Small-scale, low-cost, environment friendly irrigation schemes: sites selection and preparation of full work tender dossier
EuropeAid/137393/DH/SER/MK

MINISTRY OF AGRICULTURE, FORESTRY AND WATER ECONOMY

Component 2:
Support for stakeholders involved in planning and implementation of the irrigation sector policy

TRAINING MANUAL
For Institutional Stakeholders

SUBJECT:
- **On-farm Irrigation Water Management**

Date: 04 September 2018

This project is funded by the European Union

A project implemented by:
eptisa temelsu PointPro

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1 EXECUTIVE SUMMARY

According to the Terms of Reference (ToR), the objective of Component 2: “Support for stakeholders involved in planning and implementation of the irrigation sector policy” is to provide capacity building of stakeholders in irrigation management, targeting the Water Management Directorate (WMD) at the Ministry of Agriculture, Forestry and Water Economy (MAFWE), and the Joint Stock Company for Water Management (JSCWM) and farmer’s groups at the selected sites.

The support to the institutional stakeholders (WMD at MAFWE and JSCWM) should

1) provide clarifications and transfer necessary knowledge about practical application of the selected standardised methodology used to prepare the outputs under Component 1
2) support to successfully carry out the ongoing policy to transfer the responsibility for water management to water users

This support will be provided through the following trainings subjects:

1) **Methodology used for Pre-feasibility studies**
2) **Strategy to transfer/share water management to irrigation water users (Irrigation Management Transfer - IMT) (Workshop)**
3) **System Irrigation Management**
4) **On farm irrigation water management**
5) **Soil Moisture Balance Method. FAO Cropwat practical application**
6) **Methodology to be used for feasibility studies**
7) **Basin Water Resources Management**
8) **Agriculture economics.**

Capacity needs assessment

During the trainings, a capacity needs assessment questionnaire will identify the following subjects of interest for future training. The subjects of interest up to now are:

9) **Participatory methods**
10) **Methodology to be used for Main Designs**
11) **Formation of water users’ associations (WUAs)**
12) **Workshop(s) on water tariff methodology.**
13) **Tender Dossier Preparation (following latest EU PRAG rules)**
14) **Application procedures to different donors / multilateral and bilateral org.**

2 ON-FARM IRRIGATION WATER MANAGEMENT

2.1 INTRODUCTION. (BROUWER ET ALL, 1985 (1))

It is often thought that farmers are very experienced in surface or modern irrigation methods simply because they have been practicing them for years. However, it is rare for farmers to evaluate their irrigation application by:

- Knowing the infiltration rate of their field an adjusting the irrigation application not to surpass the soil infiltration capacity.
- Knowing the depth of the root zone
- Measuring the amount of water applied (discharges and irrigation times)
- Assessing the soil moisture status in the root zone before and after irrigation.

It is therefore difficult to know if an excessive quantity of water has been applied and lost to deep percolation below the root zone; a farmer may well have been over-irrigating for many years without knowing it.

Significant improvements in water-use efficiency and productivity can be gained through assessment of farmers' actual application practices followed by training.

2.2 BASIC CONCEPTS

2.2.1 WATER DEPTH, DISCHARGE,

Volume of water on a field. Water depth.

Suppose a one-litre bottle is filled with water. The volume of the water is thus 1 litre or 1 dm3. When the bottle of water is emptied on a table, the water will spread out over the table and form a thin water layer. The amount of water on the table is the same as the amount of water that was in the bottle; being 1 litre. The volume of water remains the same; only the shape of the "water body" changes (see Fig. 2.1).

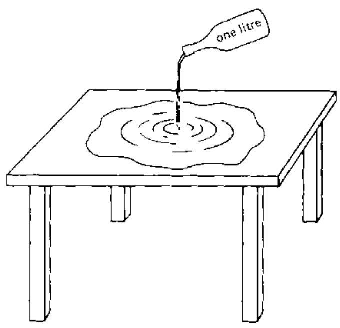


Figure 2-1 One litre of water spread over a table

A similar process happens if you spread irrigation water from a storage reservoir over a farmer's field.

QUESTION: Suppose there is a reservoir, filled with water, with a length of 5 m, a width of 10 m and a depth of 2 m. (5x10x2=100 m3) All the water from the reservoir is spread over a field of 1 hectare (10.000 m2). Calculate the water depth (which is the thickness of the water layer) on the field

The formula to use is:

$$\text{Water depth } (d) = \frac{\text{Volume of water } (V)}{\text{Surface of the field } (A)}$$

The water depth is then 100 m3 / 10.000 m2 = 0,01 m = 0,01 x 1000 mm = 10 mm.

When it rains 10 mm, a field of 1 hectare receives 100 m^3.

Flow-rate or discharge

Definition: The flow-rate or discharge of a river, or of a canal, is the volume of water discharged through this river, or this canal, during a given period of time. Related to irrigation, the volume of water is usually expressed in litres (l) or cubic metres (m3) and the time in seconds (s) or hours (h). The flow-rate is also called discharge-rate. Calculation and Units: The water running out of a tap fills a one litre bottle in one second. Thus the flow rate (Q) is one litre per second (1 l/s) (see Fig. 2.2).

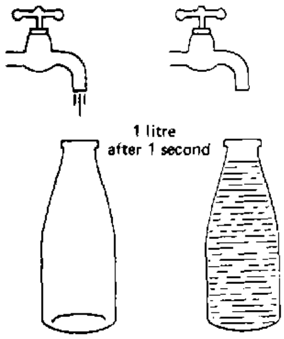


Figure 2-2 A flow-rate of one litre per second

QUESTION: The water supplied by a pump fills a drum of 200 litres in 20 seconds. What is the flow rate of this pump? The formula used is:

$$Q = \text{Flow-rate } (l/s) = \frac{\text{Volume of water (litres)}}{\text{Time (seconds)}} \qquad Q = \frac{\text{Volume of water}}{\text{Time}} = \frac{200\,l}{20\,s} = 10\,l/s$$

The unit "litre per second" is commonly used for small flows, e.g. a tap or a small ditch. For larger flows, e.g. a river or a main canal, the unit "cubic metre per second" (m3/s) is more conveniently used.

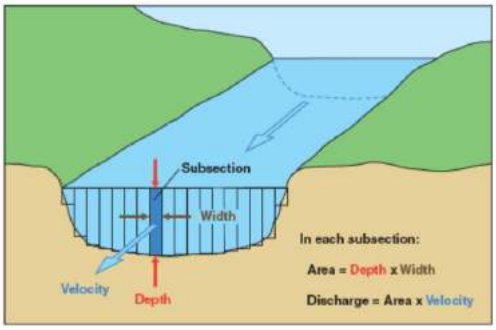


Figure 2-3 Velocity area method for discharge determination

A canal or river discharge can be determined by multiplying the area of water in a channel cross section by the average velocity of the water in that cross section.

Discharge = Area x Velocity

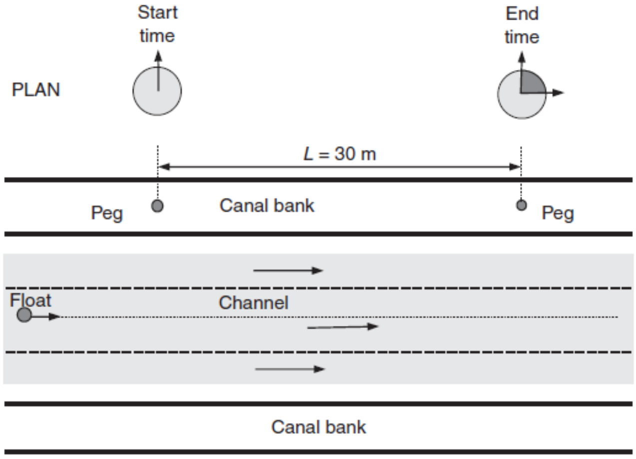
2.2.2 DISCHARGE MEASUREMENT

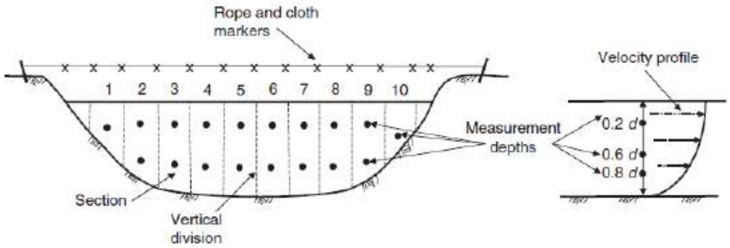
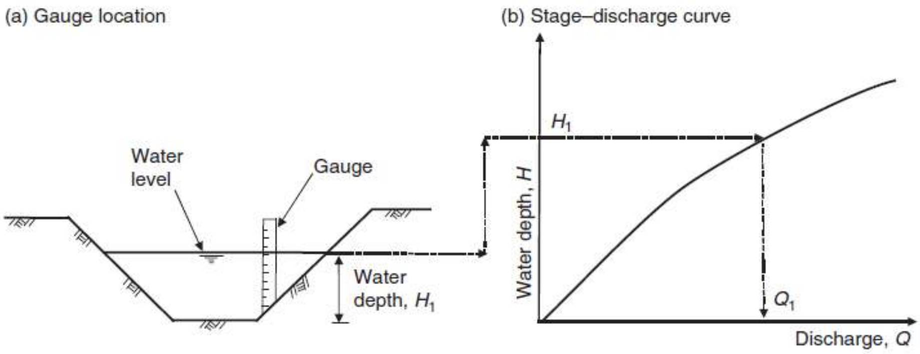
In many irrigation and drainage systems measurement of discharge is an essential component of the operation process. Discharge measurements need to be made in rivers, canals, drains and pipelines and can be made in a variety of ways using:

1. **velocity–area methods;**
2. **hydraulic structures;**
3. **flowmeters**
4. **slope–hydraulic radius–area method:** Measurement of water surface slope, cross-sectional area, and wetted perimeter over a length of uniform section channel are used to calculate the flow rate, by using a resistant equation such as the Manning formula
5. **dilution techniques:** the flow rate is measured by determining how much the flowing water dilutes an added tracer solution.

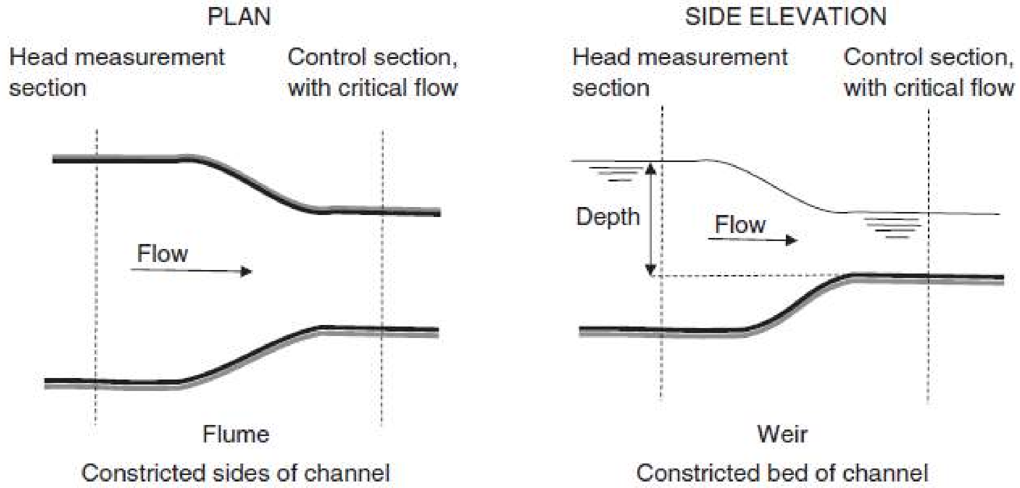
The most commonly used techniques are the velocity–area method, hydraulic structures and flowmeters.

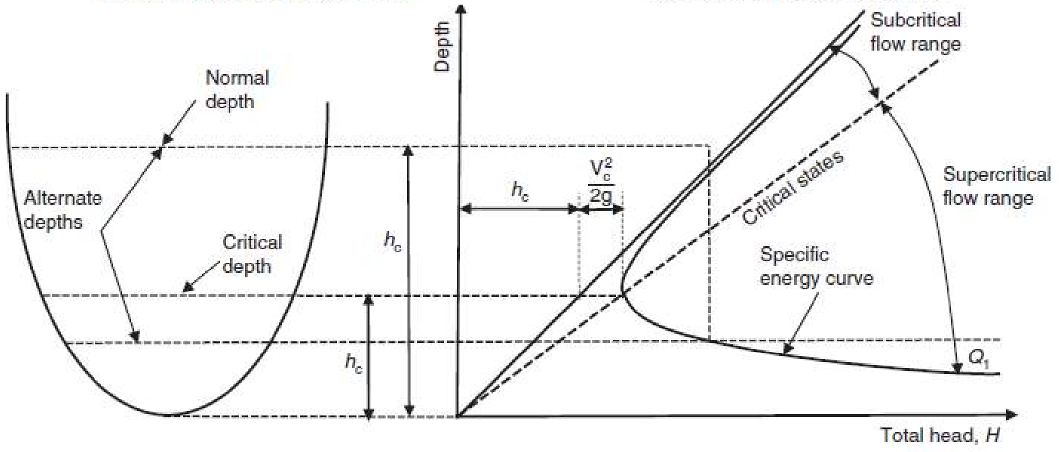
Velocity–area methods; they involve the measurement of the channel cross-sectional area (using a tape and level staff or depth gauge) and the average velocity of flow, determined with a current meter or a float.

<table>
<tr><th colspan="3">Velocity–area methods</th></tr>
<tr><td>Float method</td><td>
</td><td>
The float method is a simple, yet effective way to determine the discharge of a flow stream. (accuracy ±20–30%), well suited to smaller channels

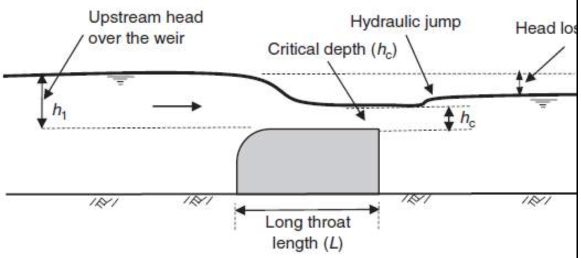
Q=0,7 * Area * Average Velocity</td></tr>
<tr><td>Current meter</td><td>
</td><td>
Current metering can be an accurate method (±5%-10%)</td></tr>
<tr><td>Stage discharge curve at gauged station</td><td>
</td><td>When measurements have been taken at a given location for a variety of flow conditions a stage–discharge curve can be formulated to enable discharge to be determined from the depth alone</td></tr>
</table>

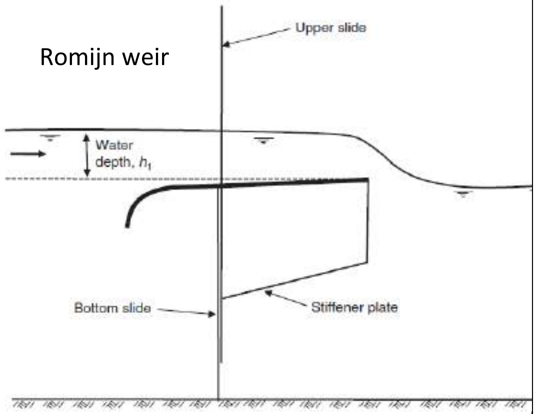
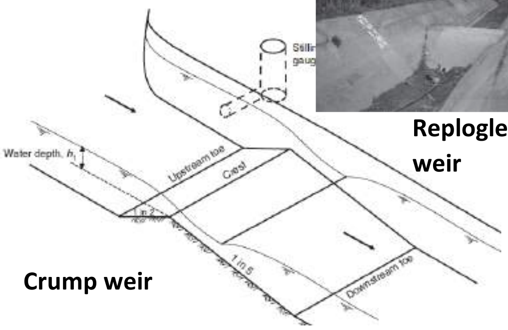
Hydraulic structures; If constructed to the standard designs they provide an easy-to-use and accurate method of discharge measurement relating a single measurement of water depth to the discharge flowing over the structure. In a measuring structure the channel cross-section is constricted (side width, bed elevation, or both) such that the specific energy level is reduced from subcritical through the minimum to supercritical. The transition from supercritical back to subcritical occurs downstream of the control section in the form of a hydraulic jump. For some measuring structures the relationship between depth and discharge can be derived mathematically; (from the relationship between the **velocity** at the critical depth, Bernoulli's equation and the continuity equation) for others it must be determined empirically through measurements in a laboratory.

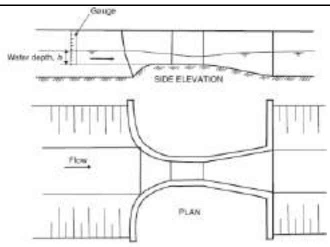


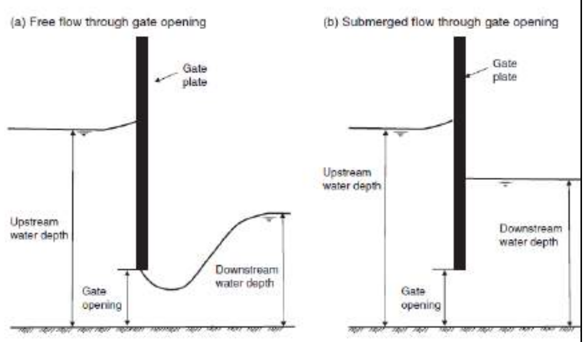
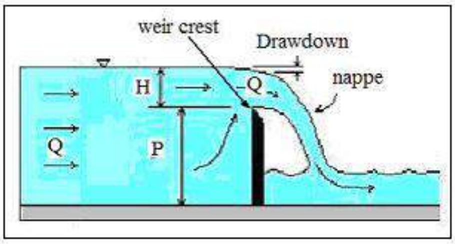
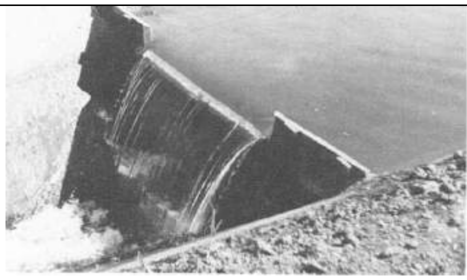


The discharge measuring structure does not reduce the flow entering the canal; this is often a cause of concern among farmers who may sometimes damage a measuring structure as they think it is impeding the flow. The structure raises the water level upstream by 5–10 cm and increases the velocity of flow in the control section. The discharge is the same as in the canal without the measuring structure.

<table>
<tr><th colspan="3">Hydraulic structures</th></tr>
<tr><td>Broad-crested weirs;</td><td>
$Q = 1.71\ b\ h_1^{(3/2)}$ (b width of the weir)

Broad-crested weirs are more robust than sharp-crested weirs though they are not as accurate. They have a high modular limit and do not require such a high head loss across the structure. On the other hand they can be difficult to construct (ensuring parallel faces, a uniform and horizontal crest, and smooth, even upstream curves in the case of round-nosed weirs)</td><td>Romijn weir
Romijn weir combines a flow regulation and a measurement function. It is adjusted up or down to pass the required discharge over its crest.</td></tr>
<tr><td>Short-crested weirs;</td><td>

Replogle weir
Crump weir</td><td>Crump weir is suitable for many sizes of canals and rivers, is accurate, relatively cheap and easy to construct, and has a high modular limit, and the structure passes sediment freely.
Replogle weir is similar to a Crump weir in having a sloping front face, but a short horizontal crest section with either a vertical or sloping back face. Easy to construct and suited to trapezoidal or parabolic lined channels.</td></tr>
<tr><td>Flumes</td><td>
Flumes are similar to weirs except that the constriction of flow is obtained by narrowing width rather than raising the bed level.
Long-throated: Can be treated analytically
Short-throated: flow in the
throat is not parallel, cannot be treated analytically, stage–discharge relationship determined by laboratory and field calibration. Parshall flume, H-flume</td><td></td></tr>
</table>

Orifices		Flow regulation gates can be used for discharge measurement but they have to be individually calibrated due to the variation in the flow conditions (gate thickness, side wall and bed shape and condition). Calibrating the gates can be difficult. Using such procedures for discharge measurement is not generally recommended for regular operating purposes; a standard measuring structure is preferred
Sharp crested weirs	 Sharp Crested Weir Parameters	
	If correctly installed and maintained, are extremely accurate (±5%). Their disadvantages are that the sharp crest is prone to damage by floating debris, a relatively large head loss is required for correct operation and they are prone to sedimentation upstream, and thus inaccuracies in measurement	
Flowmeters		 Electromagnetic flow meter
	The propeller meter is commonly used for flow measurement in pipes. It is a totalizing metering that the number of revolutions is proportional to the total flow passing	Non-intrusive flow measurement devices. These operate through Doppler shift or the accurate measurement of time of travel of ultrasonic signals located on opposite sides of the pipes.

2.2.3 THE SOIL: COMPOSITION, PROFILE, TEXTURE, STRUCTURE

Soil composition:

When dry soil is crushed in the hand, it can be seen that it is composed of all kinds of particles of different sizes. Most of these particles originate from the degradation of rocks; they are called mineral particles. Some originate from residues of plants or animals (rotting leaves, pieces of bone, etc.), these are called organic particles (or organic matter). The soil particles seem to touch each other, but in reality have spaces in between. These spaces are called pores. When the soil is "dry", the pores are mainly filled with air. After irrigation or rainfall, the pores are mainly filled with water. Living material is found in the soil. It can be live roots as well as beetles, worms, larvae etc. They help to aerate the soil and thus create favourable growing conditions for the plant roots (Fig. 2.4)

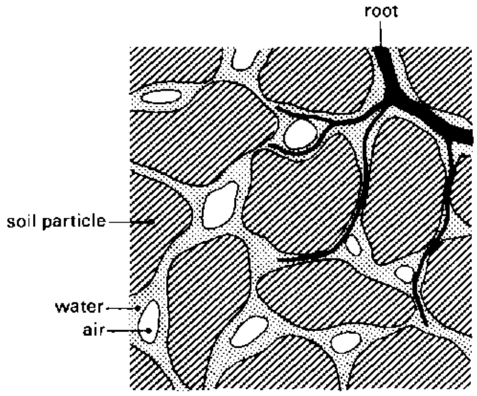


Figure 2-4 The composition of the soil

Soil profile If a pit is dug in the soil, at least 1 m deep, various layers, different in colour and composition can be seen. These layers are called horizons. This succession of horizons is called the profile of the soil (Fig. 2.5).

