium pipes may be used.

Expansion and contraction that occur under normal on-surface operating conditions should be considered (each type of pipe is affected to a different degree).

Pipelines are connected to one another with welds, glue or friction fittings, according to the type of piping in use, and are anchored to the infrastructure supporting them. All pipelines should be properly secured and anchored.

In irrigation design, pipe sizes are specified based on economic, friction loss, water hammer considerations and flushing concerns, as pipe size increases, friction loss decreases (reduced pumping cost) but initial cost increases.

Irregular field shapes are common due to topography and property boundaries. At the planning stage, care should be taken to properly size sub-main and distribution lines where field shape varies. Sub-main and distribution lines for irregularly shaped fields are designed based on actual flow rates of the main lines and laterals and not on an “average” flow rate of the system.

The piping system should be designed not only to allow the flow rate necessary for normal irrigation but also to allow sufficient flow rate for proper flushing velocities, if using a dripper or micro-irrigation (recommended minimum: 0,3 m s^{-1}/1 ft s^{-1}).

Design objectives for flushing can result in different pipe diameters being selected than those selected in the design process for normal operation. This is because the flushing flow rate required for achieving a desired flushing velocity in any section of a main, sub-main or distribution pipe may be different than the design flow rate for regular operation.

5 Pressurized irrigation design

5.1 General

When designing new irrigation systems, diverse parameters should be taken in to account in order to design an optimal and durable system. The collection of pre-design data is an essential step before starting the system design. The pre-design data can be divided into a number of categories.

5.2 Data collection

5.2.1 Soil characteristics

Depth, texture, structure, bulk density, saturation percentage, field capacity, wilting point, existence of stratified layers and infiltration rate.

5.2.2 Surface topography

Topographic maps.

5.2.3 Climate

Peak season of maximum daily evaporation, monthly average temperatures and monthly rainfall.

5.2.4 Water source and quality

Water source (river, dam, pond, well, treated wastewater), hours of supply, maximum hourly flow rate, pressure at supply connection, chemical and physical quality.

5.2.5 Crops characteristics (orchards, field crops, vegetables)

Gross and net daily crop water requirement, crop rotation details, length of growing season, spacing between rows and between plants in the row, depth of root zone, crop height, tolerance to salinity water and nutrient consumption curves.

5.2.6 Local water use regulations

The daily, weekly, monthly or annual total withdrawal of water may be controlled by local regulation. Permits to pump may be required.

6 Calculating irrigation scheduling

6.1 General

For a successful irrigation design, the amount and frequency of water that should be applied to crops should be considered. Specifically, the crops' water requirements should be met at the period of peak consumption when the irrigation interval is minimal[10].

6.2 Soil — Water reservoir

6.2.1 General

The soil is the reservoir of water to supply the needs of the crop. Once it has been filled to field capacity by irrigation or rainfall, it is depleted gradually by evapotranspiration. When the soil moisture reaches a predetermined minimum level, irrigation should be applied to refill the reservoir. The minimum should be that in which the crop is not affected by lack of water, both in its vegetative development and in its production. To quantify the size of this reservoir several steps should be taken.

6.2.2 Calculation of water available for the crop in the root zone

— The total available water of the soil (TAW) [see Formula (7)] is defined as the difference between the volumetric water content in field capacity (θ_{FC}) and the content in wilting point (θ_{WP}), expressed as % of the soil volume. These values are characteristics of the soil. Sandy soils have lower available water than clayey soils.

— From this water storage, the volume of water in an area unit at a determined depth may be calculated [see Formula (6)]. The depth that should be used is the depth of the effective root zone. This is the soil depth from which the plants take 80 % of their water needs, mostly from the upper part where the root system is denser. The rooting depths depend on the plant physiology, the type of soil, and the water availability (kind of irrigation)[11]. This value is the available water at the effective root zone (AWER).

6.2.3 Calculation of the management allowable deficit

Although all the water available in the design root zone can be absorbed by the plant, it is not customary to use this total value for the design calculations. The reasons are two: (i) technically, there can be malfunctions of the irrigation system (from the pumping station or in each place of the pipeline or the network) which momentarily prevents irrigation and bring soil moisture to the wilting point of wilting permanent with damage to the crop; and (ii) physiologically, whereby the soil moisture level needs to be maintained at a level that can be easily absorbed by the plant. This permissible deficit or depletion (MAD) of soil available water is the part of the available water that can be easily absorbed by the plants (without any stress that results in yield reduction)[11]. This value depends on types of crop, root depth, soil, climate and irrigation method. The MAD value varies between 20 % and 70 %. Depending on the crop the allowable deficit may change during the growing season, particularly for annual crops where some, during the vegetative stage, may tolerate a larger allowable deficit, and a lower deficit during the reproductive phase.

