INTERNATIONAL STANDARD

ISO 24120-1

First edition
2022-06

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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Reference number
ISO 24120-1:2022(E)

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Published in Switzerland

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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.

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3 Terms and definitions

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

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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.

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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.

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

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).

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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):

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

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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).

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

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

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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

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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).

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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.

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— 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).

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

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).

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$$\Psi_t = \Psi_g + \Psi_m + \Psi_o + \ldots \tag{8}$$

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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).

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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).

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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.

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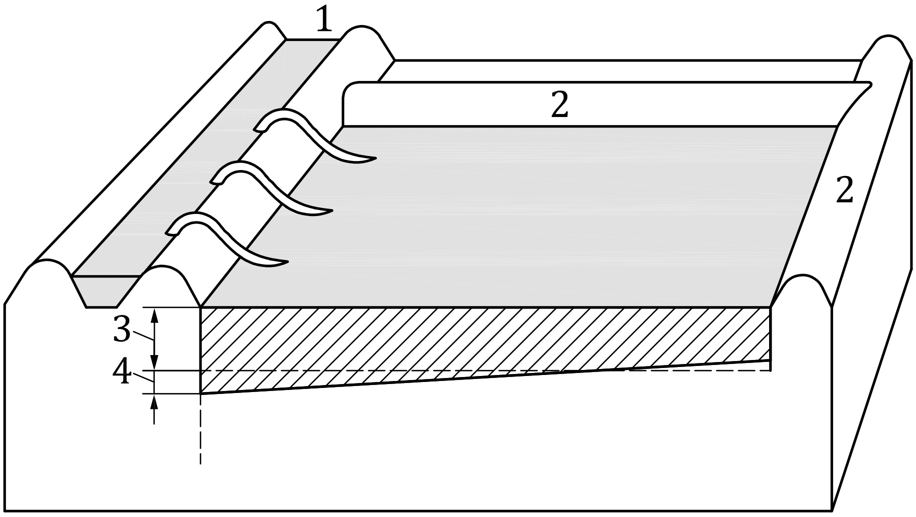
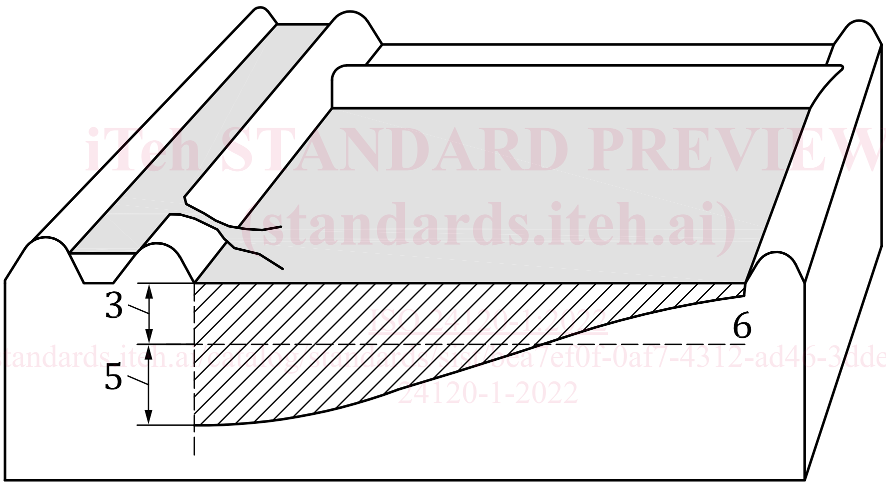


a) Ideal wetting pattern



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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]

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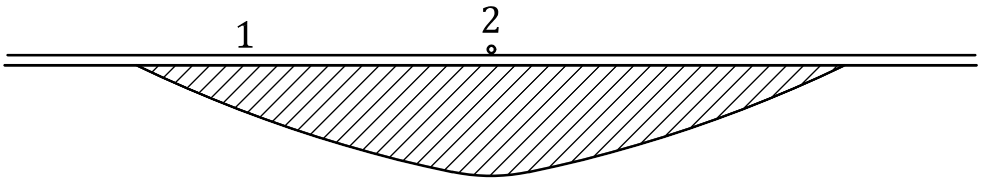
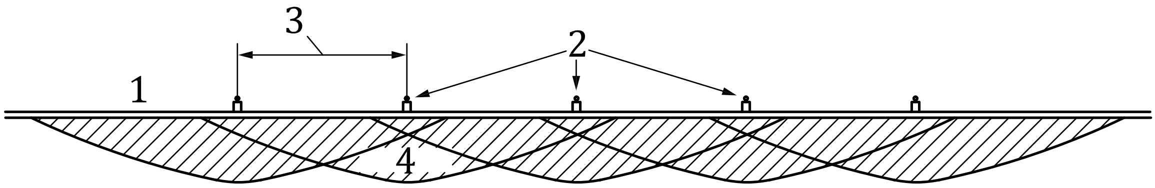


a) Wetting pattern for a single sprinkler



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]

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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).

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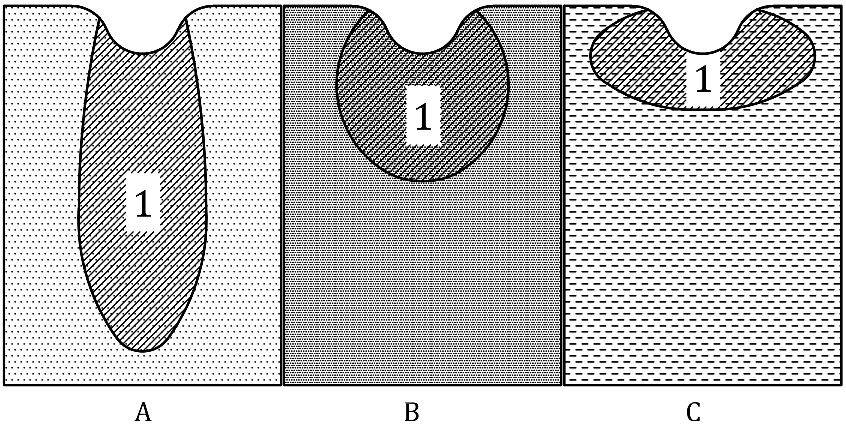

Key

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]

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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.

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