A very general and simplified soil profile can be described as follows:

a) The plough layer (20 to 30 cm thick): is rich in organic matter and contains many live roots. This layer is subject to land preparation (e.g. ploughing, harrowing etc.) and often has a dark colour (brown to black).
b) The deep plough layer: contains much less organic matter and live roots. This layer is hardly affected by normal land preparation activities. The colour is lighter, often grey, and sometimes mottled with yellowish or reddish spots.
c) The subsoil layer: hardly any organic matter or live roots are to be found. This layer is not very important for plant growth as only a few roots will reach it.
d) The parent rock layer: consists of rock, from the degradation of which the soil was formed. This rock is sometimes called parent material.

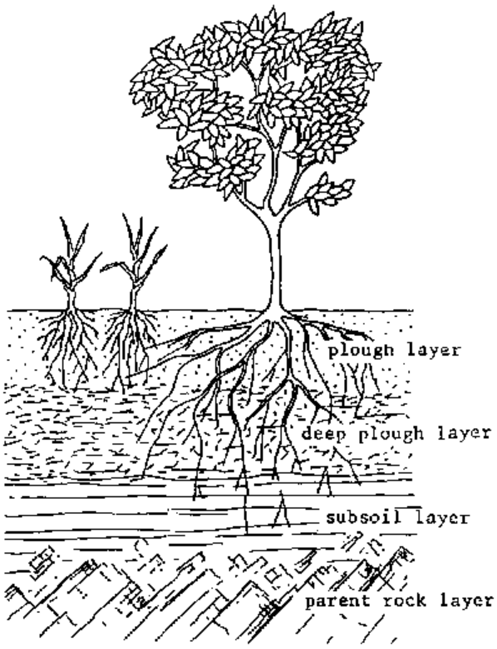


Figure 2-5 The soil profile

Soil texture: it indicates the relative content of particles of various sizes, such as sand, silt and clay in the soil

The mineral particles of the soil differ widely in size and can be classified as follows:

Table 2-1 Classification of particles of the soil

Name of the particles	Size limits in mm	Distinguishable with naked eye
Gravel	Larger than 1	Obviously
Sand	1 to 0.5	Easily
Silt	0.5 to 0.002	Barely
Clay	Less than 0.002	Impossible

The amount of sand, silt and clay present in the soil determines the soil texture.

In coarse textured soils: sand is predominant (sandy soils). In medium textured soils: silt is predominant (loamy soils). In fine textured soils: clay is predominant (clayey soils).

In the field, soil texture can be determined by rubbing the soil between the fingers. Farmers often talk of light soil and heavy soil. A coarse-textured soil is light because it is easy to work, while a fine-textured soil is heavy because it is hard to work. The texture of a soil is **permanent**, the farmer is unable to modify or change it.

Table 2-2 Denomination of soil textures

Expression used by the farmer	Expression used in literature	
light	sandy	coarse
medium	loamy	medium
heavy	clayey	fine

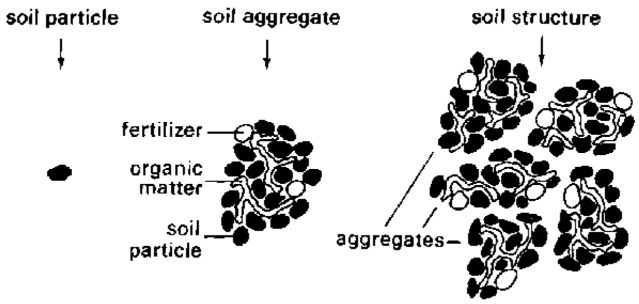


Figure 2-6 The soil structure

Soil structure: Soil structure refers to the grouping of soil particles (sand, silt, clay, organic matter and fertilizers) into porous compounds. These are called aggregates. Soil structure also refers to the arrangement of these aggregates separated by pores and cracks (Fig. 2.6). The basic types of aggregate arrangements are shown in Fig. 2.7, granular, blocky, prismatic, and massive structure.

When present in the topsoil, a massive structure blocks the entrance of water; seed germination is difficult due to poor aeration. On the other hand, if the topsoil is granular, the water enters easily, and the seed germination is better.

In a prismatic structure, movement of the water in the soil is predominantly vertical and therefore the supply of water to the plant roots is usually poor.

Unlike texture, soil structure is not permanent. By means of cultivation practices (ploughing, ridging, etc.), the farmer tries to obtain a granular topsoil structure for his fields.

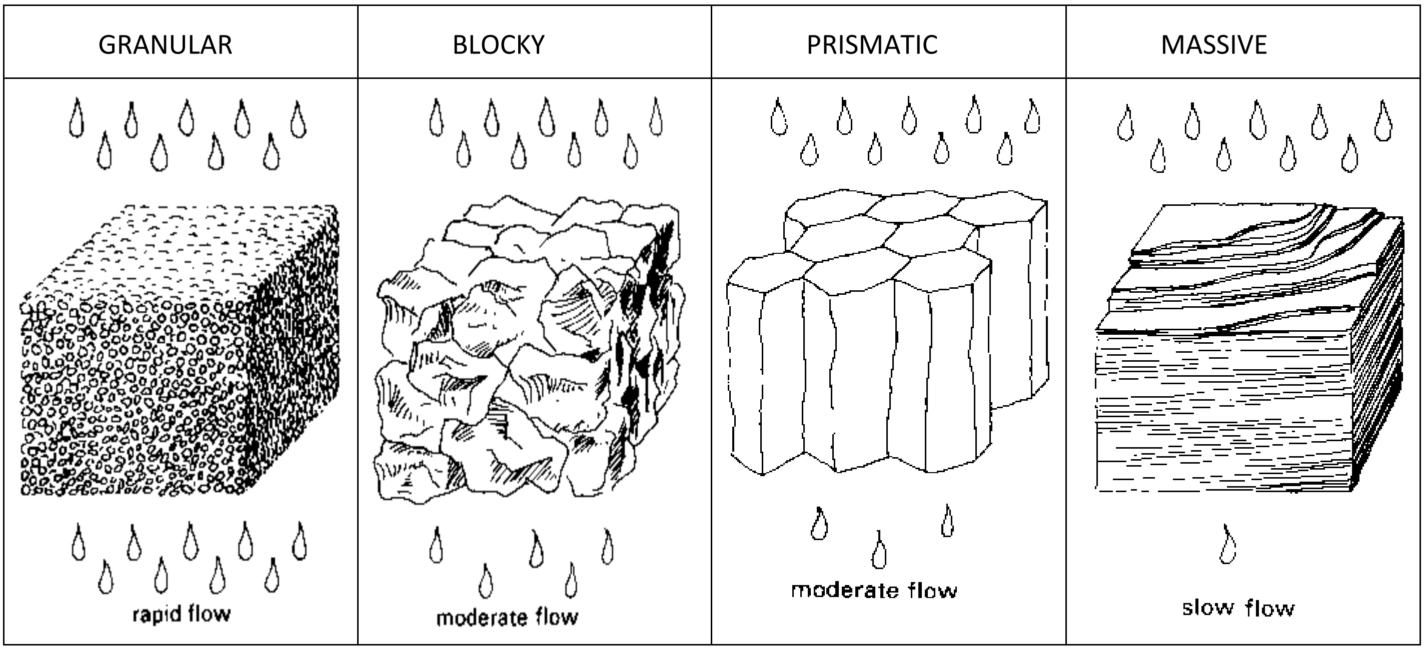
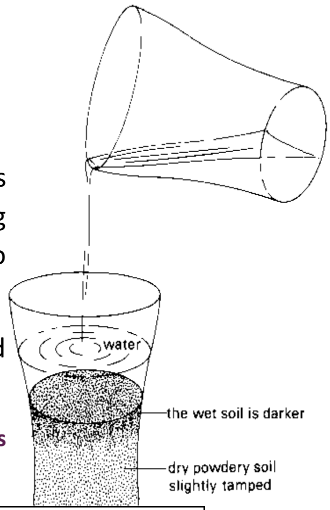


Figure 2-7 Some examples of soil structures

2.2.4 WATER INTO THE SOIL: INFILTRATION RATE, SOIL MOISTURE CONTENT



The infiltration process: When rain or irrigation water is supplied to a field, it seeps into the soil. This process is called infiltration. Infiltration can be visualized by pouring water into a glass filled with dry powdered soil, slightly tamped. The water seeps into the soil; the colour of the soil becomes darker as it is wetted (see Fig. 2.8).

Repeat the previous test, this time with two glasses. One is filled with dry sand and the other is filled with dry clay (see Fig. 2.9).

Figure 2-8 The infiltration process

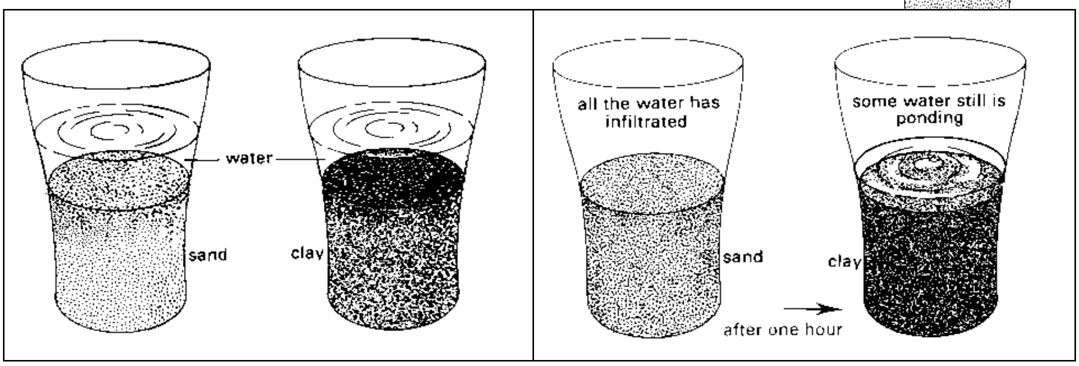


Figure 2-9 Comparison of water infiltration into sand and clay

The same amount of water is supplied to each glass. After one hour the water has infiltrated in the sand, while some water is still ponding on the clay. The infiltration of water into the sand is faster than into the clay. The sand is said to have a higher infiltration rate.

The infiltration rate of a soil is the velocity at which water can seep into it. It is commonly measured by the depth (in mm) of the water layer that the soil can absorb in an hour. An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the surface of the soil, will take one hour to infiltrate (see fig. 2.10).

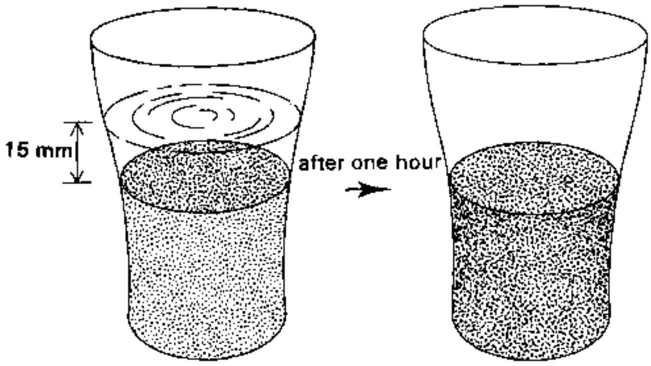
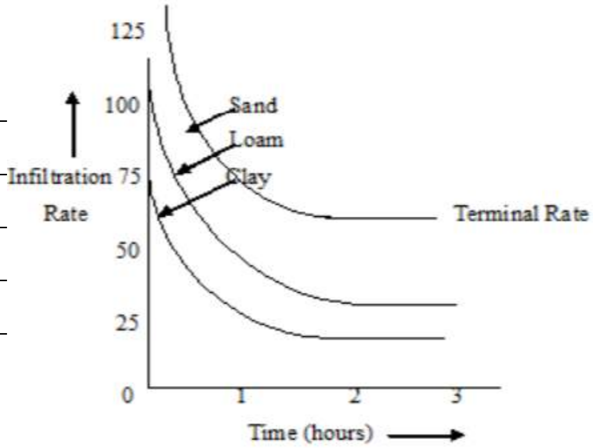


Figure 2-10 Soil with an infiltration rate of 15 mm/hour

Table 2-3 Typical values for soils infiltration rates

Low infiltration rate	less than 15 mm/hour
medium infiltration rate	15 to 50 mm/hour
high infiltration rate	more than 50 mm/hour



The infiltration rate of a soil determines the maximum rate at which irrigation should be applied. When irrigation water is applied at a higher rate it results in ponding of water and surface runoff, which can cause erosion in slopping fields and water wastage.

Factors influencing the infiltration rate: The infiltration rate of a soil depends on factors that are constant, such as the soil texture, and it also depends on factors that vary, such as the soil moisture content.

i. Soil Texture

Coarse textured soils have mainly large particles in between which there are large pores. On the other hand, fine textured soils have mainly small particles in between which there are small pores (see Fig. 2.11).

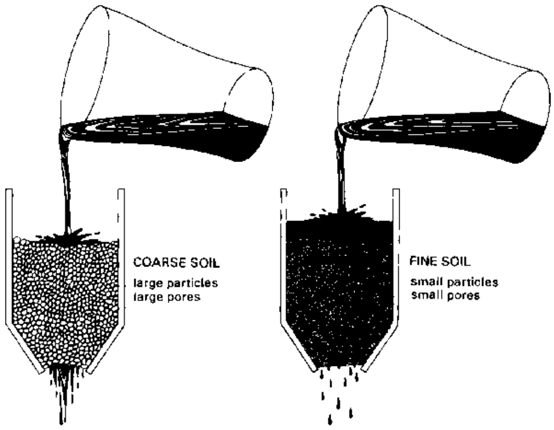


Figure 2-11 Infiltration rate and soil texture

In coarse soils, the rain or irrigation water enters and moves more easily into larger pores; it takes less time for the water to infiltrate into the soil. In other words, infiltration rate is higher for coarse textured soils than for fine textured soils.

ii. The soil moisture content

The water infiltrates faster (higher infiltration rate) when the soil is dry, than when it is wet. As a consequence, when irrigation water is applied to a field, the water at first infiltrates easily, but as the soil becomes wet, the infiltration rate decreases.

iii. The soil structure

Generally speaking, water infiltrates quickly (high infiltration rate) into granular soils but very slowly (low infiltration rate) into massive and compact soils. Because the farmer can influence the soil structure (by means of cultural practices), he can also change the infiltration rate of his soil.

iv. Organic Matter:

Organic Matter raises the entry of water by protecting the soil masses from getting broken down during the impact of raindrops.

v. Vegetation:

The foliage of grasses and plants capture the falling precipitation, keeping that water away from being absorbed into the earth. The water flowing through the vegetation reduces the velocity of the flowing and this will provide time to the ground to absorb the water. The ground without vegetation, have usually high runoff and less infiltration rates.

vi. Surface Sealing and Crusting:

A crust on the soil surface can seal the pores and restrict the entry of water into the soil. The formation of a seal 5 mm thick lead to a 75% decrease in infiltration rate.

vii. Rainfall rates

A high rainfall rates may cause destruction of the soil surface leading to surface sealing or the formation of soil crusts and reduction in infiltration rate.

The measure of infiltration rate: The measure of infiltration of water into the soil is an important indication concerning: the efficiency of irrigation and drainage, optimizing the availability of water for plants, improving the yield of crops and minimizing erosion.

Equipment: a double ring infiltrometer (Two steel rings of 300 and 600mm diameter x 370mm height, a wooden piece in order to drive the rings into the soil, hammer, bucket, measuring jug, knife, stopwatch, measuring tape, washcloth, and water.

Measurement procedure: Both (inner and outer) cylinders are driven into the soil (to a depth of 15 cm). It is recommended that the turf around the rings' periphery is cut with a knife, the soil is then less disturbed by driving the rings into it. A perforated metal plate, (or newspaper paper) is placed on the soil surface in the inner cylinder, in order to dissipate the force of the applied water, to distribute water uniformly inside the ring and to prevent disturbance of the soil surface. Two nail points of different lengths are fixed to the metal plate. (or two marks are done in the inner cylinder) These points are used for observation of decreasing water level during the infiltration. (the water level in the inner cylinder should reach the upper nail point or mark).

Then water is poured into both cylinders. (the water level in the inner cylinder should reach the upper nail point or mark). The measurement is taken in the inner cylinder; the outer cylinder is used only as a tool to ensure that water from the inner cylinder will flow downwards and not laterally.

The stopwatch is started, and the time needed for the water level to drop from the upper to the lower mark is measured and recorded. After this elapsed time, a certain amount of water was infiltrated. When the water level reaches the lower mark, the time is recorded, and the same amount of water is poured back from a prepared graduated bottle. The water level in the outer cylinder is kept at the same level as the water level in the inner one.

The measured data are recorded and then plotted into a graph (mm paper in the field or MS Excel) for the visual check of the measured data. The measured data can be analysed using Philip's infiltration equations (Philip, 1957)

Steady-state infiltration rate after a longer time of infiltration (the line of the infiltration rate is parallel to the horizontal axis of time) remains constant and its value is close to the value of saturated hydraulic conductivity K. Thus, this method allows also to determine k in field conditions.

			
Both cylinders are driven into the soil	A perforated metal plate, (or newspaper paper) is placed on the soil surface in the inner cylinder	Water is poured into inner cylinder up to the upper mark	Water level in the outer cylinder is kept at the same level as in the inner one. Amount of water and time are recorded.

Figure 2-12 Double ring infiltrometer measurement procedure

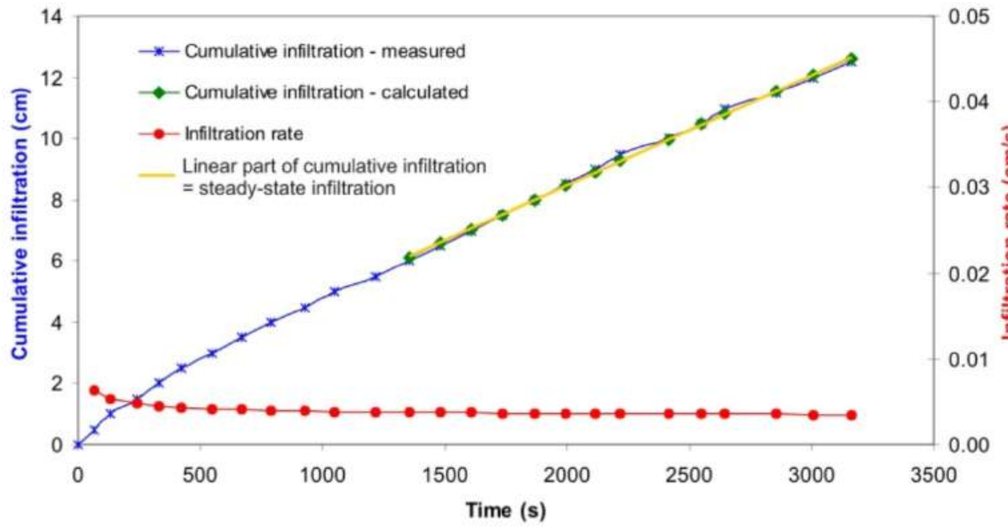


Figure 2-13 Cumulative infiltration and infiltration rate plots

Soil moisture content: The soil moisture content indicates the amount of water present in the soil.

It is commonly expressed as the amount of water (in mm of water depth) present in a depth of one metre of soil. For example: when an amount of water (in mm of water depth) of 150 mm is present in a depth of one metre of soil, the soil moisture content is 150 mm/m (see Fig. 2.14).

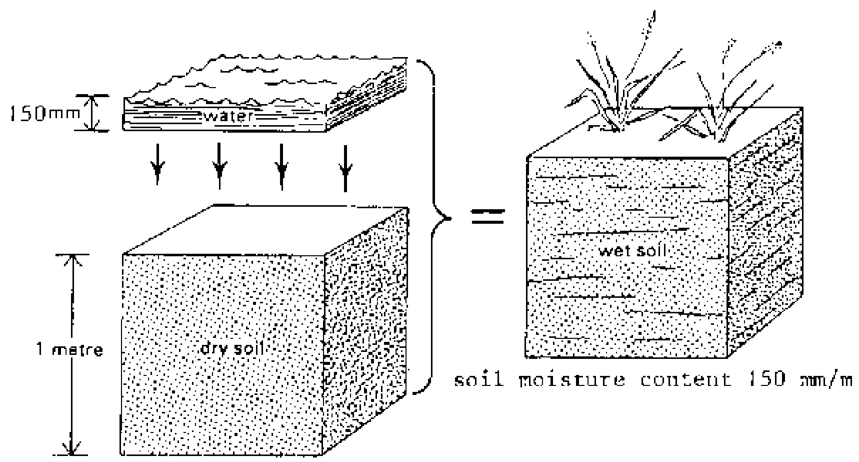


Figure 2-14 A soil moisture content of 150 mm/m

The soil moisture content can also be expressed in percent of volume. In the example above, 1 m3 of soil (e.g. with a depth of 1 m, and a surface area of 1 m2) contains 0.150 m3 of water (e.g. with a depth of 150 mm = 0.150 m and a surface area of 1 m2). This results in a soil moisture content in volume percent of:

$$\frac{0.150\,m^3}{1m^3} \times 100\% = 15\%$$

Thus, a moisture content of 100 mm/m corresponds to a moisture content of 10 volume percent. Note: The amount of water stored in the soil is not constant with time but may vary.