6.2.4 Net irrigation depth (NID)

If the value of the available water at the effective root zone (AWER) is multiplied by the value of the maximum depletion allowed (MAD), net irrigation depths are obtained for irrigation methods with total surface wetting (surface basin irrigation and sprinkler irrigation). In methods with partial surface wetting (furrows, drip, micro-sprinkler and moving water application devices such as LEPA) the percentage of the area under irrigation (and depending on this, the volume of moistened soil) depends on the irrigation system, the location of the emitter, the operating pressure and the hourly discharge. In drip irrigation, the wetting area is set according to the distance between drippers and the distance between the laterals, taking into account the overlapping between the areas wetted by two neighbouring drippers on the lateral, which is approximately 20 %. Multiplying the net irrigation depth (NID) by the percentage of the area under irrigation (P_a), whose value is 50 % to 100 %, the corrected NID is obtained.

6.2.5 Gross irrigation depth (GID)

During the irrigation process, significant water losses occur through evaporation, deep percolation, runoff, uniformity of application, wind drift, etc. The amount lost depends on the efficiency of the system. These losses are compensated by adding sufficient water to fill the net irrigation depth (NID) in the root zone. To calculate the GID, the NID should be divided by the efficiency of the system (%) divided by 100. The value obtained does not include the requirements for leaching the salts accumulated in the soil. Estimated values of seasonal irrigation efficiencies are presented in Tables 1, 2 and 3.

Table 1 — Estimated seasonal average irrigation efficiencies (modified from[12])

Type of irrigation system	Efficiency range (%)
Surface	
Furrow (without reuse of runoff water)	55-77
Border (without reuse of runoff water)	63-84
Basin	70-80
Precision-leveled basin	77-84

Table 2 — Attainable application efficiencies for sprinkler irrigation (application efficiency of the low quarter, modified from[13])

Type of sprinkler irrigation system	Efficiency range (%)
Hand Move, End-tow side roll laterals (highest w/ alternate sets)	65-85
Traveling gun, boom	60-65
Center pivot, linear move	75-90
Solid set, side move	70-80
LEPA	80-93
Under tree orchard (non-overlap)	80-93

Table 3 — Estimated seasonal average irrigation efficiencies

Type of irrigation system	Efficiency range (%)
Drip irrigation	
Compensated	74-93
Non compensated	70-87

6.2.6 Leaching

The concentration of soluble salts in the root zone can have a negative effect on the growth of the plant and the level of production. The crops vary among them in their sensitivity to salinity, there are very sensitive and very resistant, and among them with intermediate sensitivity. The sensitivity is to the concentration of salts in the soil solution, that is correlated to the salt content in the irrigation water, and is also affected by the type of soil and its hydraulic characteristics, the climate and the irrigation system. Irrigation systems differ in the distribution of salts in the soil as explained in 4.1.8. The accumulation of salts in the soil may be accepted up to a limit (limit value) (some examples are presented in Annex C). To avoid reaching this limit and reduce the concentration, an excess of water (leaching fraction) should be applied that percolates through and below the root zone carrying with it a portion of the accumulated soluble salts. This leaching fraction should be applied in all the irrigations or periodically according to the needs. The leaching requirements should be considered for the calculation of the gross irrigation depth (GID).

6.3 Crop water requirements

The amount of water which evaporates from wet soils and plant surfaces is called evapotranspiration (ET). Its value is largely determined by climate factors. Out of the total evapotranspiration, evaporation from the soil accounts for about 10 % and plant transpiration for the remaining 90 %. Crop water requirements encompass the total amount of water used in evapotranspiration[11]. There are alternative approaches for estimating or measure evapotranspiration. Crop factors (the growth stage of the plant) should be accounted for to convert the computed or measured free-water evaporation or potential ET into the consumptive use of water by the crop. For the purposes of system design and calculation of irrigation intervals, the period of maximum consumption by the plant is used.

6.4 Irrigation interval

Irrigation interval is the number of days between two consecutive irrigations. It is calculated by dividing the net depth by the evapotranspiration of the crop at the period of maximum consumption. The number obtained can be a non-integer number, so an approximation is made to the lower integer number. In this case, the net depth values should be corrected, which will be lower than those previously calculated.

Annex A
(informative)

Example of soil data

Soil texture	Sand	Silt	Clay	Porosity	Soil bulk density	Field capacity θ_{FC}	Wilting point θ_{WP}	Total available water in 1 m depth
	%			%	g cm^{-3}	%		m^3 Ha^{-1}
Sand	85-100	0-10	0-10	32-42	1,55-1,80	10-20	3-10	700-1 000
Sandy loam	50-70	30-50	10-15	40-47	1,40-1,60	15-27	6-12	500-1 500
Loam	40-50	30-50	10-30	43-49	1,34-1,50	26-37	11-17	1 400-1 900
Clay loam	25-45	30-50	30-40	47-51	1,30-1,40	31-42	15-20	1 700-2 200
Sandy clay	45-65	0-25	35-55	49-53	1,25-1,35	35-45	17-22	1 800-2 300
Clay	0-45	0-40	55-100	51-55	1,20-1,30	39-49	19-24	2 000-2 500