Saturation: during a rain shower or irrigation application, the soil pores will fill with water. If all soil pores are filled with water the soil is said to be saturated. There is no air left in the soil (see Fig. 2.15a). It is easy to determine in the field if a soil is saturated. If a handful of saturated soil is squeezed, some (muddy) water will run between the fingers.

Plants need air and water in the soil. At saturation, no air is present, and the plant will suffer. Many crops cannot withstand saturated soil conditions for a period of more than 2-5 days. Rice is one of the exceptions to this rule. The period of saturation of the topsoil usually does not last long. After the rain or the irrigation has stopped, part of the water present in the larger pores will move downward. This process is called drainage or percolation.

The water drained from the pores is replaced by air. In coarse textured (sandy) soils, drainage is completed within a period of a few hours. In fine textured (clayey) soils, drainage may take some (2-3) days.

Field capacity: After the drainage has stopped, the large soil pores are filled with both air and water while the smaller pores are still full of water. At this stage, the soil is said to be at field capacity. At field capacity, the water and air contents of the soil are considered to be ideal for crop growth (see Fig. *2.15*b).

Permanent wilting point: Little by little, the water stored in the soil is taken up by the plant roots or evaporated from the topsoil into the atmosphere. If no additional water is supplied to the soil, it gradually dries out.

The dryer the soil becomes, the more tightly the remaining water is retained and the more difficult it is for the plant roots to extract it. At a certain stage, the uptake of water is not sufficient to meet the plant's needs. The plant loses freshness and wilts; the leaves change colour from green to yellow. Finally, the plant dies.

The soil water content at the stage where the plant dies, is called permanent wilting point. The soil still contains some water, but it is too difficult for the roots to suck it from the soil (see Fig. 2.15c).

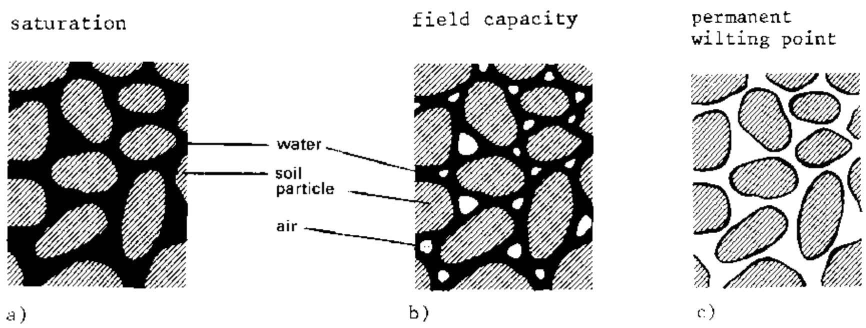


Figure 2-15 Some soil moisture characteristics

Available water content: The soil can be compared to a water reservoir for the plants. When the soil is saturated, the reservoir is full. However, some water drains rapidly below the rootzone before the plant can use it (see Fig. 2-15a).

When this water has drained away, the soil is at field capacity. The plant roots draw water from what remains in the reservoir (see Fig. 2-15b).

When the soil reaches permanent wilting point, the remaining water is no longer available to the plant (see Fig. 2-15c).

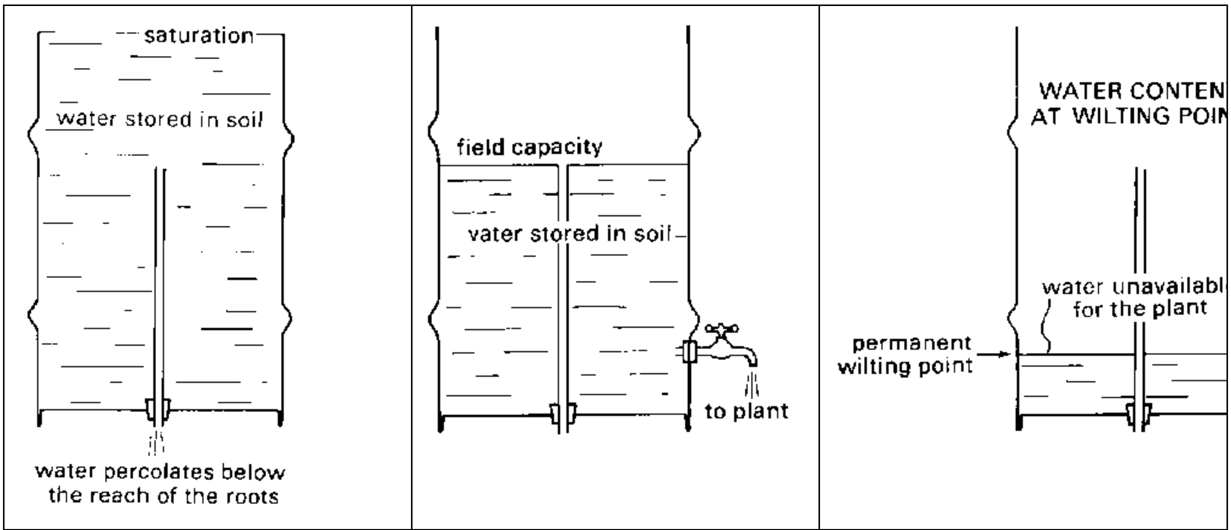


Fig. 2-14a. Saturation	Fig. 2-14b. Field capacity	Fig. 2-14c. Wilting point

Figure 2-16 Typical amounts of water at different soil moisture characteristics

The amount of water actually available to the plant is the amount of water stored in the soil at field capacity minus the water that will remain in the soil at permanent wilting point. This is illustrated in Fig. 2-16.

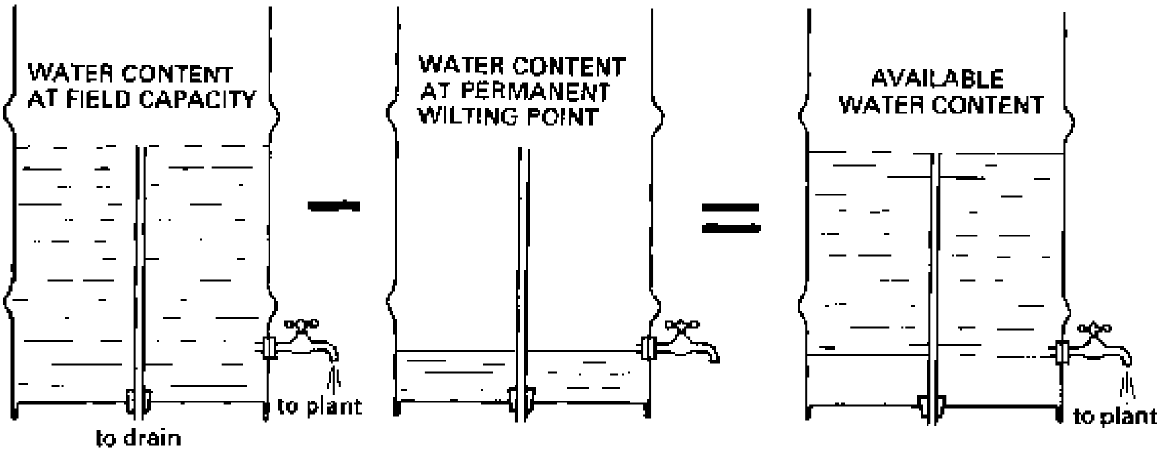


Figure 2-17 The available soil moisture or water content

Available water content = water content at field capacity - water content at permanent wilting point

The available water content depends greatly on the soil texture and structure. A range of values for different types of soil is given in the following table.

Table 2-4 Available water content of different soils

Soil	Available water content in mm water depth per m soil depth (mm/m)
sand	25 to 100
loam	100 to 175
clay	175 to 250

The field capacity, permanent wilting point (PWP) and available water content are called the soil moisture characteristics. They are constant for a given soil but vary widely from one type of soil to another.

2.2.5 GROUNDWATER TABLE AND CAPILLARY RISE

Groundwater table: Part of the water applied to the soil surface drains below the rootzone and feeds deeper soil layers which are permanently saturated; the top of the saturated layer is called groundwater table or sometimes just water table. The depth of the groundwater table varies greatly from place to place, mainly due to changes in topography of the area (see Fig. 2-18).

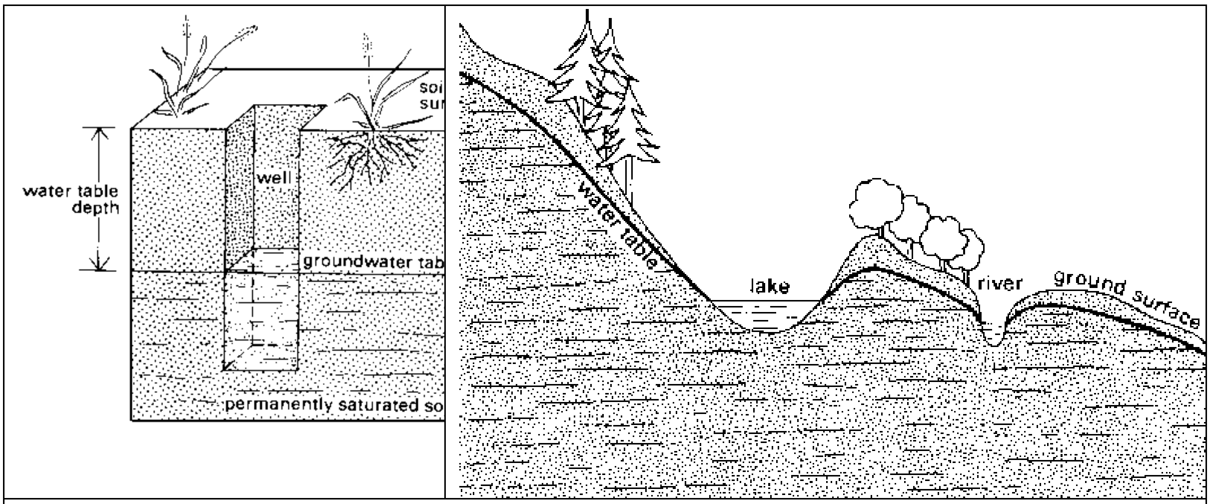


Figure 2-18 The groundwater table and its depth

Capillary rise: So far, it has been explained that water can move downward, as well as horizontally (or laterally). In addition, water can move upward. If a piece of tissue is dipped in water, the water is sucked upward by the tissue. The same process happens with a groundwater table and the soil above it. The groundwater can be sucked upward by the soil through very small pores that are called capillars. This process is called capillary rise.

In fine textured soil (clay), the upward movement of water is slow but covers a long distance. On the other hand, in coarse textured soil (sand), the upward movement of the water is quick but covers only a short distance.

Table 2-5 Height of capillary rise at different soil textures

Soil texture	Capillary rise (in cm)
coarse (sand)	20 to 50 cm
medium	50 to 80 cm
fine (clay)	more than 80 cm up to several metres

2.2.6 ELEMENTS OF TOPOGRAPHY: SLOPES, CONTOUR LINES (BROUWER ET ALL, 1985 (2))

Slopes: a slope is the rise or fall of the land surface. It is important for the farmer or irrigator to identify the slopes on the land. A slope is easy to recognize in a hilly area. Start climbing from the foot of a hill toward the top, this is called a rising slope (see Fig. 2.19, black arrow). Go downhill, this is a falling slope (see Fig. 2.19, white arrow).

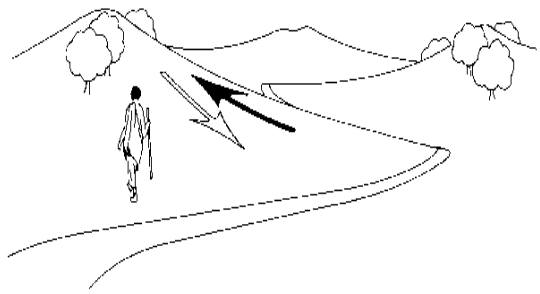


Figure 2-19 A rising and a falling slope

Flat areas are never strictly horizontal; there are gentle slopes in a seemingly flat area, but they are often hardly noticeable to the naked eye. An accurate survey of the land is necessary to identify these so called "flat slopes".

Method of expressing slopes: The slope of a field is expressed as a ratio. It is the vertical distance, or difference in height, between two points in a field, divided by the horizontal distance between these two points. The formula is:

$$\text{Slope} = \frac{\text{height difference (m) between A and B}}{\text{horizontal distance (m) between A and B}} = \frac{3\text{ m}}{1000\text{ m}} = 0.003$$

$$\text{Slope} = \frac{\text{height difference (metres)}}{\text{horizontal distance (metres)}}$$

The slope can also be ***expressed in percent***; the formula used is then:

$$\text{Slope in \%} = \frac{\text{height difference (metres)}}{\text{horizontal distance (metres)}} \times 100$$

Using the same measurements:

$$\text{Slope in \%} = \frac{3\text{ m}}{1000\text{ m}} \times 100 = 0.3\%$$

Finally, the slope can be ***expressed in per mil or per thousand***; the formula used is then:

$$\text{Slope in ‰} = \frac{\text{height difference (metres)}}{\text{horizontal distance (metres)}} \times 1000$$

with the figures from the same example:

(NOTE: Slope in ‰ = slope in % x 10)

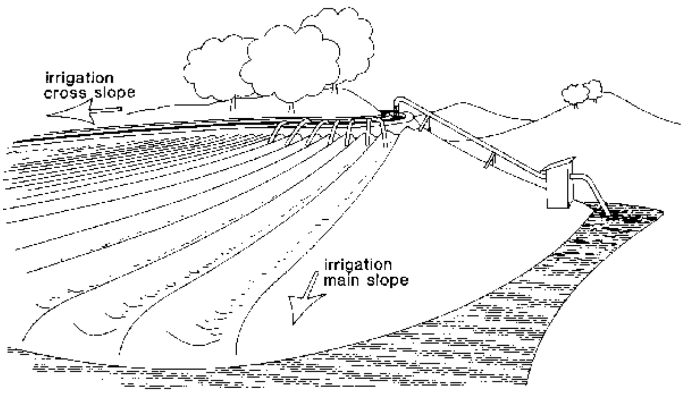
$$\text{Slope in ‰} = \frac{3\text{ m}}{1000\text{ m}} \times 1000 = 0.3‰$$

QUESTION: What is the slope in percent and in per mil of a field with a horizontal length of 200 m and a height difference of 1.5 m between the top and the bottom? ANSWER: (1.5 m / 200 m) x 100 = 0,75% = 7,5‰

QUESTION: What is the difference in height between the top and the bottom of a field when the horizontal length of the field is 300 m and the slope is 2‰? ANSWER: 0.002 x 300 m = 0.6 m.

Table 2-6 Range of slopes commonly referred to in irrigated fields

Slope	%	‰
Horizontal	0-0.2	0-2
Very flat	0.2-0.5	2-5
Flat	0.5-1	5-10
Moderate	1-2.5	10-25
Steep	More than 2.5	More than 25



An irrigation field can have a main slope and a cross slope, as shown in figure 2.20

Figure 2-20 Main and Cross slopes of an irrigation field

Thick arrow: direction of main slope; thin arrow: direction of the cross slope.

Contour lines: A contour line is the imaginary horizontal line that connects all points in a field which have the same elevation. A contour line is imaginary but can be visualized by taking the example of a lake: The water level of a lake may move up and down, but the water surface always remains horizontal. The level of the water on the shore line of the lake makes a contour line because it reaches points which are all at the same elevation. Suppose the water level of the lake rises 50 cm above its original level. The contour line, formed by the shore line, changes and takes a new shape, now joining all the points 50 cm higher than the original lake level.

Contour lines are useful means to illustrate the topography of a field on a flat map; the height of each contour line is indicated on the map so that the hills or depressions can be identified.

2.2.7 Soil Erosion by Water

Erosion is the transport of soil from one place to another. Climatic factors such as wind and rain can cause erosion, but also under irrigation it may occur. Over a short period, the process of erosion is almost invisible. However, it can be continuous and the whole fertile top layer of a field may disappear within a few years.

Soil erosion by water depends on:

- the slope: steep, sloping fields are more exposed to erosion;

- the soil structure: light soils are more sensitive to erosion;
- the volume or rate of flow of surface runoff water: larger or rapid flows induce more erosion.

Erosion is usually heaviest during the early part of irrigation, especially when irrigating on slopes. The dry surface soil, sometimes loosened by cultivation, is easily removed by flowing water. After the first irrigation, the soil is moist and settles down, so erosion is reduced. Newly irrigated areas are more sensitive to erosion, especially in their early stages.

There are two main types of erosion caused by water: sheet erosion and gully erosion. They are often combined.

Sheet erosion: Sheet erosion is the even removal of a very thin layer or "sheet" of topsoil from sloping land. It occurs over large areas of land and causes most of the soil losses. The signs of sheet erosion are:

- only a thin layer of topsoil; or the subsoil is partly exposed; sometimes even parent rock is exposed;
- quite large amounts of coarse sand, gravel and pebbles in the arable layer, the finer material has been removed;
- exposure of the roots;
- deposit of eroded material at the foot of the slope.

Gully erosion: Gully erosion is defined as the removal of soil by a concentrated water flow, large enough to form channels or gullies. These gullies carry water during heavy rain or irrigation and gradually become wider and deeper.

	
Sheet erosion	**Gully erosion**

Figure 2-21 Sheet and Gully erosion

2.3 IRRIGATION REQUIREMENT (BROUWER & HEIBLOEM, 1986)

One of the main problems of the irrigator is to know the amount of water that has to be applied to the field to meet the water needs of the crops; in other words, the irrigation requirement needs to be determined. Too much water means a waste of water which is so precious in arid countries. It can also lead to a rise of the groundwater table and an undesirable saturation of the rootzone and soil erosion. Too little water during the growing season causes the plants to wilt. Long periods during which the water supply is insufficient, result in loss of yield or even crop failure. In addition, the irrigation requirement needs to be determined for proper design of the irrigation system and for establishment of the irrigation schedules.

2.3.1 RAINFALL

All crops need water to grow and produce yields. The most important source of water for crop growth is rainfall. When rainfall is insufficient, irrigation water may be supplied to guarantee a good harvest.

Rainfall: The primary source of water for agricultural production, for large parts of the world, is rainfall or precipitation. Rainfall is characterized by *its amount, intensity and distribution in time*.

Amount of rainfall: Imagine an open square container, 1 m wide, 1 m long and 0.5 m high (see Fig. 2-20a). This container is placed horizontally on an open area in a field (see Fig. 2-22b).

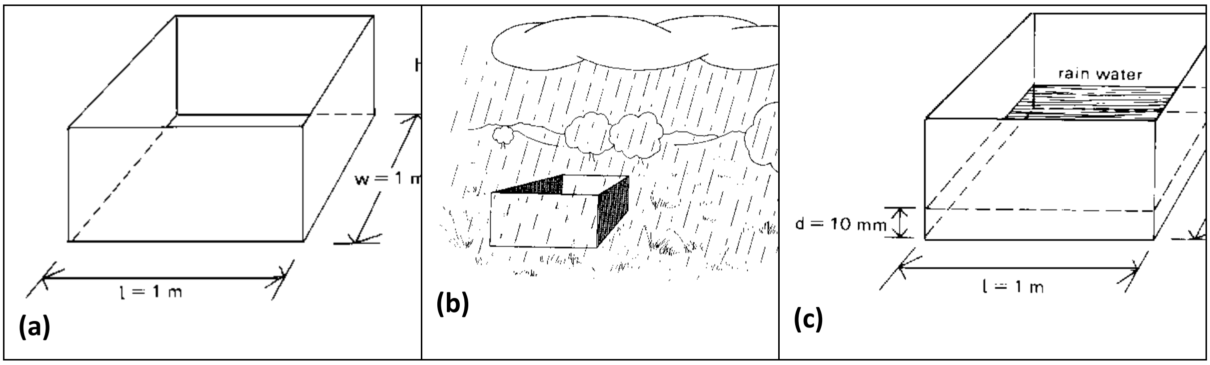


Figure 2-22 An open container to collect rainwater

During a rain shower, the container collects the water. Suppose that when the rain stops, the depth of water contained in the pan is 10 mm (see Fig. 2.22c). The volume of water collected in the pan is:

$$V (m^3) = l (m) \times w (m) \times d (m) = 1 m \times 1 m \times 0.010 m = 0.01 m^3 \text{ or } 10 \text{ litres}$$

In terms of volume, with a rainfall of 10 mm, every square metre of the field receives 0.01 m3, or 10 litres, of rain water. With a rainfall of 1 mm, every square metre receives 1 litre of rain water.

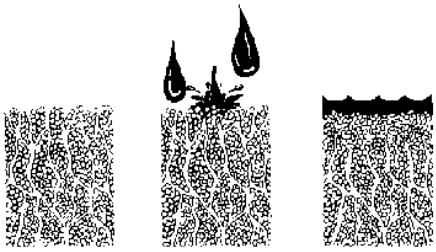
A rainfall of 1 mm supplies 0.001 m3, or 1 litre of water to each square metre of the field. Thus 1 ha receives 10 000 litres.

Rainfall intensity:

$$\text{Rainfall intensity (mm/hour)} = \frac{\text{total amount of rain water (mm)}}{\text{duration of the rainfall (hours)}}$$

The rainfall intensity is the depth of water (in mm) received during a shower divided by the duration of the shower (in hours). It is expressed in millimetres of water depth per hour (mm/hour). For example, a rain shower lasts 3.5 hours and supplies 35 mm of water. The intensity of this shower is 35 mm / 3,5 hours = 10 mm/hour.

Suppose the same amount of water (35 mm) is supplied in one hour only, thus by a shower of higher intensity: 35 mm / 1,0 hour = 35 mm/hour.



Although the same amount of water (35 mm) has been supplied by both showers, the high intensity shower is less profitable to the crops. The high intensity rainfall usually has big drops that fall with more force on the soil surface. In fine textured soil especially, the soil aggregates break down rapidly into fine particles that seal the soil surface (see Fig. 2.23). The infiltration is then reduced, and surface runoff increases

Figure 2-23 Sealing of the soil surface by raindrops

The low intensity rainfall has finer drops. The soil surface is not sealed, the rainwater infiltrates more easily and surface runoff is limited.

Rainfall Distribution

Suppose that during one month, a certain area receives a total amount of rain water of 100 mm (100 mm/month). For crop growth, the distribution of the various showers during this month is important.

Rainwater falls during two showers of 50 mm each, one at the beginning of the month and the other one at the end of the month.	In between these two showers, the crop undergoes a long dry period and may even wilt. Irrigation during this period is then required.
Rainwater is supplied regularly by little showers, evenly distributed over the month.	Adequate soil moisture is continuously maintained, and irrigation might not be required.

Not only the rainfall distribution within a month is important. It is also important to look into the rainfall distribution over the years.

Suppose that in a certain area the average rainfall in May is 150 mm and that this amount is just sufficient to satisfy the water need of the crops during this month. You may however find that, in this area, the rainfall in an exceptionally dry year is only 75 mm, while in a wet year the rainfall is 225 mm. In a dry year it would thus be necessary to irrigate the crops in May, while in an average year or a wet year, irrigation is not needed.

Effective Rainfall

When rain water ((1) in Fig. 2-24) falls on the soil surface, some of it infiltrates into the soil (2), some stagnates on the surface (3), while some flows over the surface as runoff (4).

When the rainfall stops, some of the water stagnating on the surface (3) evaporates to the atmosphere (5), while the rest slowly infiltrates into the soil (6).

From all the water that infiltrates into the soil ((2) and (6)), some percolates below the rootzone (7), while the rest remains stored in the rootzone (8).

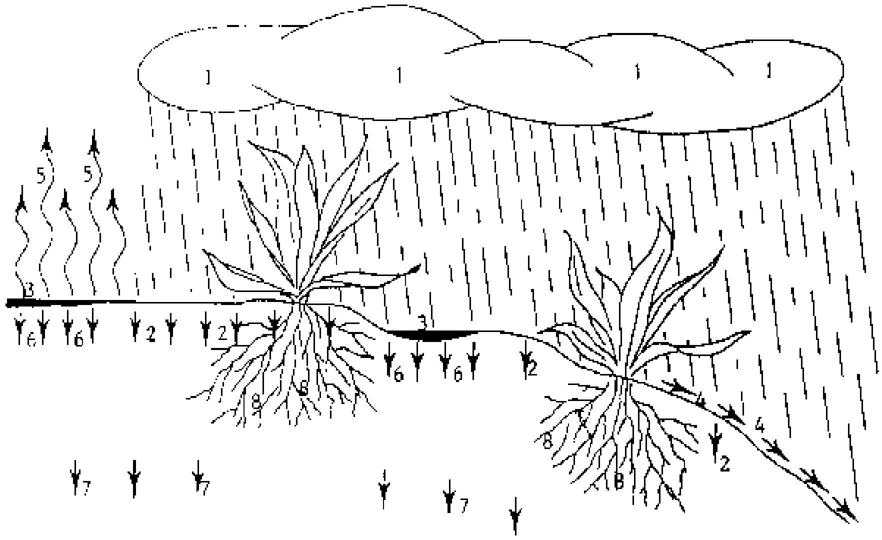


Figure 2-24 Effective rainfall (8) = (1) - (4) - (5) - (7)

In other words, the effective rainfall (8) is the total rainfall (1) minus runoff (4) minus evaporation (5) and minus deep percolation (7); only the water retained in the root zone (8) can be used by the plants, and represents what is called the effective part of the rainwater. The term effective rainfall is used to define this fraction of the total amount of rainwater useful for meeting the water need of the crops.

Factors influencing effective rainfall

Many factors influence the amount of the effective rainfall. There are factors which the farmer cannot influence (e.g. the climate and the soil texture) and those which the farmer can influence (e.g. the soil structure).

a. Climate: The climate determines the amount, intensity and distribution of rainfall which have direct influence on the effective rainfall

b. Soil texture: In coarse textured soil, water infiltrates quickly but a large part of it percolates below the rootzone. In fine textured soil, the water infiltrates slowly, but much more water is kept in the rootzonel.

c. Soil structure: The condition of the soil structure greatly influences the infiltration rate and therefore the effective rainfall. A favourable soil structure can be obtained by cultural practices (e.g. ploughing, mulching, ridging, etc.).

d. Depth of the rootzone: Soil water stored in deep layers can be used by the plants only when roots penetrate to that depth. The depth of root penetration is primarily dependent on the type of crop, but also on the type of soil. The thicker the rootzone, the more water available to the plant. (see Fig. 2.25).

e. Topography: On steep sloping areas, because of high runoff, the water has less time to infiltrate than in rather flat areas (see Fig. 2.26). The effective rainfall is thus lower in sloping areas.

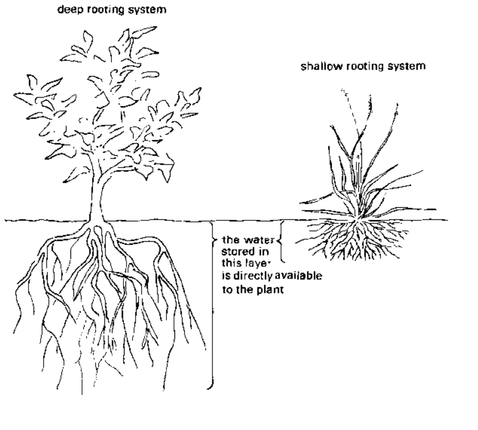


Figure 2-25 Effective rainfall and depth of the rootzone

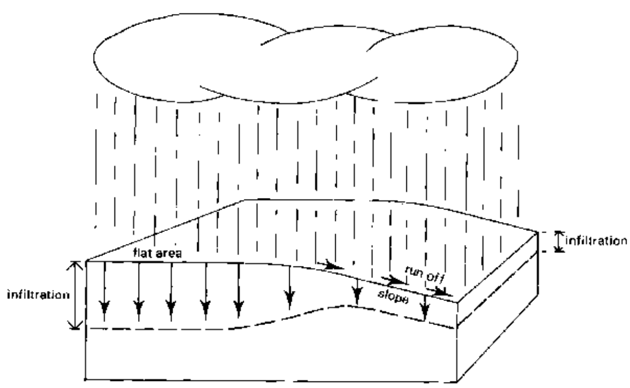


Figure 2-26 Effective rainfall and topography

f. Initial soil moisture content: Chapter 2.2.3, explained that for a given soil, the infiltration rate is higher when the soil is dry than when it is moist. This means that for a rain shower occurring shortly after a previous shower or irrigation, the infiltration rate is lower and the surface runoff higher (see Fig. 2.27).

g. Irrigation methods: There are different methods of irrigation, and each method has a specific influence on the effective rainfall.

In basin irrigation there is no surface runoff. All the rainwater is trapped in the basin and has time to infiltrate (Fig. 2.28a).

In inclined border and furrow irrigation, the runoff is relatively large. At the lower end of the field the runoff water is collected in a field drain and carried away (Fig.2.28b). Thus the effective rainfall under border or furrow irrigation is lower than under basin irrigation.

In contour furrow irrigation there is very little or no slope in the direction of the furrow and thus runoff is limited; the runoff over the cross slope is also limited as the water is caught by the ridges. This results in a relatively high effective rainfall, compared to inclined border or furrow irrigation (see Fig. 2.29)

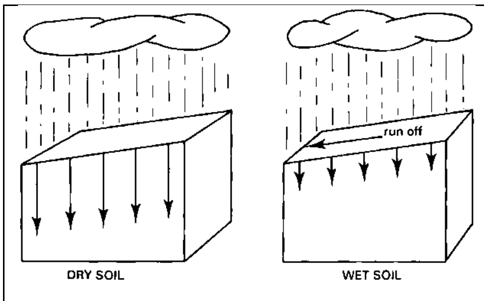


Figure 2-27 Effective rainfall and initial soil moisture content

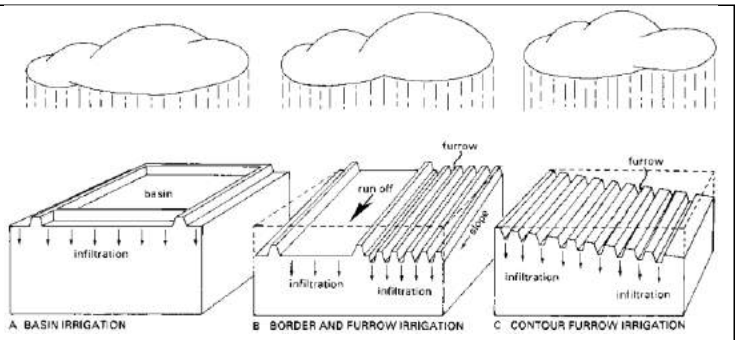


Figure 2-28 Effective rainfall and irrigation methods

2.3.2 EVAPOTRANSPIRATION

1.1.1.1 EVAPORATION

Imagine the same open container as used for the collection of rain water, but this time with a depth of 10 mm of water in it; leave the container in the field for 24 hours. Make sure that it does not rain during those 24 hours (Fig. 2.29).

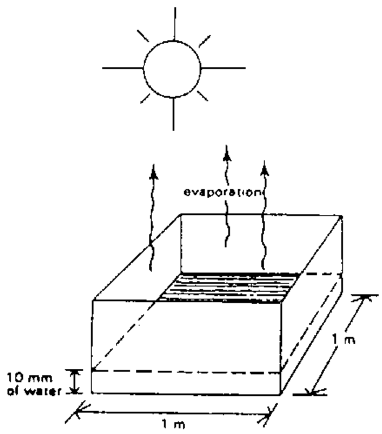


Figure 2-29 Container with 10 mm of water

At the end of the 24 hours, part of the water originally in the container has evaporated. If only 6 mm of water depth remains in the container, then the evaporation during this day was 10 - 6 = 4 mm.

Some water from the soil in the field surrounding the container has also evaporated during the day. But it would be wrong to assume that the evaporation from the container is the same as the evaporation from the soil.

In fact, evaporation from the soil surface is at most equal but usually considerably less than evaporation from an open water surface.

1.1.1.2 TRANSPIRATION

The plant roots suck or extract water from the soil to live and grow. The main part of this water does not remain in the plant, but escapes to the atmosphere as vapour through the plant's leaves and stems. This process is called transpiration of the plant. Transpiration happens mainly during the day time. The amount of water used by the plants for transpiration can, like evaporation, be expressed in millimetres of water per day (mm/day). Note that a day has 24 hours.

1.1.1.3 EVAPOTRANSPIRATION

The evapotranspiration of a crop is the total amount of soil water used for transpiration by the plants and evaporation from the surrounding soil surface. In other words, the crop evapotranspiration represents the amount of water utilized by the crop and its environment. The evapotranspiration is commonly expressed in millimetres of water used per day (mm/day) or per week (mm/week) or per month (mm/month).

Table 2-7 Factors influencing crop evapotranspiration

Factor	**Effect on crop evapotranspiration**	
Climate	**High**	**Low**
Climate	Hot	Cool
	Dry	Wet
	Windy	No wind
	No clouds	Cloudy
Crop	Mid / late	Initial or ripening
	Dense plant spacing	Wide plant spacing
Soil moisture	Moist	Dry

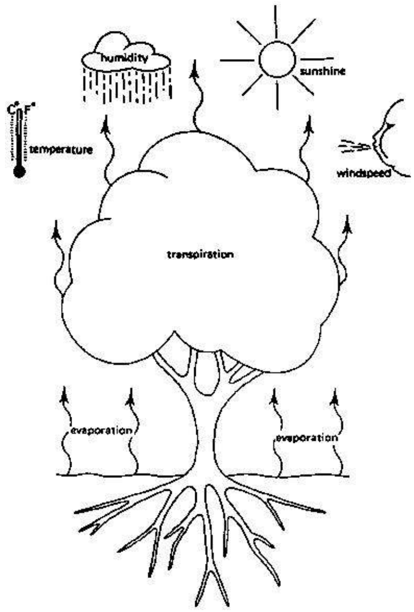


Figure 2-30 Effect of climatic factors on evapotranspiration

2.3.3 *IRRIGATION WATER NEEDS*

All field crops need soil, water, air and light (sunshine) to grow. The soil gives stability to the plants; it also stores the water and nutrients which the plants can take up through their roots. The sunlight provides the energy which is necessary for plant growth (Fig. 2.31). The air allows the plants to "breath".

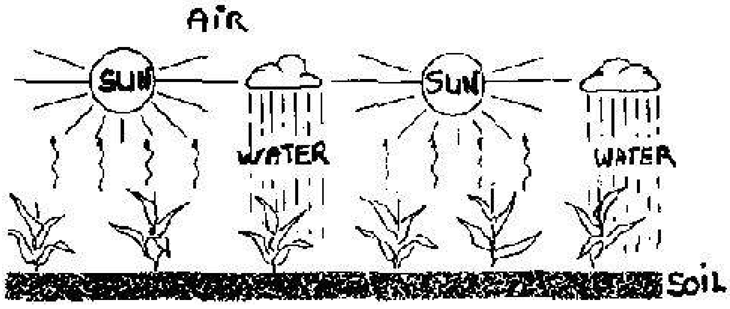


Figure 2-31 Plants need soil, water, air and sunlight

Without water crops cannot grow. Too much water is not good for many crops either. Apart from paddy rice, there are only very few crops which like to grow "with their feet in the water". The most well-known source of water for plant growth is rain water. There are two important questions which come to mind: What to do if there is too much rain water? What to do if there is too little rain water?

If there is too much rain, the soil will be full of water and there will not be enough air. Excess water must be removed. The removal of excess water - either from the ground surface or from the root zone - is called **drainage**.

If there is too little rain, water must be supplied from other sources; **irrigation** is needed (Fig. 2.32). The amount of irrigation water which is needed depends not only on the amount of water already available from rainfall, but also on the total amount of water needed by the various crops.

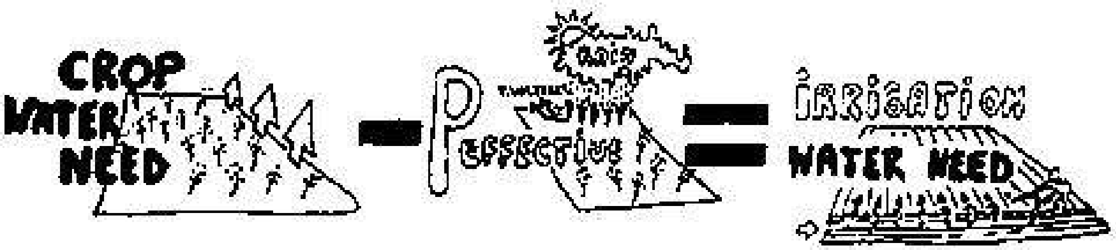


Figure 2-32 Irrigation water need

In many countries it is already well known what the crop water needs, and irrigation water needs are of the most commonly grown crops. Such data can usually be obtained from the Extension Service, the Irrigation Department or Ministry of Agriculture. It is then not necessary to determine the crop and irrigation water need. However, there may be situations where it is not possible to obtain these data and it would thus be necessary to determine them on the spot.

Suppose the water need of a certain crop in a very hot, dry climate is 10 mm/day. This means that each day the crop needs a water layer of 10 mm over the whole area on which the crop is grown (Fig. 5). It does not mean that this 10 mm has to indeed be supplied by rain or irrigation every day.

It is, of course, still possible to supply, for example, 50 mm of irrigation water every 5 days. The irrigation water will then be stored in the root zone and gradually be used by the plants: every day 10 mm.

The crop water need mainly depends, as the evapotranspiration, on the climate, the growth stage and crop type.

The influence of the crop type on the crop water need is important in two ways:

1. The crop type has an influence on the *daily water needs* of a fully-grown crop; i.e. the peak daily water needs: a fully developed maize crop will need more water per day than a fully developed crop of onions.

2. The crop type has an influence on *the duration of the total growing season* of the crop. There are short duration crops, e.g. peas, with a duration of the total growing season of 90-100 days and longer duration crops, e.g. melons, with a duration of the total growing season of 120-160 days. And then there are, of course, the perennial crops that are in the field for many years, such as fruit trees.

The influence of the growth stage: When the plants are very small the evaporation will be more important than the transpiration. When the plants are fully grown the transpiration is more important than the evaporation.

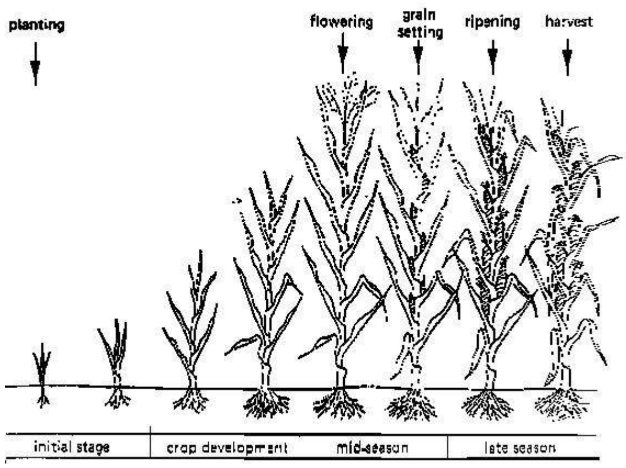


Figure 2-33 Growth stages of a crop

At planting and during the initial stage, the evaporation is more important than the transpiration and the evapotranspiration or crop water need during the initial stage is estimated at 50 percent of the crop water need during the mid - season stage, when the crop is fully developed.

During the so-called crop development stage the crop water need gradually Increases from 50 percent of the maximum crop water need to the maximum crop water need. The maximum crop water need is reached at the end of the crop development stage which is the beginning of the mid-season stage.

With respect to the late season stage, which is the period during which the crop ripens and is harvested, a distinction can be made between two groups of crops:

Fresh harvested crops: such as lettuce, cabbage, etc. With these crops the crop water need remains the same during the late season stage as it was during the mid-season stage. The crops are harvested fresh and thus need water up to the last moment.

Dry harvested crops: such as cotton, maize (for grain production), sunflower, etc. During the late season stage these crops are allowed to dry out and sometimes even die. Thus, their water needs during the late season stage are minimal. If the crop is indeed allowed to die, the water needs are only some 25 percent of the crop water need during the mid-season or peak period. Of course, no irrigation is given to these crops during the late season stage.

2.3.4 CROP WATER NEED (ET CROP)

1.1.1.4 REFERENCE CROP EVAPOTRANSPIRATION (ETO)

The highest crop water needs are thus found in areas which are hot, dry, windy and sunny. The lowest values are found when it is cool, humid and cloudy with little or no wind.

From the above it is clear that one crop grown in different climatic zones will have different water needs. For example, a certain maize variety grown in a cool climate will need less water per day than the same maize variety grown in a hotter climate.

It is therefore useful to take a certain standard crop or reference crop and determine how much water this crop needs per day in the various climatic regions. As a standard crop or reference crop grass has been chosen.

Table 2.8 indicates the average daily water needs of this reference grass crop. The daily water needs of the grass depend on the climatic zone (rainfall regime) and daily temperatures.

For example, the standard grass crop grown in a semi-arid climate with a mean temperature of 20°C needs approximately 6.5 mm of water per day. The same grass crop grown in a sub-humid climate with a mean temperature of 30°C needs some 7.5 mm of water per day.

Climatic zone	Mean daily temperature		
	low	medium	high
	(less than 15°C)	(15-25°C)	(more than 25°C)
Desert/arid	4-6	7-8	9-10
Semi arid	4-5	6-7	8-9
Sub-humid	3-4	5-6	7-8
Humid	1-2	3-4	5-6

Table 2-8 Average daily water need of standard grass during irrigation season

This daily water need of the standard grass crop is also called **"reference crop evapotranspiration"**. In the following paragraphs it will be discussed how do determine the water needs of the crops grown on, for an example, an irrigation scheme relate to the water need of the standard grass".

The crop water need (ET crop) is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of water needed by the various crops to grow optimally.

The crop water need always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favourable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment.

The influence of the climate on crop water needs is given by the reference crop evapotranspiration (ETo). The ETo is usually expressed in millimetres per unit of time, e.g. mm/day, mm/month, or mm/season. Grass has been taken as the reference crop.

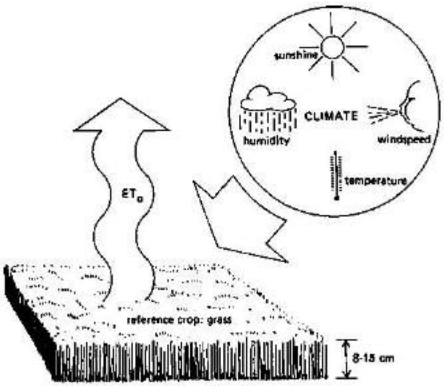


Figure 2-34 Reference crop evapotranspiration

Definition of ETo: Eto is the rate of evapotranspiration from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water (see Fig. 2.34).

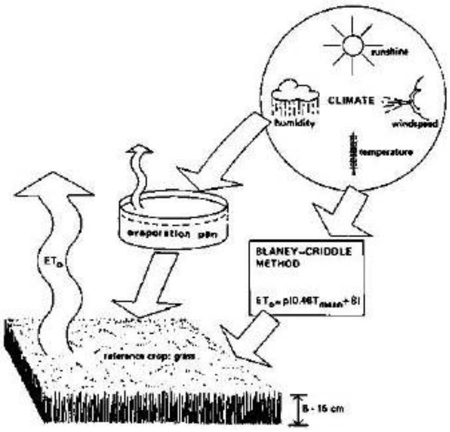
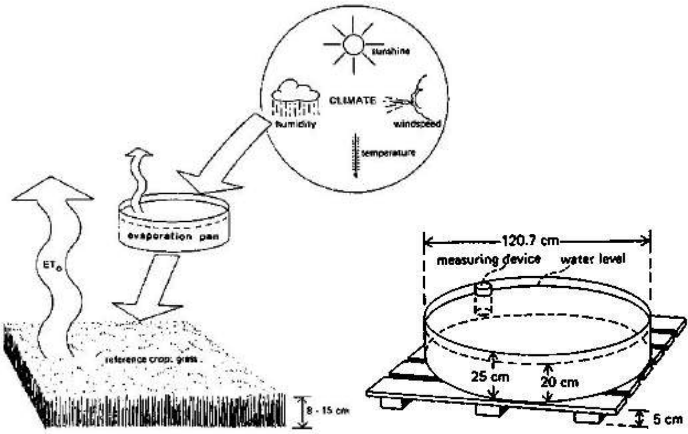


Figure 2-35 Methods to determine reference crop evapotranspiration

Methods to determine the ETo

There are several methods to determine the ETo (see Fig. 2.35). They are either:

- experimental, using an evaporation pan, or
- theoretical, using measured climatic data, e.g. the Blaney-Criddle method or the modified Penman method



Pan evaporation method

Pan Evaporation Method

Evaporation pans provide a measurement of the combined effect of temperature, humidity, windspeed and sunshine on the reference crop evapotranspiration ETo.

The principle of the evaporation pan is the following:

1. the pan is installed in the field
2. the pan is filled with a known quantity of water (the surface area of the pan is known and the water depth is measured)
3. the water is allowed to evaporate during a certain period of time (usually 24 hours). For example, each morning at 7 o'clock a measurement is taken. The rainfall, if any, is measured simultaneously
4. after 24 hours, the remaining quantity of water (i.e. water depth) is measured
5. the amount of evaporation per time unit (the difference between the two measured water depths) is calculated; this is the pan evaporation: E pan (in mm/24 hours)
6. the E pan is multiplied by a pan coefficient, K pan, to obtain the ETo.

Formula: ETo = K pan x E pan

Determination of K pan: when using the evaporation pan to estimate the ETo, in fact, a comparison is made between the evaporation from the water surface in the pan and the evapotranspiration of the standard grass. Of course the water in the pan and the grass do not react in exactly the same way to the climate. Therefore a special coefficient is used (K pan) to relate one to the other.The pan coefficient, K pan, depends on:

- the type of pan used (for the Class A evaporation pan, the K pan varies between 0.35 and 0.85. Average K pan = 0.70., and for the Sunken Colorado pan, the K pan varies between 0.45 and 1.10. Average K pan = 0.80).
- the pan environment: if the pan is placed in a fallow or cropped area
- the climate: the humidity and windspeed

Blaney-Criddle Method

If no measured data on pan evaporation are available locally, a theoretical method (e.g. the Blaney-Criddle method) to calculate the reference crop evapotranspiration ETo has to be used. There are a large number of theoretical methods to determine the ETo. Many of them have been determined and tested locally. If such local formulae are available they should be used. If such local formulae are not available one of the general theoretical methods has to be used.

Here only the Blaney-Criddle method is given. The Blaney-Criddle method is simple, using measured data on temperature only. It should be noted, however, that this method is not very accurate; it provides a rough estimate or "order of magnitude" only. Especially under "extreme" climatic conditions the Blaney-Criddle method is inaccurate: in windy, dry, sunny areas, the ETo is underestimated (up to some 60 percent), while in calm, humid, clouded areas, the ETo is overestimated (up to some 40 percent).

The Blaney-Criddle formula: ETo = p (0.46 T mean + 8)

Where:

ETo = Reference crop evapotranspiration (mm/day) as an average for a period of 1 month
T mean = mean daily temperature (°C)
p = mean daily percentage of annual daytime hours

The Blaney-Criddle method always refers to mean monthly values, both for the temperature and the ETo. If, for example, it is found that T mean in March is 28°C, it means that during the whole month of March the mean daily temperature is considered to be 28°C.

The use of the Blaney-Criddle formula

Step 1: Determination of the mean daily temperature: T mean

If in a local meteorological station, the daily minimum and maximum temperatures are measured, the mean daily temperature is calculated as follows:

$$T\ max = \frac{\text{sum of all T max values during the r}}{\text{number of days of the month}} \quad T\ min = \frac{\text{sum of all T min values during the n}}{\text{number of days of the month}} \quad T\ mean = \frac{T\ max + T\ mi}{2}$$

Step 2: Determination of the mean daily percentage of annual daytime hours: p

To determine the value of p. Table 2.9 is used. To be able to determine the p value it is essential to know the approximate latitude of the area: the number of degrees north or south of the equator (see Fig. 12).

Table 2-9 Mean daily percentage (p) of annual daytime hours for different latitudes

Latitude	North	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	South	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
60°		.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
55		.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
50		.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
45		.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
40		.22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35		.23	.25	.27	.29	.31	.32	.32	.30	.28	.25	.23	.22
30		.24	.25	.27	.29	.31	.32	.31	.30	.28	.26	.24	.23
25		.24	.26	.27	.29	.30	.31	.31	.29	.28	.26	.25	.24
20		.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25
15		.26	.26	.27	.28	.29	.29	.29	.28	.28	.27	.26	.25
10		.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5		.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0		.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

Suppose the p value for the month March has to be determined for an area with a latitude of 45° South. From the table 4 it can be seen that the p value during March = 0.28.

<u>Step 3: Calculate ETo</u>, using the formula: ETo = p (0.46 T mean + 8)

<u>Example of calculation of ETo with Blaney Criddle Method:</u>

Location: EXAMPLE... Date: 1/8/86...

Latitude: ....13..... °North/South

Month	T min (°C)	T max (°C)	T mean (°C)	p Table 4	ETo mm/day
Jan	15.5	32.1	23.8	0.26	4.9
Feb	18.8	35.8	27.3	0.26	5.3
Mar	21.8	38.0	29.9	0.27	5.9
Apr	24.5	38.7	31.6	0.28	6.3
May	26.0	39.0	32.5	0.29	6.7
Jun	25.0	36.6	30.8	0.29	6.4
Jul	22.7	32.6	27.6	0.29	6.0
Aug	22.0	30.8	26.4	0.28	5.6
Sep	23.0	31.8	27.4	0.28	5.8
Oct	21.3	34.8	28.0	0.27	5.6
Nov	18.7	35.0	26.8	0.26	5.3
Dec	16.6	32.0	24.3	0.25	4.8

The modified Penman method

The most commonly used theoretical method is the modified Penman method which is described in detail in FAO Irrigation and Drainage Paper 24. This method, however, is rather complicated. It is better to use FAO CROPWAT software to use this method. The use of FAO CROPWAT software will be explained in the next training event.

1.1.1.5 Crop Water Need (ET crop)

The influence of the climate on crop water needs, as it has been discussed, is given by the reference crop evapotranspiration ETo; the reference crop used for this purpose is grass.

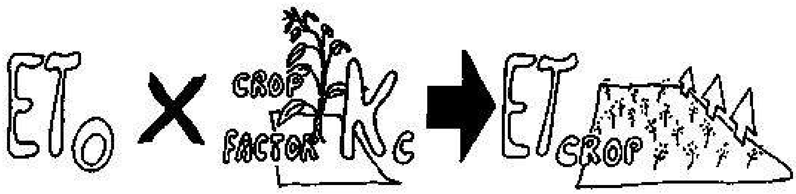
The influence of the crop type and growth stage on crop water needs is discussed in this section. In other words, this section discusses the relationship between the reference grass crop and the crop actually grown in the field.

The relationship between the reference grass crop and the crop actually grown is given by the crop factor, Kc, as shown in the following formula:

$$ET\ crop = Kc \times Eto$$

ET crop = crop evapotranspiration or crop water need (mm/day)
Kc = crop factor
ETo = reference evapotranspiration (mm/day)

Both ET crop and ETo are expressed in the same unit: usually in mm/day (as an average for a period of one month) or in mm/month.



The crop factor, Kc, mainly depends on:

- the type of crop
- the growth stage of the crop
- the climate

Kc and the type of crop :Fully developed maize, with its large leaf area will be able to transpire, and thus use, more water than the reference grass crop: Kc, maize is higher than 1. Cucumber, also fully developed, will use less water than the reference grass crop: Kc, cucumber is less than 1.

Kc and the growth stage of the crop: A certain crop will use more water once it is fully developed, compared to a crop which has just recently been planted.

Kc and the climate: the climate influences the duration of the total growing period and the various growth stages. In a cool climate a certain crop will grow slower than in a warm climate. Thus, to determine the crop factor Kc, it is necessary, for each crop, to know the total length of the growing season and the lengths of the various growth stages.

The determination of the Kc values for the various growth stages of the crops involves several steps:

Step 1 - Determination of the total growing period of each crop
Step 2 - Determination of the various growth stages of each crop
Step 3 - Determination of the Kc values for each crop for each of the growth stages

Determination of the Total Growing Period

The total growing period (in days) is the period from sowing or transplanting to the last day of the harvest. It is mainly dependent on:

- the type of crop and the variety
- the climate
- the planting date

As the growing period heavily depends on local circumstances (e.g. local crop varieties) it is always best to obtain these data locally. Only if no data are available locally should Table 2.10 can be used.

Table 2-10 Indicative values of the total growing period

Crop	Total growing period (days)	Crop	Total growing period (days)
Alfalfa	100-365	Millet	105-140
Banana	300-365	Onion green	70-95
Barley/Oats/Wheat	120-150	Onion dry	150-210
Bean green	75-90	Peanut/Groundnut	130-140
Bean dry	95-110	Pea	90-100
Cabbage	120-140	Pepper	120-210
Carrot	100-150	Potato	105-145
Citrus	240-365	Radish	35-45
Cotton	180-195	Rice	90-150
Cucumber	105-130	Sorghum	120-130
Eggplant	130-140	Soybean	135-150
Flax	150-220	Spinach	60-100
Grain/small	150-165	Squash	95-120
Lentil	150-170	Sugarbeet	160-230
Lettuce	75-140	Sugarcane	270-365
Maize sweet	80-110	Sunflower	125-130
Maize grain	125-180	Tobacco	130-160
Melon	120-160	Tomato	135-180

As can be seen from Table 6 there is a large variation of values not only between crops but also within one crop type. In general, it can be assumed that the growing period for a certain crop is longer when the climate is cool and shorter when the climate is warm.

Determination of the Growth Stages

Once the total growing period is known, the duration (in days) of the various growth stages has to be determined. The total growing period is divided into 4 growth stages

1. The initial stage: this is the period from sowing or transplanting until the crop covers about 10% of the ground.
2. The crop development stage: this period starts at the end of the initial stage and lasts until the full ground cover has been reached (ground cover 70-80%); it does not necessarily mean that the crop is at its maximum height.
3. The mid - season stage: this period starts at the end of the crop development stage and lasts until maturity; it includes flowering and grain-setting.
4. The late season stage: this period starts at the end of the mid-season stage and lasts until the last day of the harvest; it includes ripening.

Table 2.10 shows the duration of the various growth stages for some of the major field crops. For each crop the "minimum" and "maximum" duration of total growing period (see table 2.11) have been taken and sub-divided in the various growth stages.

Table 2-11 Growth stages for some of the major field crops

		STAGES			
	Total	**Initial**	**Crop Develop**	**Mid season**	**Late season**
Barley/Oats/Wheat	120	15	25	50	30
	150	15	30	65	40
Bean/green	75	15	25	25	10
	90	20	30	30	10
Bean/dry	95	15	25	35	20
	110	20	30	40	20
Cabbage	120	20	25	60	15
	140	25	30	65	20
Carrot	100	20	30	30	20
	150	25	35	70	20
Cotton/Flax	180	30	50	55	45
	195	30	50	65	50
Cucumber	105	20	30	40	15
	130	25	35	50	20
Eggplant	130	30	40	40	20
	140	30	40	45	25
Grain/small	150	20	30	60	40
	165	25	35	65	40
Lentil	150	20	30	60	40
	170	25	35	70	40
Lettuce	75	20	30	15	10
	140	35	50	45	10
Maize, sweet	80	20	25	25	10
	110	20	30	50	10
Maize, grain	125	20	35	40	30
	180	30	50	60	40
Melon	120	25	35	40	20
	160	30	45	65	20
Millet	105	15	25	40	25
	140	20	30	55	35
Onion/green	70	25	30	10	5
	95	25	40	20	10
Onion/dry	150	15	25	70	40
	210	20	35	110	45
Peanut/Groundnut	130	25	35	45	25
	140	30	40	45	25
Pea	90	15	25	35	15
	100	20	30	35	15
Pepper	120	25	35	40	20
	210	30	40	110	30
Potato	105	25	30	30	20
	145	30	35	50	30
Radish	35	5	10	15	5
	40	10	10	15	5
Sorghum	120	20	30	40	30
	130	20	35	45	30
Soybean	135	20	30	60	25
	150	20	30	70	30
Spinach	60	20	20	15	5
	100	20	30	40	10
Squash	95	20	30	30	15
	120	25	35	35	25
Sugarbeet	160	25	35	60	40
	230	45	65	80	40
Sunflower	125	20	35	45	25
	130	25	35	45	25
Tomato	135	30	40	40	25
	180	35	45	70	30

With respect to Table 2.11 the following should be noted:

1. The table always refers to "sown" crops. When the crop is transplanted, the length of the initial stage should be reduced. For example:
   Tomatoes: growing period 180 days from sowing
   Direct sowing: initial stage 35 days
   Transplanted: (estimated) initial stage 15 days
   The growing period from transplant is thus (180 - 20) = 160 days
2. When a crop is harvested "green" or "fresh" the late season stage is short. Compare, for example, green beans with dry beans. The duration of the late season stage is 10 and 20 days respectively.
3. If a crop is planted in the winter or is growing in the cool season the total growing period is long. The same is the case with the individual lengths of growing stages. The difference will be most pronounced for the stage during which the temperature is the lowest.

It should be kept in mind that the influence of variations in the total growing period on the crop water need is very important. Less important is the choice of the various lengths of growth stages. In other words: it is important to obtain (preferably locally) an accurate estimate of the total growing period. The duration of the four growth stages can be estimated with the help of Table 2.10.

Determination of Crop Factors

Per crop, four crop factors have to be determined: one crop factor for each of the four growth stages. Table 2.12 indicates per crop the Kc values for each of the four growth stages.

Table 2-12 Values of the crop factor (kc) for various crops and growth stages

	STAGES			
Crop	**Initial**	**Crop Deve**	**Mid season**	**Late season**
Barley/Oats/Wheat	0.35	0.75	1.15	0.45
Bean, green	0.35	0.70	1.10	0.90
Bean, dry	0.35	0.70	1.10	0.30
Cabbage/Carrot	0.45	0.75	1.05	0.90
Cotton/Flax	0.45	0.75	1.15	0.75
Cucumber/Squash	0.45	0.70	0.90	0.75
Eggplant/Tomato	0.45	0.75	1.15	0.80
Grain/small	0.35	0.75	1.10	0.65
Lentil/Pulses	0.45	0.75	1.10	0.50
Lettuce/Spinach	0.45	0.60	1.00	0.90
Maize, sweet	0.40	0.80	1.15	1.00
Maize, grain	0.40	0.80	1.15	0.70
Melon	0.45	0.75	1.00	0.75
Millet	0.35	0.70	1.10	0.65
Onion, green	0.50	0.70	1.00	1.00
Onion, dry	0.50	0.75	1.05	0.85
Peanut/Groundnut	0.45	0.75	1.05	0.70
Pea, fresh	0.45	0.80	1.15	1.05
Pepper, fresh	0.35	0.70	1.05	0.90
Potato	0.45	0.75	1.15	0.85
Radish	0.45	0.60	0.90	0.90
Sorghum	0.35	0.75	1.10	0.65
Soybean	0.35	0.75	1.10	0.60
Sugarbeet	0.45	0.80	1.15	0.80
Sunflower	0.35	0.75	1.15	0.55
Tobacco	0.35	0.75	1.10	0.90

The table above shows average Kc values for the various crops and growth stages. In fact, the Kc is also dependent on the climate and, in particular, on the relative humidity and the windspeed. The values indicated above should be reduced by 0.05 if the relative humidity is high (RH > 80%) and the windspeed is low (u < 2 m/sec), e.g. Kc = 1.15 becomes Kc = 1.10. The values should be increased by 0.05 if the relative humidity is low (RH < 50%) and the windspeed is high (u > 5 m/sec), e.g. Kc = 1.05 becomes Kc = 1.10.

DATA SHEET 4 Determination of crop factors

Location : Example   Date : 1/8/86

Humidity : crop 1: high/(medium)/low   Wind speed : crop 1: high/(medium)/low

crop 2: high/(medium)/low   crop 2: high/(medium)/low

Crop 1 : Maize (grain)   Planting Date : 1 July

Duration of total growing period : 130 days
(from local information or Table 6)

Estimated duration of growth stages (Table 7) :

		Dates
Initial stage	: 20 days	1 July - 20 July
Crop dev. stage	: 35 days	21 July - 25 August
Mid-season stage	: 45 days	26 August - 10 October
Late season stage	: 30 days	11 October - 10 November

Crop factors, Kc (Table 8) :

Initial stage	: 0.40*
Crop dev. stage	: 0.80*
Mid-season stage	: 1.15*
Late season stage	: 0.70*

Crop 2 : Cotton   Planting Date : 1 June

Duration of total growing period : 165 days
(from local information or Table 6)

Estimated duration of growth stages (Table 7) :

		Dates
Initial stage	: 25 days	1 June - 25 June
Crop dev. stage	: 45 days	26 June - 10 August
Mid-season stage	: 50 days	11 August - 30 September
Late season stage	: 45 days	1 October - 15 November

Crop factors, Kc (Table 8) :

Initial stage	: 0.45
Crop dev. stage	: 0.75
Mid-season stage	: 1.15
Late season stage	: 0.35

* In case of low RH & high windspeed the Kc values would resp. be: 0.45, 0.85, 1.20 & 0.75. In case of high RH & low windspeed the Kc values would resp. be: 0.35, 0.75, 1.10 & 0.65.

CALCULATION OF THE CROP WATER NEED (ET crop)

ET crop is calculated using the formula: ET crop = ETo × Kc. Although the formula is easy to apply, there are still some practical problems to be overcome, which can best be explained using an example.

Determine the crop water need of tomatoes, given:

Month	Jan	Feb	March	April	May	June	July
Eto	4,0	5,0	5,8	6,3	6,8	7,1	6,5

Humidity medium (60%)
Wind speed Medium (3 m/s)
Duration of growing period (from sowing): 150 days
Planting date: 1 February (direct sowing)

CALCULATION

Step 1: Estimate the duration of the various growth stages, using Table 2.10.

Crop	Total	Initial	Crop Develop	Mid season	Late season
Tomato	150	35	40	50	25

Step 2: Indicate on table, as per example below, the ETo values and the duration of the growth stages.

Note: When calculating the crop water needs, all months are assumed to have 30 days. For the calculation of the reference crop evapotranspiration (ETo, section 3.1), the actual number of days of each month is used e.g., January 31 days, February 28 or 29 days, etc.

Crop: Tomatoes.... Planting Date: 1 Februery..

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		INITIAL ST.	CROP dev. St	mid season st		late S.st						

Planting date	1 Feb
Initial stage, 35 days	1 Feb-5 Mar
Crop development stage, 40 days	6 Mar-15 Apr
Mid-season stage, 50 days	16 Apr-5 Jun
Late season stage, 25 days	6 Jun-30 Jun
Last day of the harvest	30 Jun

Step 3: Estimate the Kc factor for each of the 4 growth stages, using Table 8 and bearing in mind that the humidity and windspeed are medium

Kc, initial stage =	0.45
Kc, crop development stage =	0.75
Kc, mid season stage =	1.15
Kc, late season stage =	0.8

The Kc values are inserted in the Table:

Crop: Tomatoes Planting Date: 1 February

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		initial st.	crop dev. st	mid season st		late s.st						
Kc per gr. st.		0.45	0.75	1.15		0.8						

It can be seen from the table above that the months and growth stages do not correspond. As a consequence the ETo and the Kc values do not correspond. Yet the ET crop (= ETo × Kc) has to be determined on a monthly basis. It is thus necessary to determine the Kc on a monthly basis, which is done as follows:

February: Kc Feb = 0.45

March: 5 days: Kc = 0.45

25 days: Kc = 0.75

$$Kc\,March: Kc = \frac{5}{30} \times 0.45 + \frac{25}{30} \times 0.75 = 0.07 + 0.62 = 0.69 = approx\,0.70$$

NOTE: The Kc values are rounded to the nearest 0.05 or 0.00.

April: 15 days: Kc = 0.75

15 days: Kc = 1.15

$$Kc, April: Kc = \frac{15}{30} \times 0.75 + \frac{15}{30} \times 1.15 = 0.38 + 0.58 = 0.96 = approx.\,0.95$$

May: Kc, May = 1.15

June: 5 days: Kc = 1.15

: 25 days: Kc = 0.80

$$Kc, June: = \frac{5}{30} \times 1.15 + \frac{25}{30} \times 0.80 = 0.19 + 0.67 = 0.86 = approx.\,0.85$$

In summary:

Crop: Tomatoes Planting Date: 1 Februery

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		initial st.	crop dev. st	mid season st		late s.st						
Kc per gr. st.		0.45	0.75	1.15		0.8						
Kc per month		0.45	0.70	0.95	1.15	0.85						

Step 4: Calculate, on a monthly basis, the crop water need, using the formula:

ET crop = ETo × Kc (mm/day)

February: ET crop = 5.0 × 0.45 = 2.3 mm/day
March: ET crop = 5.8 × 0.70 = 4.1 mm/day
April: ET crop = 6.3 × 0.95 = 6.0 mm/day
May: ET crop = 6.8 × 1.15 = 7.8 mm/day
June: ET crop = 7.1 × 0.85 = 6.0 mm/day

Crop: Tomatoes Planting Date: 1 February

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		initial st.	crop dev st.	mid season st		late s.st						
Kc per gr. st.		0.45	0.75	1.15		0.8						
Kc per month		0.45	0.70	0.95	1.15	0.85						
ET crop (mm/day)		2.3	4.1	6.0	7.8	6.0						

Step 5: Calculate the monthly and seasonal crop water needs.

Note: all months are assumed to have 30 days.

February ET crop = 30 × 2.3 = 69 mm/month

March ET crop = 30 × 4.1 = 123 mm/month

April ET crop = 30 × 6.0 = 180 mm/month

May ET crop = 30 × 7.8 = 234 mm/month

June ET crop = 30 × 6.0 = 180 mm/month

The crop water need for the whole growing season of tomatoes is 786 mm. In summary:

Crop: Tomatoes Planting Date: 1 February

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		initial st.	crop dev st.	mid season st		late s.st						
Kc per gr. st.		0.45	0.75	1.15		0.8						
Kc per month		0.45	0.70	0.95	1.15	0.85						
ET crop (mm/day)		2.3	4.1	6.0	7.8	6.0						
ET crop (mm/m)		69	123	180	234	180						

Special Cases

In the previous sections it has been indicated how the crop water need is calculated for a variety of field crops: ET crop = Kc × ETo. However there are some crops that do not directly fit this model: their crop factor Kc is determined in a different way. The special cases include:

- **alfalfa, pasture and clover**: Alfalfa, pasture and clover are regularly cut during the year. Just after cutting they are in the "initial stage", while just before the next cutting, they are in the "late season stage". To determine the crop water need it is best to use an average value of the crop factor Kc
- **bananas:** The establishment of a new banana plantation takes approximately 6 months from planting to full ground cover. One year after planting, the first harvest takes place, after which the shoots that have produced are removed. Meanwhile young shoots have fully developed and take over the production
- **citrus:** The crop factor Kc for clean cultivated citrus is 0.70 year-round. This value is applicable for large mature trees, covering some 70% of the ground surface. If there is no weed control, a Kc value of 0.90 year-round should be used.
- **Rice:** special table with values of Kc for rice.
- **sugarcane:** Crop coefficients for sugarcane vary widely depending on climate and sugarcane variety. It is best to use locally available data.
- **cacao, coffee, tea, olives:** year-round Kc values are recommended
- **grapes:** Kc values provided can be used for the months starting with the first leaf appearance

Indicative Values of Crop Water Needs

Table 2.13 gives indicative values of the crop water needs for the total growing period of various important field crops.

Table 2-13 Indicative values of crop water needs and sensitivity to drought

Crop	Crop water need	Sensitivity to drought
	(mm/total growing period)	
Alfalfa	800-1600	low-medium
Banana	1200-2200	high
Barley/Oats/Wheat	450-650	low-medium
Bean	300-500	medium-high
Cabbage	350-500	medium-high
Citrus	900-1200	low-medium
Cotton	700-1300	low
Maize	500-800	medium-high
Melon	400-600	medium-high
Onion	350-550	medium-high
Peanut	500-700	low-medium

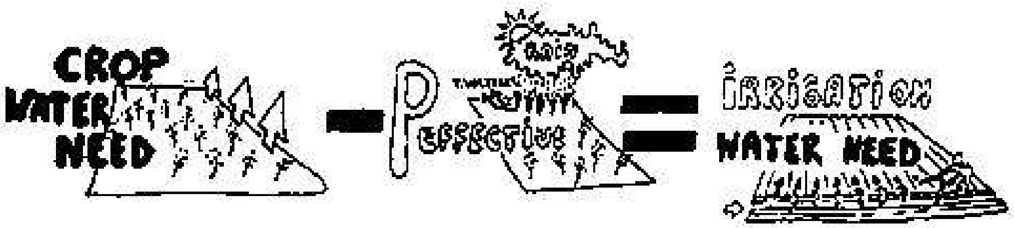
Crop	Crop water need	Sensitivity to drought
	(mm/total growing period)	
Pea	350-500	medium-high
Pepper	600-900	medium-high
Potato	500-700	high
Rice (paddy)	450-700	high
Sorghum/Millet	450-650	low
Soybean	450-700	low-medium
Sugarbeet	550-750	low-medium
Sugarcane	1500-2500	high
Sunflower	600-1000	low-medium

The values indicated in the table provide a rough estimate and should only be used if the crop water needs cannot be calculated more accurately due to lack of data. The table provide for each crop a minimum and a maximum value for the crop water need. As the crop water needs depend heavily on the duration of the total growing period, the maximum value should be used in the case of a long

total growing period (see also Table 6) and the minimum value should be used when the total growing period is short. An average value is to be used with a medium total growing period.
In addition, Table 14 gives an indication of the sensitivity of the various crops to water shortages or drought. If the sensitivity is high it means that the crop cannot withstand water shortages very well and such shortages should be avoided. If the sensitivity is low it means that the crop is relatively drought resistant and can withstand water shortages fairly well.

EFFECTIVE RAINFALL

The irrigation water need of a certain crop is the difference between the crop water need and that part of the rainfall which can be used by the crop (the effective rainfall).



For each of the crops grown on an irrigation scheme the crop water need is determined, usually on a monthly basis; the crop water need is expressed in mm water layer per time unit, in this case mm/month.

The effective precipitation is estimated on a monthly basis, using measured rainfall data and Table 6 (or local information, if available).

For all crops and for each month of the growing season, the irrigation water need is calculated by subtracting the effective rainfall from the crop water need.

DETERMINATION OF THE EFFECTIVE RAINFALL

The FAO / AGLW formula is provided to estimate the fraction of the total rainfall which is used effectively. There are other formulae that can also be applied in areas with a maximum slope of 4-5%:

$$Pe = 0.8\,(P - 25) \text{ if } P_{monthly} > 75 \text{ mm/month}$$

$$Pe = 0.6\,(P - 10) \text{ if } P_{monthly} < 75 \text{ mm/month}$$

with P = rainfall or precipitation (mm/month)

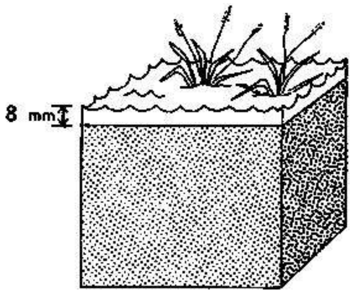
Pe = effective rainfall or effective precipitation (mm/month)

NOTE: Pe is always equal to or larger than zero; never negative

2.4 IRRIGATION SCHEDULE (BROUWER ET ALL, 1989)

In this Chapter the determination of the irrigation schedule is explained. The irrigation schedule indicates how much irrigation water has to be given to the crop, and how often or when this water is given.

How much and how often water has to be given depends on the irrigation water need of the crop. How to determine the irrigation water need has been discussed in Volume 3. The irrigation water need is defined as the crop water need minus the effective rainfall. It is usually expressed in mm/day or mm/month. When, for example, the irrigation water need of a certain crop, grown in a hot, dry climate is 8 mm/day (see Figure 1), this means that each day the crop needs a water layer of 8 mm over the whole area on which the crop is grown. This water has to be supplied by means of irrigation.



An irrigation water need of 8 mm/day, however, does not mean that this 8 mm has to be supplied by irrigation every day. In theory, water could be given daily. But, as this would be very time and labour consuming, it is preferable to have a longer irrigation interval. It is, for example, possible to supply 24 mm every 3 days or 40 mm every 5 days. The irrigation water will then be stored in the root zone and gradually be used by the plants: every day 8 mm. The irrigation interval has to be chosen in such a way that the crop will not suffer from water shortage.

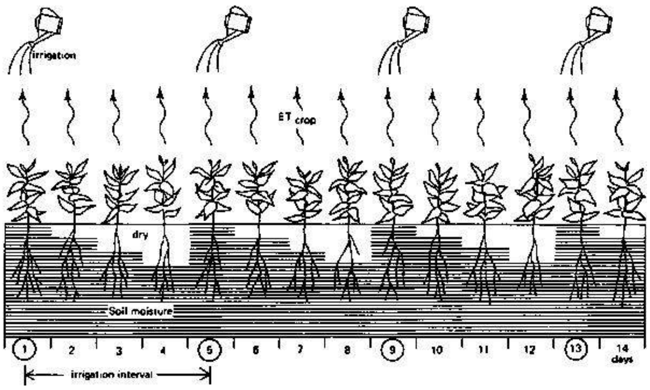
IN SUMMARY:

How often to irrigate? Often enough to prevent the plants suffering from drought.

How much to irrigate? As much as the plants have used since the previous irrigation.

If irrigation water is applied regularly, the plants do not suffer from water shortage

The amount of irrigation water which can be given during one irrigation application is however limited.

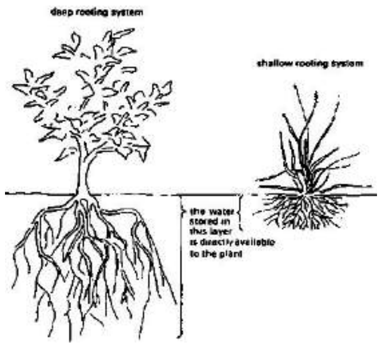


The **maximum amount which can be given** has to be determined and may be influenced by:

- the soil type
- the root depth
- the irrigation method.

The soil type influences the maximum amount of water which can be stored in the soil per metre depth (Available Water Content). Sand can store only a little water or, in other words, sand has a low available water content. On sandy soils it will thus be necessary to irrigate frequently with a small amount of water. Clay has a high available water content. Thus, on clayey soils larger amounts can be given, less frequently. The infiltration rate also should be considered as a limitant to the amount of water that can be delivered per unit of time.

The root depth of a crop also influences the maximum amount of water which can be stored in the root zone (see Figure 2.5). If the root system of a crop is shallow, little water can be stored in the root zone and frequent - but small - irrigation applications are needed. With deep rooting crops more water can be taken up and more water can be applied, less frequently. Young plants have shallow roots compared to fully grown plants. Thus, just after planting or sowing, the crop needs smaller and more frequent water applications than when it is fully developed.



Plants with deep roots take up water over a greater depth than shallow rooting plants.

2.4.1 DETERMINATION OF THE IRRIGATION SCHEDULE (NOT FOR RICE)

The accurate determination of an irrigation schedule is a time-consuming and complicated process. The introduction of computer programs, however, has made it easier and it is possible to schedule the irrigation water supply exactly according to the water needs of the crops. Ideally, at the beginning of the growing season, the amount of water given per irrigation application, also called the irrigation depth, is small and given frequently. This is due to the low evapotranspiration of the young plants and their shallow root depth. During the mid season, the irrigation depth should be larger and given less frequently due to high evapotranspiration and maximum root depth. Thus, ideally, the irrigation depth and/or the irrigation interval (or frequency) vary with the crop development).

When sprinkler and drip irrigation methods are used, it may be possible and practical to vary both the irrigation depth and interval during the growing season. With these methods it is just a matter of turning on the tap longer/shorter or less/more frequently.

When surface irrigation methods are used, however, it is not very practical to vary the irrigation depth and frequency too much. With, in particular, surface irrigation, variations in irrigation depth are only possible within limits. It is also very confusing for the farmers to change the schedule all the time.
Therefore, it is often sufficient to estimate or roughly calculate the irrigation schedule and to fix the most suitable depth and interval; in other words, to keep the irrigation depth and the interval constant over the growing season. In this Chapter, three simple methods to determine the irrigation schedule are briefly described: plant observation method, estimation method and simple calculation method. In the last section of this chapter, some remarks are made about taking into account actual rainfall in irrigation scheduling.

- **The plant observation method** is the method which is normally used by farmers in the field to estimate "when" to irrigate. The method is based on observing changes in plant characteristics, such as changes in colour of the plants, curling of the leaves and ultimately plant wilting.
- **Soil moisture measurements method**: Another method used to determine the irrigation schedule involves soil moisture measurements in the field. When the soil moisture content has dropped to a certain critical level, irrigation water is applied. Instruments to measure the soil moisture include gypsum blocks, tensiometers and neutron probes.
- In the **estimation method** section, a table is provided with irrigation schedules for the major field crops grown under various climatic conditions.
- The **simple calculation method** is based on the estimated depth (in mm) of the irrigation application, and the calculated irrigation water need of the crop during the growing season.

PLANT OBSERVATION METHOD

The plant observation method determines "when" the plants have to be irrigated and is based on observing changes in the plant characteristics, such as changes in colour of the plants, curling of the leaves and ultimately plant wilting. The changes can often only be detected by looking at the crop as a whole rather than at the individual plants. When the crop comes under water stress the appearance changes from vigorous growth (many young leaves which are light green) to slow or even no growth (fewer young leaves, darker in colour, and sometimes greyish and dull).

Some crops (such as cassava) react to water stress by changing their leaf orientation: with adequate water available, the leaves are perpendicular to the sun (thus allowing optimal transpiration and production). However, when little water is available, the leaves turn away from the sun (thus reducing the transpiration and production).
To use the plant observation method successfully, experience is required as well as a good knowledge of the local circumstances. A farmer will, for example, know where the sandy spots in the field are, which is where the plants will first show stress characteristics: the colour changes and wilting are more pronounced on the sandy spots.

An example of the plant observation method is given in Figure 2.37. The sugarcane in Figure 9 suffers heavily from water shortage: the leaves are stiff (bent towards the centre) and curled. Figure 10 shows the same sugarcane when enough moisture is available: the lower leaves are hanging, thus exposing them fully to the sunlight and allowing maximum evapotranspiration (water use of the plants) and crop production.

To use the plant observation method successfully, experience is required as well as a good knowledge of the local circumstances. A farmer will, for example, know where the sandy spots in the field are, which is where the plants will first show stress characteristics: the colour changes and wilting are more pronounced on the sandy spots.

An example of the plant observation method is given in Figure 2.37.

	
heavy water shortage: the leaves are stiff (bent towards the centre) and curled	The same sugarcane when enough moisture is available: the lower leaves are hanging, thus exposing them fully to the sunlight and allowing maximum evapotranspiration (water use of the plants) and crop production

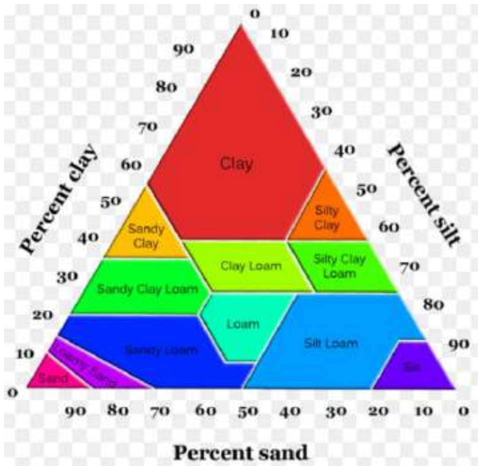
Figure 2-36 Sugarcane suffering from water shortage

The disadvantage of the plant observation method is that by the time the symptoms are evident, the irrigation water has already been withheld too long for most crops and yield losses are already inevitable. It is important to note that it is not advisable to wait for the symptoms. Especially in the early stages of crop growth (the initial and crop development stages), irrigation water has to be applied before the symptoms are evident.

Another indicator of water availability is the leaf temperature. If the leaves are cool during the hot part of the day (Figure 11), the plants do not suffer from water stress. However, if the leaves are warm, irrigation is needed. Special devices (infra-red thermometers) have been developed to measure the leaf temperature in relation to the air temperature. However, they must be calibrated for specific conditions before being used to determine the irrigation schedule.

SOIL MOISTURE MEASUREMENTS METHOD

It is necessary to take soil samples to a laboratory in order to know the soil characteristics:



Soil texture: sand, loam and clay, and sub groups. This is also needed to know if tensiometers can be used. Clayey and silty soils still retain over 50 percent of their plant-available water at suctions greater than 80 cb, which is outside the working range of a tensiometer. In that case electrical resistant blocks can be used.

Field Capacity (FC): The soil-water content after the force of gravity has drained or removed all the water it can, usually 1 to 3 days after rainfall. Field capacity is considered the upper limit of plant-available water. When measured under field conditions it is equivalent to a soil-water tension of approximately 0.1 bar.

Permanent Wilting Point (PWP): he soil-water content at which healthy plants can no longer extract water from the soil fast enough to recover from wilting. The permanent wilting point is considered the lower limit of plant-available water. At this point, the soil-water tension is considered to be 15 bars.

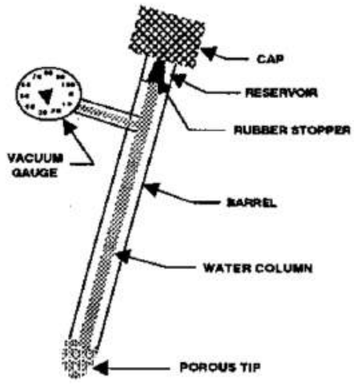
Plant-Available Water (PAW): The amount of water held in the soil that is available to plants; the difference between field capacity and the permanent wilting point.

Steady-state infiltration rate (= saturated hydraulic conductivity K) : the rate at which water can be infiltrated to the soil in saturated conditions.

A variety of methods and devices can be used to measure soil-water. These include the feel method, gravitational method, tensiometer, electrical resistance blocks, neutron probe, Phene cells, and time domain reflectometer. Most of these methods and devices do not measure soil-water directly; they measure a property of the soil that can be related to soil-water status and are therefore called indirect methods. These methods differ in their ease of use, reliability, cost, and amount of labor required.

Feel Method: as its name implies, the feel method involves estimating soil-water by feeling the soil. This method is easy to use, and many growers schedule irrigation in this way. However, this method is entirely subjective; the results depend on the experience of the individual making the measurement. The reliability of this method is usually poor unless the operator is very experienced. The feel method is not generally recommended and should be used only as a last resort.

Gravimetric Method: with the gravimetric method, soil moisture is determined by taking a soil sample from the desired soil depth, weighing it, drying it in an oven (for 24 hours at 104 degrees Celsius), and then reweighing the dry sample to determine how much water was lost. This method is simple and reliable. Unfortunately, it is not practical for scheduling irrigation because it takes a full day to dry the sample. In a sandy soil that dries quickly, irrigation may be needed before the results of the measurement are obtained. The gravimetric method is most useful for calibrating other devices for measuring soil-water.



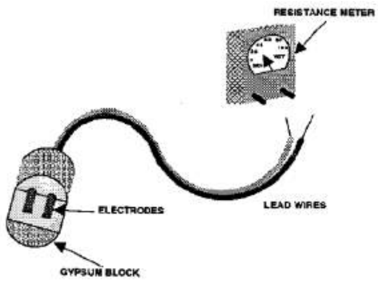
Tensiometer

A tensiometer is a sealed, airtight, water-filled tube (barrel) with a porous tip on one end and a vacuum gauge on the other. A tensiometer measures soil water suction (negative pressure), which is usually expressed as tension. This suction is equivalent to the force or energy that a plant must exert to extract water from the soil. The instrument must be installed properly so that the porous tip is in good contact with the soil, ensuring that the soil-water suction is in equilibrium with the water suction in the tip. The suction force in the porous tip is transmitted through the water column inside the tube and displayed as a tension reading on the vacuum gauge. Soil-water tension is commonly expressed in units of bars or centibars (cb).

The suction at the tip is transmitted to the vacuum gauge because of the cohesive forces between adjacent water molecules. As the suction approaches approximately 0.8 bar (80 cb), the cohesive forces are exceeded by the suction and the water molecules separate. When this occurs, air can enter the tube through the porous tip and the tensiometer no longer functions correctly. This condition is referred to as *breaking tension*. Tensiometers work in the range from 0 to 0.8 bar. The suction scale on the vacuum gauge of most commercial tensiometers reads from 0 to 100 cb.

Tensiometers are quite affordable for scheduling irrigation. The cost ranges from $25 to $50 each, depending on length of the barrel, which ranges from 6 to 72 inches. The only other equipment required is a small hand-held vacuum pump used for calibration and periodic servicing. Tensiometers are easy to use but may give faulty readings if they are not serviced regularly.

Tensiometers are best suited for use in soils that release most of their plant-available water (PAW) at soil-water suctions between 0 and 80 cb. Soil textures in this category are those that consist of sand, loamy sand, sandy loam, and the coarser-textured range of loam and sandy clay loam. Many clayey and silty soils still retain over 50 percent of their plant-available water at suctions greater than 80 cb, which is outside the working range of a tensiometer. Tensiometers are not recommended for clayey and silty soils unless irrigation is to be scheduled before 50 percent depletion of the plant-available water, which is the normal practice for some vegetable crops such as tomatoes.



Electrical Resistance Blocks

Electrical resistance blocks consist of two electrodes enclosed in a block of porous material. The block is often made of gypsum, although fiberglass or nylon is sometimes used. Electrical resistance blocks are often referred to as *gypsum blocks* and sometimes just *moisture blocks*. The electrodes are connected to insulated lead wires that extend upward to the soil surface.

Resistance blocks work on the principle that water conducts electricity. When properly installed, the water suction of the porous block is in equilibrium with the soil-water suction of the surrounding soil. As the soil moisture changes, the water content of the porous block also changes. The electrical resistance between the two electrodes increases as the water content of the porous block decreases. The block's resistance can be related to the water content of the soil by a calibration curve.

To make a soil-water reading, the lead wires are connected to a resistance meter containing a voltage source. The meter normally reads from 0 to 100 or 0 to 200. High readings on the scale (corresponding to low electrical resistance) indicate high levels of soil-water, whereas low meter readings indicate low levels. Electrical resistance blocks are fairly inexpensive, costing from $3 to $12 each. A portable, hand-held resistance meter costs $250 to $300 and can be connected to read many different blocks in turn.

Because of the pore size of the material used in most electrical resistance blocks, particularly those made of gypsum, the water content and thus the electrical resistance of the block does not change dramatically at suctions less than 0.5 bar (50 cb). Therefore, resistance blocks are best suited for use in fine-textured soils such as silts and clays that retain at least 50 percent of their plant-available water at suctions greater than 0.5 bar. Electrical resistance blocks are not reliable for determining when to irrigate sandy soils where over 50 percent of the plant-available water is usually depleted at suctions less than 0.5 bar

Neutron Probe

The neutron probe uses a radiation source to measure soil-water. An empty tube (access tube) with a 2-inch inside diameter must be installed vertically in the soil at each field location where the soil-water is to be measured. When properly calibrated, the neutron probe is easy to use, reliable, and accurate, but it is expensive ($3,000 to $4,000 per unit). One of its advantages is that soil-water measurements can be made easily at different depths in the soil profile. Because of its cost, a neutron probe is not as practical as other methods for on-farm use. It may be a viable option for operators with large acreages of irrigated land. At present, it is used by some irrigation consultants to perform the technical tasks required to schedule irrigation.

Phene Cell

The Phene cell works on the principle that a soil conducts heat in relation to its water content. By measuring the heat conducted from a heat source and calibrating the conductance versus water content for a specific soil, the Phene cell can be used reliably to determine soil-water content. Because the Phene cell is placed at the desired soil depth, a separate cell is needed for each depth at each location to be monitored. A cell costs about $100, and the instrument required to measure the heat dissipation costs an additional $1,000. For irrigating small acreages, the total cost of using the Phene cell is less than that of the neutron probe. For large acreages, the neutron probe may be more cost effective.

Time Domain Reflectometer

The time domain reflectometer (TDR) is a new device developed to measure soil-water content. Two parallel rods or stiff wires are inserted into the soil to the depth at which the average water content is desired. The rods are connected to an instrument that sends an electromagnetic pulse (or wave) of energy along the rods. The rate at which the wave of energy is conducted into the soil and reflected back to the soil surface is directly related to the average water content of the soil. One instrument can be used for hundreds of pairs of rods. This device, just becoming commercially available, is easy to use and reliable.
The TDR is expensive, costing nearly $8,000 per unit. Although it is probably too expensive for scheduling irrigation (except for very large operations), it may become the preferred device in the future.

ESTIMATION METHOD

The estimation method to determine the irrigation schedule can only be used when no significant rainfall occurs during the growing season. In case there is significant rainfall, the method should be adjusted computing the soil water balance.

Shallow and/or sandy soil	In a sandy soil or a shallow soil (with a hard pan or impermeable layer close to the soil surface), little water can be stored; irrigation will thus have to take place frequently but little water is given per application.
Loamy soil	In a loamy soil more water can be stored than in a sandy or shallow soil. Irrigation water is applied less frequently and more water is given per application.
Clayey soil	In a clayey soil even more water can be stored than in a medium soil. Irrigation water is applied even less frequently and again more water is given per application.
Climate 1	Represents a situation where the reference crop evapotranspiration ETo = 4 - 5 mm/day.
Climate 2	Represents an ETo = 6 - 7 mm/day.
Climate 3	Represents an ETo = 8 - 9 mm/day.

In this section, a table is provided to estimate the irrigation schedule for the major field crops during the period of peak water demand; the schedules are given for three different soil types and three different climates. The table is based on calculated crop water needs and an estimated root depth for each of the crops under consideration. The table assumes that with the irrigation method used the maximum possible net application depth is 70 mm.

With respect to soil types, a distinction has been made between sand, loam, and clay, which have, respectively, a low, a medium and a high available water content.

With respect to climate, a distinction is made between three different climates.

Climatic zone	Mean daily temperature		
	low (less than 15°C)	medium (15-25°C)	high (more than 25°C)
Desert/arid	4 - 6	7 - 8	9 - 10
Semi-arid	4 - 5 (3)	6 - 7	8 - 9
Sub-humid	3 - 4 (2)	5 - 6	7 - 8
Humid	1 - 2 (1)	3 - 4	5 - 6

Table 2-14 Estimated irrigation schedules for the major field crops during peak water use periods

	Shallow and/or sandy soil				loamy soil				clayey soil			
	Interval (days)			Net irr. depth (mm)	Interval (days)			Net irr. depth (mm)	Interval (days)			Net irr. depth (mm)
Climate	1	2	3		1	2	3		1	2	3	
Alfalfa	9	6	5	40	13	9	7	60	16	11	8	70
Banana	5	3	2	25	7	5	4	40	10	7	5	55
Barley/Oats	8	6	4	40	11	8	6	55	14	10	7	70
Beans	6	4	3	30	8	6	4	40	10	7	5	50
Cacao	9	6	5	40	13	9	7	60	16	11	8	70
Carrot	6	4	3	25	7	5	4	35	11	8	6	50
Citrus	8	6	4	30	11	8	6	40	15	10	8	55
Coffee	9	6	5	40	13	9	7	60	16	11	8	70
Cotton	8	6	4	40	11	8	6	55	14	10	7	70
Cucumber	10	7	5	40	15	10	8	60	17	12	9	70
Crucifers*	3	2	2	15	4	3	2	20	7	5	4	30
Eggplant	6	4	3	30	8	6	4	40	10	7	5	50
Flax	8	6	4	40	11	8	6	55	14	10	7	70
Fruit trees	9	6	5	40	13	9	7	60	16	11	8	70
Grains, small	8	6	4	40	11	8	6	55	14	10	7	70
Grapes	11	8	6	40	15	11	8	55	19	13	10	70
Grass	9	6	5	40	13	9	7	60	16	11	8	70
Groundnuts	6	4	3	25	7	5	4	35	11	8	6	50
Lentils	6	4	3	30	8	6	4	40	10	7	5	50
Lettuce	3	2	2	15	4	3	2	20	7	5	4	30
Maize	8	6	4	40	11	8	6	55	14	10	7	70
Melons	9	6	5	40	13	9	7	60	16	11	8	70
Millet	8	6	4	40	11	8	6	55	14	10	7	70
Olives	11	8	6	40	15	11	8	55	19	13	10	70
Onions	3	2	2	15	4	3	2	20	7	5	4	30
Peas	6	4	3	30	8	6	4	40	10	7	5	50
Peppers	6	4	3	25	7	5	4	35	11	8	6	50
Potatoes	6	4	3	30	8	6	4	40	10	7	5	50
Radish	4	3	2	15	5	4	3	20	7	5	4	30
Safflower	8	6	4	40	11	8	6	55	14	10	7	70
Sorghum	8	6	4	40	11	8	6	55	14	10	7	70
Soybeans	8	6	4	40	11	8	6	55	14	10	7	70
Spinach	3	2	2	15	4	3	2	20	7	5	4	30
Squash	10	7	5	40	15	10	8	60	17	12	9	70
Sugarbeet	8	6	4	40	11	8	6	55	14	10	7	70
Sugarcane	7	5	4	40	10	7	5	55	13	9	7	70
Sunflower	8	6	4	40	11	8	6	55	14	10	7	70
Tea	9	6	5	40	13	9	7	60	16	11	8	70
Tobacco	6	4	3	30	8	6	4	40	10	7	5	50
Tomatoes	6	4	3	30	8	6	4	40	10	7	5	50
Wheat	8	6	4	40	11	8	6	55	14	10	7	70

* cabbage. cauliflower. etc.

It is important to note that the irrigation schedules given in Table 2.13 are based on the crop water needs in the peak period. It is further assumed that little or no rainfall occurs during the growing season.

EXAMPLES

1. *Estimate the irrigation schedule for groundnuts grown on a deep, clayey soil, in a hot and dry climate.*

Firstly, the climatic class has to be identified: climate 3 (ETo = 8-9 mm/day) represents a hot climate. Table 2.13 shows that for climate 3 the interval for groundnuts grown on a clayey soil is 6 days and the net irrigation depth is 50 mm. This means that every 6 days the groundnuts should receive a net irrigation application of 50 mm.

2. *Estimate the irrigation schedule for spinach grown on a loamy soil, in an area with an average temperature of 12º C during the growing season.*

The average temperature is low: climate 1 (ETo = 4-5 mm/day). Table 2.13 shows, with climate 1, for spinach, grown on a loamy soil an interval of 4 days and a net irrigation depth of 20 mm.

3. *Estimate the irrigation schedule of sorghum grown on a sandy soil, in an area with a temperature range of 15-25º C during the growing season.*

The average temperature is medium: climate 2 (ETo = 6-7 mm/day). Table 2.13 shows, with climate 2 for sorghum grown on a sandy soil, an irrigation interval of 6 days and a net irrigation depth of 40 mm.

Conversion of mm/day into litres/sec.ha

In the previous section it has been explained how to determine the irrigation depth of each irrigation application (in mm) and the interval between two irrigation applications (in days). From these figures it is, however, not easy to visualize what the flow of Irrigation water to a block of, for example, one hectare would be. Below a "rule of thumb" is given on how to convert an irrigation depth and interval into a continuous water flow.

mm/day	l/sec.ha	l/sec.ha	mm/day
2	0.23	0.2	1.7
3	0.35	0.3	2.6
4	0.46	0.4	3.5
5	0.58	0.5	4.3
6	0.69	0.6	5.2
7	0.81	0.7	6.0
8	0.93	0.8	6.9
9	1.04	0.9	7.8
10	1.16	1.0	8.6
12	1.39	1.2	10.4
14	1.62	1.4	12.1
16	1.85	1.6	13.8
18	2.08	1.8	15.6
20	2.31	2.0	17.3

8.64 mm/day = 1.0 litre/sec.hectare

In other words, an irrigation application of 8.64 mm per day corresponds to a continuous water flow of 1.0 litre per second per hectare. Further details of the conversion are given in the Scheme Irrigation Supply Training Manual. The table may assist with the conversion of mm/day into l/sec.ha.

EXAMPLE: Determine the continuous water flow when the gross irrigation depth is 64 mm and the interval is 8 days, for an area of 50 ha.

ANSWER: 64 mm every 8 days is 64/8 = 8 mm/day; 8 mm/day corresponds to 0.93 l/sec.ha. For an area of 50 ha the net continuous flow would be: 50 x 0.93 = 46.5 l/sec.

<u>Adjusting the irrigation schedule</u>

Adjustments for the non-peak periods

The irrigation schedule, which is obtained using Table 2.13, is valid for the peak period; in other words, for the mid-season stage of the crop.

During the early growth stages, when the plants are small, the crop water need is less than during the mid-season stage. Therefore, it may be possible to irrigate during the early stages of crop growth, with the same frequency as during the mid-season, but with smaller irrigation applications. It is risky to give the same irrigation application as during the mid-season, but less frequently; the young plants may suffer from water shortage as their roots are not able to take up water from the lower layers of the root zone.

Dry harvested crops or crops which are allowed to die before harvest (for example grain maize) need less water during the late season stage than during the mid-season stage (the peak period). During the late season stage, the roots of the crops are fully developed and therefore the same amount of water can be stored in the root zone as during the mid-season stage. It is thus possible to irrigate

during the late season stage less frequently but with the same irrigation depth as during the peak period.
In summary, in order to save water, it may be feasible to irrigate, during the early stages of the crop development, with smaller irrigation applications than during the peak period. During the late season stage it may be feasible to irrigate less frequently, in particular if the crop is harvested dry.

When adjusting the irrigation schedule for the non-peak periods, it should always be kept in mind that the irrigation schedules must be simple, in particular in surface irrigation schemes where many farmers are involved. It will often be necessary to discuss with the farmers, before implementing the irrigation schedule, the various alternatives and come to an agreement which best satisfies all parties involved.

Adjustment for climates with considerable rainfall during the growing season

The schedules obtained from Table 2.13 are based on the assumption that little or no rainfall occurs during the growing season. If the contribution from the rainfall is considerable during the growing season, the schedules need to be adjusted: usually by making the interval longer. It may also be possible to reduce the net irrigation depth. It is difficult to estimate to which values the interval and the irrigation depth should be adjusted. It is therefore suggested to use the simple calculation method, instead of the estimation method, in the case of significant rainfall during the growing season. Alternatively, it is possible to adjust the irrigation schedule to the actual rainfall as is described in the following paragraphs.

The estimation method to determine the irrigation schedule can only be used when no significant rainfall occurs during the growing season. The simple calculation method is based on the average irrigation water need of the crop which is the average crop water need minus the average effective rainfall. This method is used when designing and implementing an irrigation system with a "rotational" water supply: each field receives a certain amount of water on dates that are already fixed in advance. The rotational supply takes into account the average rainfall only and thus does not take into account the actual rainfall; this results in over-irrigation in wetter than average years and under-irrigation in drier than average years. In surface irrigation systems the rotational water supply method is most commonly used.

There are also water supply methods which allow the irrigation water to be distributed "on demand". The farmer can take water whenever necessary. In this case it is possible to take the actual rainfall into account and thus give the correct amount of irrigation water even in drier or wetter years. With this method of irrigation scheduling, however, the rainfall has to be measured on a daily basis (for details see Annex I). The net irrigation depth (d net) has to be determined in accordance with the irrigation method used. In addition, the crop water need has to be known on a daily basis for each month of the growing season. As soon as the accumulated water deficit exceeds the value of the net irrigation depth, irrigation water is supplied.

An example is given below for a situation with a crop water need (CWN) of 8 am/day and a net irrigation depth (d net) of 45 mm. As soon as the accumulated deficit exceeds the d net (= 45 mm), irrigation water is supplied. Note that the "deficit" can never be positive; maximum zero.

day	CWN (mm/day)	Rain (mm)	d net (mm)		Accumulated deficit (mm)
1	8	-	-		-8
2	8	-	-	(-8-8)	-16
3	8	-	-	(-16-8)	-24
4	8	-	-	(-24-8)	-32
5	8	-	-	(-32-8)	-40
6	8	-	45	(-40-8+45)	-3
7	8	-	-	(-3-8)	-11
8	8	12	-	(-11-8+12)	-7
9	8	24	-	(-7-8+24)	0
10	8	-	-	(0-8)	-8
11	8	-	-	(-8-8)	-16
12	8	-	-	(-16-8)	-24
13	8	4	-	(-24-8+4)	-28
14	8	-	-	(-28-8)	-36
15	8	-	-	(-36-8)	-44
16	8	-	45	(-44-8+45)	-7
17	8	-	-	(-7-8)	-15
etc.					

In the above example of adjusting the irrigation schedule to the actual_rainfall, irrigation takes place on day 6, on day 16, etc. with on each occasion a net irrigation depth of 45 mm.

Adjustment for local irrigation practices or irrigation method used

It may happen that the net irrigation depth obtained from Table 3 is not suitable for the local conditions. It may not be possible, for example, to infiltrate 70 mm with the irrigation method used locally. Tests may have shown that it is only possible to infiltrate some 50 mm per application. In such cases, both the net irrigation depth and the interval must be adjusted simultaneously. For example, suppose that maize is grown on a clayey soil in a moderately warm climate. According to Table 2.13, the Interval is 10 days and the net irrigation depth is 70 mm. This corresponds to an irrigation water need of 70/10 = 7 mm/day. Instead of giving 70 mm every 10 days, it is also possible to give:

- 63 mm every 9 days
- 56 mm every 8 days
- 49 mm every 7 days
- 42 mm every 6 days etc.

This means that in the above example an interval of seven days is chosen with a net application depth of 49 mm.

Adjustment for shallow soils
A soil which is shallow can only store a little water, even if the soil is clayey. For shallow soils - sandy, loamy or clayey - the column "shallow and/or sandy soil" of Table 2.13 should be used.

Adjustment for salt-affected soils
In the case of irrigating salt-affected soils, special attention needs to be given to the determination of the irrigation schedule. This topic can be consulted in FAO training manual (Drainage and Salinity).

SIMPLE CALCULATION METHOD
This section provides a simple calculation method for the irrigation schedule; **this schedule is based on the entire growing season**. Then it is explained how to adjust the schedule to the period of peak water demand.

The simple calculation method to determine the irrigation schedule is based on the estimated depth (in mm) of the irrigation applications, and the calculated irrigation water need of the crop over the growing season.

Unlike the previous estimation method, the simple calculation method is based on calculated irrigation water needs. Thus, the influence of the climate, i.e. temperature and rainfall, is more accurately taken into account. The result of the simple calculation method will therefore be more accurate than the result of the estimation method.

The simple calculation method to determine the irrigation schedule involves the following four steps that are explained in detail below:

- **Step 1**: Estimate the net and gross irrigation depth (d) in mm.
- **Step 2**: Calculate the irrigation water need (IN) in mm, over the total growing season.
- **Step 3**: Calculate the number of irrigation applications over the total growing season.
- **Step 4**: Calculate the irrigation interval in days.

Step 1: Estimate the net and gross irrigation depth (d) in mm

The net irrigation depth is best determined locally by checking how much water is given per irrigation application with the local irrigation method and practice. If no local data are easily available, Table 2.14 can be used to estimate the net irrigation depth (d net), in mm. As can be seen from the table, the net irrigation depth is assumed to depend only on the root depth of the crop and on the soil type. It must be noted that the d net values in the table are approximate values only. Also the root depth is best determined locally. If no data are available, Table 2.15 can be used which gives an indication of the root depth of the major field crops.

Table 2-15 Approximate net irrigation depths, in mm

	Shallow rooting crops	Medium rooting crops	Deep rooting crops
Shallow and/or sandy soil	15	30	40
Loamy soil	20	40	60
Clayey soil	30	50	70

Table 2-16 Approximate root depth of the major field crops

Shallow rooting crops (30-60 cm):	Crucifers (cabbage, cauliflower, etc.), celery, lettuce, onions, pineapple, potatoes, spinach, other vegetables except beets, carrots, cucumber.
Medium rooting crops (50-100 cm):	Bananas, beans, beets, carrots, clover, cacao, cucumber, groundnuts, palm trees, peas, pepper, sisal, soybeans, sugarbeet, sunflower, tobacco, tomatoes.
Deep rooting crops (90-150 cm):	Alfalfa, barley, citrus, cotton, dates, deciduous orchards, flax, grapes, maize, melons, oats, olives, safflower, sorghum, sugarcane, sweet potatoes, wheat.

Not all water which is applied to the field can indeed be used by the plants. Part of the water is lost through deep percolation and runoff. To reflect this water loss, the field application efficiency (ea) is used. For more detail on irrigation efficiencies, see Annex II. The gross irrigation depth (d gross), in mm, takes into account the water loss during the irrigation application and is determined using the following formula:

$$\text{d gross} = \frac{100 \bullet \text{d net}}{\text{ea}}$$

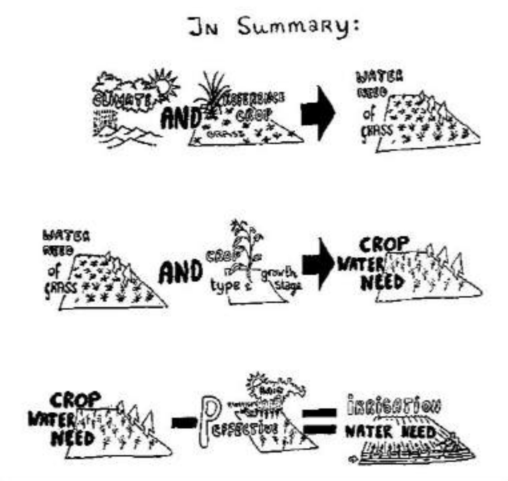
Where d gross = gross irrigation depth in mm
d net = net irrigation depth in mm
ea = field application efficiency in percent

If reliable local data are available on the field application efficiency, these should be used. If such data are not available, the following values for the field application efficiency can be used:

- for surface irrigation: ea = 60%
- for sprinkler irrigation: ea = 75%
- for drip irrigation: ea = 90%

If, for example, tomatoes are grown on a loamy soil, Tables 2.14 and 2.15 show that the estimated net irrigation depth is 40 mm. If furrow irrigation is used, the field application efficiency is 60% and the gross irrigation depth is determined as follows:

$$d\ gross = \frac{100 \bullet 40}{60} = 67\ mm = rounded\ 65\ mm$$



Step 2: Calculate the irrigation water need (IWN) in - over the total growing season
The calculation of the irrigation water need has described in Section 2.3.3
Assume that the irrigation water need (in mm/month) for tomatoes, planted 1 February and harvested 30 June, as calculated in section 2.3.3 and considering the following effective rain, is as follows:

CROP Tomato planting date 1st February					
(Values in mm/month)	**Feb**	**March**	**April**	**May**	**June**
Et crop or CWN	69	123	180	234	180
Effective rain	2	13	14	39	0
Irrig.water need IWN	67	110	166	195	180

The irrigation water need of tomatoes for the total growing season (Feb-June) is thus (67 + 110 + 166 + 195 + 180 =) 718 mm. This means that over the total growing season a net water layer of 718 mm has to be brought onto the field. If no data on irrigation water needs are available, the estimation method (section 3.2) should be used.

Step 3: Calculate the number of irrigation applications over the total growing season
The number of irrigation applications over the total growing season can be obtained by dividing the irrigation water need over the growing season (Step 2) by the net irrigation depth per application (Step 1).
If the net depth of each irrigation application is 40 mm (d net = 40 mm; Step 1), and the irrigation water need over the growing season is 718 mm (Step 2), then a total of (718/40 =) 18 applications are required.

Step 4: Calculate the irrigation interval (INT) in days
Thus a total of 18 applications is required. The total growing season for tomatoes is 5 months (Feb-June) or 5 x 30 = 150 days. Eighteen applications in 150 days corresponds to one application every 150/18 =

8.3 days.

In other words, the interval between two irrigation applications is 8 days. To be on the safe side, the interval is always rounded off to the lower whole figure: for example 7.6 days becomes 7 days; 3.2 days becomes 3 days.

CONCLUSION
In this example, the irrigation schedule for tomatoes is as follows:
d net = 40 mm
d gross = 65 mm
interval = 8 days

Adjusting the Simple Calculation Method for the Peak Period

When using the simple calculation method to determine the irrigation schedule, it is advisable to ensure that the crop does not suffer from undue water shortage in the months of peak irrigation water need.

For instance, in the above example the interval is 8 days, while the net irrigation depth is 40 mm. Thus every 30 days (or each month): 30/8 x 40 mm = 150 mm water is applied. The amount of water given during each month (d net) should be compared with the amount of irrigation water needed during that month (IWN).

The result is shown below. The "IN" values represent the irrigation water needs, while the "d net" values represent the amount of water applied. The "d net - IN" values show whether too much or too little water has been applied:

Adjusting the Simple Calculation Method for the Peak Period

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The result is shown below. The "IN" values represents the irrigation water needs, while the "d net" values represent the amount of water applied. The "d net - IN" values show whether too much or too little water has been applied:

CROP Tomato planting date 1st February						
(Values un mm/month)	Feb	March	April	May	June	Total
Et crop or CWN	69	123	180	234	180	786
Effective rain	2	13	14	39	0	68
Irrig.Water Need IWN	67	110	166	195	180	718
d net	150	150	150	150	150	750
d net - IWN	83	40	-16	-45	-30	32

The total net amount of irrigation water applied (750 mm) is more than sufficient to cover the total irrigation water need (718 mm). However, in February and March too much water has been applied, while in April, May and June, too little water has been applied.

Care should be taken with under-irrigation (too little irrigation) in the peak period as this period normally coincides with the growth stages of the crops that are most sensitive to water shortages.
To overcome the risk of water shortages in the peak months, it is possible to refine the simple calculation method by looking only at the months of peak irrigation water need and basing the determination of the interval on the peak period only.

In the example given above for tomatoes, this means looking at the months April, May and June:

Months of peak irrigation water need				
	April	May	June	Sub-Total
Irrig.Water Need IWN	166	195	180	541

The total irrigation water need from April to June (90 days) is 541 mm, while the net irrigation depth is 40 mm. Thus 541/40 = 13.5 (rounded 14) applications are needed. Fourteen applications in 90 days means one application every 6.4 (rounded 6) days. Calculated this way the irrigation schedule for the tomatoes would be:

d net = 40 mm
d gross = 65 mm
interval = 6 days

Over the total growing period of 150 days, this means 150/6 = 25 applications, each 40 mm net and thus in total 25 x 40 = 1000 mm.

The overall result of adjusting the irrigation schedule to the months of peak irrigation water demand is shown below:

CROP Tomato planting date 1st February						
(Values un mm/month)	Feb	March	April	May	June	Total
Irrig.Water Need IWN	67	110	166	195	180	718
d net	200	200	200	200	200	1000
d net - IWN	133	90	34	5	20	282

This way of determining the irrigation schedule avoids water shortages in the month of peak water needs but on the other hand also results in a higher seasonal irrigation water application.
It is possible to combine the two schedules. In this way some water is saved, and there are no water shortages in the peak period, but it is a bit more complicated for the farmers.
The result of the combined irrigation schedule for the whole growing season is as follows:

CROP Tomato planting date 1st February						
(Values un mm/month)	Feb	March	April	May	June	Total
Irrig.Water Need IWN	67	110	166	195	180	718
d net	150	150	200	200	200	900
d net - IWN	83	40	34	5	20	182

In summary:

Feb-March
- d net = 40 mm
- d gross = 65 mm
- Interval = 8 days

April-May-June
- d net = 40 mm
- d gross = 65 mm
- Interval = 6 days

Calculation Example Irrigation Scheduling

QUESTION: Determine the irrigation schedule for groundnuts:

1. *Based on the total growing period.*
2. *Based on the months of peak irrigation water need.*
3. *Based on a combination of the two schedules above (1 and 2).*

GIVEN:
Crop: ground nuts
Soil type: loam
Irrigation method: furrow irrigation
Field application efficiency: 60%
Total growing period: 130 days
Planting date: 15 July

Irrigation water need (IWN):

CROP Groundnut planting date 15th July							
(Values un mm/month)	**Jul***	**Aug**	**Sep**	**Oct**	**Nov****	**Total**	* as of 15 July
Irrig.Water Need IWN	38	115	159	170	45	527	** up to 25 November

<u>ANSWER 1</u>: irrigation schedule for groundnuts, based on the total growing period

Step 1: Determine the net and gross depth (d) in mm of the irrigation applications

Table 2.15 shows that groundnuts have a medium root depth. Grown on a loamy soil, the net irrigation depth (d net) will thus be approximately 40 mm (Table 2.14). The field application efficiency (ea) is 60%.

The gross irrigation depth (d gross) can be calculated using the following formula:

=

$$d\ gross = \frac{100 \bullet d\ net}{ea} \qquad d\ gross = \frac{100 \bullet 40}{60} = 67\ mm\ \text{(rounded to nearest5 mm : 65 mm)}$$

Step 2: Calculate the irrigation water need (IWN) in mm over the total growing season
The irrigation water need over the total growing season of 130 days (15 July – 25 November) is 38 + 115 + 159 + 170 + 45 = 527 mm (see data).

Step 3: Calculate the number of irrigation applications over the total growing season
The number of applications equals the seasonal irrigation water need (Step 2) divided by the net irrigation depth (Step 1). Thus the number of applications is 527/40 = 13.2 = rounded 13 applications.

Step 4: Calculate the irrigation interval in days
A total of 13 applications is given during the total growing period of 130 days. The interval is thus 130/13 = 10 days.

IN SUMMARY:

The irrigation schedule for groundnuts, based on the total growing period is:
d net = 40 mm
d gross = 65
Interval = 10 days

The comparison of the irrigation water required (IWN) and the irrigation water applied (d net) is given below:

CROP Groundnut planting date 15th July						
(Values un mm/month)	**Jul***	**Aug**	**Sep**	**Oct**	**Nov****	**Total**
Irrig.Water Need IWN	38	115	159	170	45	527
d net	60	120	120	120	100	520
d net - IWN	22	5	-39	-50	55	-7

* July: 15 days only, as the planting date is 15 July
** Nov.: 25 days only, as the last day of the harvest is 25 November

<u>ANSWER 2:</u> Irrigation schedule for groundnuts based on months of peak irrigation water need
As can be seen from the table above, the months of peak Irrigation water need are September and October. In this example the irrigation schedule will be based on these two months.
Step 1: Estimate the net and gross depth (d) in mm of the Irrigation applications. The net and gross depth (d) are calculated in the same way as in Answer 1.
Thus:
d net = 40 mm
d gross = 65 mm (rounded)

Step 2: Calculate the irrigation water need over the months of peak irrigation water need
The months of peak irrigation water need are September and October, and during these two months the IWN (159 + 170) = 329 mm.

CROP Groundnut planting date 15th July			
(Values un mm/month)	**Sep**	**Oct**	**Total**
Irrig.Water Need IWN	159	170	329

Step 3: Calculate the number of irrigation applications during the peak months
The number of applications is 329/40 = 8.2, rounded 8 applications.

Step 4: Calculate the irrigation interval in days
8 applications are given during the peak months September and October i.e. during 60 days:

the interval = 60/8 = 7.5 = rounded 7 days.

IN SUMMARY:

The irrigation schedule for groundnuts, based on the months of peak irrigation water need is:
d net = 40 mm
d gross = 65 mm
Interval = 7 days

The comparison of the irrigation water required (IN) and the irrigation water applied (d net) is given below:

CROP Groundnut planting date 15th July						
(Values un mm/month)	**Sep**	**Oct**	**Sep**	**Oct**	**Nov****	**Total**
Irrig.Water Need IWN	38	115	159	170	45	527
d net	85	170	170	170	140	735
d net - IWN	47	55	11	0	95	208

* July: 15 days only, as the planting date is 15 July, ** Nov.: 25 days only, as the last day of the harvest is 25 November

There are no water shortages in the peak months, but the total amount of water applied is high.

<u>ANSWER 3</u>: Irrigation schedule for groundnuts combining the two previous schedules
It is possible to combine the two schedules obtained in answer 1 and answer 2. For the non-peak period, the Answer 1 schedule is used. For the peak period, Answer 2 is used. The result is shown below.

CROP Groundnut planting date 15th July						
(Values un mm/month)	**Sep**	**Oct**	**Sep**	**Oct**	**Nov****	**Total**
Irrig.Water Need IWN	38	115	159	170	45	527
d net	60	120	170	170	100	620
d net - IWN	22	5	11	0	55	93

July, August, November
- d net = 40 mm
- d gross = 65 mm
- interval = 10 days

September, October
- d net = 40 mm
- d gross = 65 mm
- interval = 7 days

Similarly, other schedules can be determined by trial and error. The objective should be to best match the required amount of water with the amount actually given. The schedules thus obtained, however, should not be too difficult for the farmer to implement.

2.5 DETERMINATION OF THE IRRIGATION SCHEDULE FOR PADDY RICE

Paddy rice is usually grown in level basins which are flooded with water throughout most of the growing season. The main reason for flooding the rice fields is that most rice varieties maintain better growth and produce higher yields when grown in flooded soils, than when grown in dry soils. The water layer also helps to suppress the weeds.
The irrigation water needs and irrigation scheduling for paddy rice is a particular case. It can be consulted in (Brouwer et all, 1989)

2.6 FARM OR SCHEME IRRIGATION NEEDS (HOEVENAARS ET ALL, 1992)

2.6.1 CROPPING PATTERN

In a farm, or a given bigger area, there are more than one crop being cropped at the same time. For this scheme, the irrigation flow requirements can be calculated based on the scheme's cropping pattern. The cropping pattern, or cropping schedule of an irrigation area provides information, for a period of at least one season, on three important elements:

- which crops are grown
- when are they cultivated
- how many hectares of each crop are grown.

This information is written down, in detail, let us say for the area of one farmer for one year, and from this record there emerges a pattern. For example, the cropping pattern for farm A:

- onions cultivated from April 15 to September 15 on 1 ha
- potatoes from October 15 to February 15 on 1/2 ha, on the same plot as the onions
- cotton from July 10 to January 20 on 1 and 1/2 ha

Information on the type of crop and the period of cultivation can be visualized in a line diagram.

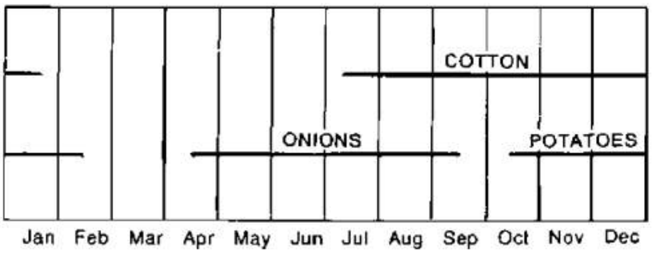


Figure 2-37 Line diagram of an example farm's crop calendar

This crop calendar diagram shows that farmer A starts with onion cultivation in mid-April which he then harvests mid-September. Within one month he will plant potatoes on the same plot, which he expects to uproot in mid-February. Farmer A has a second plot on which he grows cotton over a six-month period from mid-July to the end of January of the following year.

If the area of each crop has to be shown, the lines representing individual crops should be replaced by bars where the height of each bar is a measure of the area of each crop. In the example below, for instance, an area of one hectare is represented by a bar-height of about 0.5 centimetre. The length of the bar indicates the period in which the crop is grown. A diagram with crop bars rather than crop lines is called a cropping pattern.

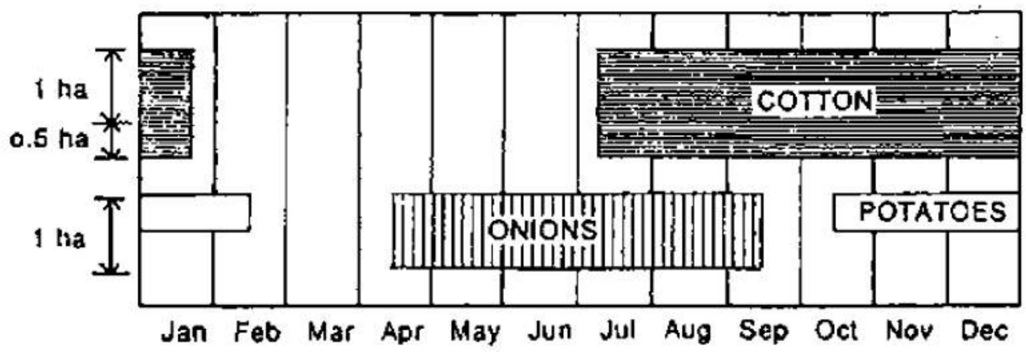


Figure 2-38 Bar diagram of an example farm's cropping pattern

Figure 2.39 shows that farmer A grew 1 and 1/2 ha of cotton from 10 July to 20 January, 1 ha of onions from mid-April to mid-September and 1/2 ha of potatoes from mid-October to mid-February.
The diagram can indicate more crop husbandry dates, such as crop manuring and periods of weeding and transplanting, etc. It is also possible to draw up a cropping pattern diagram for larger areas, including a group of farmers, or an entire irrigation scheme. The only difference is that with a single farm, it was supposed that the crop was sown or planted on one specific day. The same assumption cannot be made in the case of a larger irrigation scheme. In fact, there are several reasons why farmers do not all start planting on the same day on an irrigation scheme:

- labour and machinery needed to prepare the land is in short supply, and each has to wait his turn;
- a farmer is not ready due to other activities, so he postpones planting the crop for a while;
- also, it is impossible to supply all the fields on an irrigation scheme with the water required to start a crop on the same day. The larger the scheme's area, the longer the time it takes to serve all the fields.

The cultivation of any crop on an irrigation scheme is thus spread over a certain period of time. This is called staggered cultivation or a staggered cropping pattern.

2.6.2 THE CALCULATION METHODS

THE APPROXIMATE METHOD

The approximate method of determining the gross Farm or Scheme irrigation need (SINgross) assumes a constant average irrigation need, INnet, for the entire season. The most simplified standard value of this INnet is 1 litre per second per hectare. This is equivalent to a daily water requirement of 8.6 mm. When the daily water requirement is 4.3 mm, the irrigation need would be 0.5 l/s.
Like most rules of thumb, this rule should be applied with caution. The proxy values of INnet in hot and dry climates can be three times as great as in humid climates. Typical values are presented in Table 2-17.

Table 2-17 Approximate average innet values for different climates and rice

Humid tropical climate	0.5 l/s/ha
Monsoon climate wet season	0.5 l/s/ha
Monsoon climate dry season	1.0 l/s/ha
Semi-arid climate wet season	1.0 l/s/ha
Semi-arid climate dry season	1.5 l/s/ha
Arid climate	1.5 l/s/ha
Rice	1.5 l/s/ha

The approximate values of the irrigation need for an entire area, SINnet may be calculated by multiplying the INnet with the area, Area (in hectares). Therefore, the equation representing the approximate Net Scheme Irrigation Need is:

SINnet (l/s) = Area (ha) x INnet (l/s/ha)

EXAMPLE: The area of a farm or irrigation scheme on which several crops are grown is 5 ha. The estimated net irrigation requirement is 1 l/s/ha. Thus the SINnet for the entire scheme would be:
5 (ha) x 1 (l/s/ha) = 5 (l/s)

The net scheme irrigation need, SINnet is the amount of water needed to meet crop water needs of an entire scheme minus the effective rainfall. Water lost during delivery must be added before the gross scheme irrigation need, SINgross, can be determined.

The SINgross is calculated by dividing SINnet by the overall scheme irrigation efficiency (e), which is the product of the conveyance efficiency (ec) and the field application efficiency (ea). The subject of irrigation efficiencies is discussed at length in Annex II.

If a conveyance efficiency of about 85% and an application efficiency of about 60% are selected, they result in an overall area irrigation efficiency of about 50%. Once the scheme irrigation efficiency (e, expressed in percentages) is known, SINgross can be calculated with the following formula:
SINgross (l/s) = 100/e x SINnet (l/s)

The formula above shows that as the efficiency drops (becomes smaller), more water has to be supplied to satisfy the irrigation need of a scheme.

EXAMPLE: A farm or irrigation scheme of 7 ha located in a semi-arid area is irrigated during the dry season.

The average INnet can be estimated at 1.5 l/s/ha (see Table 2.16). The total net irrigation need of the scheme is: Area times INnet which is 7 x 1.5 = 10,5 l/s. The irrigation efficiency is 50% and thus the SINgross equals 100/e x SINnet, which equals 100/50 x 10,5, or 21,0 l/s.

SIN gross and SIN net are expressed in a **<u>CONTINUOUS FLOW</u>** of litres per second. This means that the same flow of water is supplied continuously, second after second, hour after hour, and day after day without interruption throughout the entire growing season.

However, water is not always supplied continuously. If irrigation water is applied only 12 out of a possible 24 hours per day, then during these 12 hours twice as much water must be given to supply the same total.

Further, if irrigation does not take place every day, more water must be supplied on irrigation days in order to maintain the same total quantity per week.

The Operational Criteria

The ratios of hours per day and days per week during which the irrigation system functions are called, in this manual**, the operational criteria**. By using these operational criteria, the required scheme irrigation supply can be determined with the following formula:

$$SIN_{op}\ (l/s) = SIN_{gross}/T_{op}$$

$$T_{op} = d/7 \times h/24$$

where:
SINop = operational scheme irrigation need
Top = operational criteria
d = number of irrigation days per week
h = number of irrigation hours per day
SINgross = gross scheme irrigation need

The formula above shows that the fewer the number of irrigation applications per week and the fewer the number of hours of irrigation per day, the larger the scheme's supply should be, and the larger should also be the capacity of the irrigation system.

THE CROPPING PATTERN METHOD

When accurate crop and climatic data are available, a much more precise prediction may be made of the gross scheme irrigation need, SINgross, while the operational scheme irrigation need, SINop, can be finely tuned to the real irrigation need. However, when a scheme has many crops, this more precise method also requires more complex calculations. A calculation method example is presented in this section to help field technicians and extension agents understand and become familiar with the underlying principles and the basic elements involved in calculating scheme water needs.

The calculation of an individual crop's irrigation water need, INnet, has already been explained. Using this calculation as a point of departure, which ends with the net irrigation need of an individual crop expressed in millimetres of water depth per month (mm/mon), this section will focus on determining the net farm or scheme irrigation need SINnet (in litres per second) of an entire irrigation scheme with a variety of crops throughout the year.

Farm or Scheme irrigation need for a one- crop cropping system

Suppose that 60 ha of onions are planted on an irrigation scheme of 150 ha and that the planting of onions is spread out evenly over one month. Planting is begun on 1 April and finished on 30 April.

The irrigation water need of the earliest planted onions during the month of April is 98 mm, which is 3.3 mm/day for 30 days. Onions which are not planted until April 15 do not need water during the first 15 days of April. For the remaining 15 days of April, the irrigation water need is 15 x 3.3 mm, or 49 mm. Onions which are planted on the last day of April do not need any irrigation water in April at all.

This example indicates that the irrigation water need of the onions which are planted in between the earliest and the latest planted onions, lies in between the irrigation water need of the earliest and latest planted onions. In general, the average irrigation water need of an area cropped with onions, or any other crop, is the average of the irrigation water need of the earliest (INe) and the irrigation water need of the latest (INl) planting. This is also expressed in the formula below:

$$IN_{av} = \frac{IN_e + IN_1}{2} \ (mm / month)$$

This monthly irrigation need, INav, is presented as a water layer which is applied during that month on a certain area. However, water flows are not actually expressed in millimetres of water covering a certain area over a certain period of time, but in litres per second, or cubic metres per second. Therefore the INav per month should be converted into a current irrigation water flow. SINnet in litres per second (net scheme irrigation need) can be calculated as follows:

$$SIN_{net} = \frac{IN_{av}(mm / month) \times Area\ (ha) \times 10\,000\ (l / mm.ha)}{30\ (days / month) \times 86\,400\ (s / day)} \ (l / s)$$

Or

$$SIN_{net} = \frac{IN_{av}\ (mm / month) \times Area\ (ha)}{260} \ (l / s)$$

When the monthly irrigation need of an area with staggered crop cultivation must be determined, the irrigation needs of the earliest and of the latest plantings must be calculated.

ASSUMPTIONS:
Crop: Dry Onions Earliest planting: 1 April
Total area: 60 ha Latest planting: 30 April
Duration of crop growth phases Crop factors: (Kc)
Initial stage: 15 days Kc 0.5
Crop devt. stage: 25 days Kc 0.75
Mid season: 70 days kc 1.05
Late season: 40 days Kc 0.85

Potential Evapotranspiration (**ET_0**) in the example location:

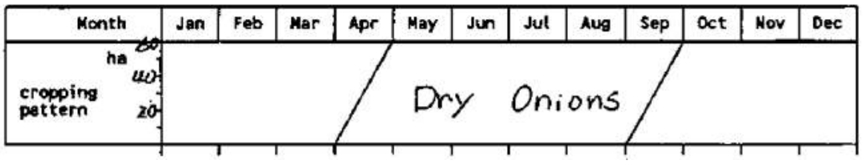
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET_0 (mm/day)	4.7	5.1	5.2	5.6	5.7	6.1	5.8	5.5	5.6	5.2	4.3	4.6

Effective rainfall (P_e) in the example place:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P_e (mm/mon)	1	3	7	10	12	13	72	82	16	7	1	0

CALCULATION:

Step 1: Draw the cropping pattern.



Step 2: Calculate the INe according to the method explained.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET_o (mm/day)				5.6	5.7	6.1	5.8	5.5				
Growth stages		(Days in	a month)	IS 15 / DS 15	10 / 20	Mid 30	20 / Late 10	30				
K_c per gr. st.				0.5 / 0.75		1.05		0.85				
K_c per month[1]				0.65	0.95	1.05	1.0	0.85				
ET_{cr} mm/mon[2]				108	162	192	174	141				
P_e mm/mon[3]				10	12	13	72	82				
IN_e mm/mon[4]				98	150	179	102	59				

1 average of K_c per month. For example, K_c for May=0.75x(10/30)+1.05x(20/30)=0.95

2 ET_{cr} (mm/mon) = ET_o (mm/day) x Crop growing days per month x K_c (per month)

3 P_e (mm/mon) : effective rainfall per month

4 IN_e or IN_l (mm/mon) = ET_{cr} (mm/mon) - P_e (mm/mon)

Step 3: Calculate the INl in the same way.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET_o (mm/day)					5.7	6.1	5.8	5.5	5.6			
Growth stages		(Days	in a	month)	IS 15 / DS 15	10 / 20	Mid 30	20 / 10	Late 30			
K_c per gr. st.					0.5 / 0.75		1.05		0.85			
K_c per month[1]					0.65	0.95	1.05	1.0	0.85			
ET_{cr} mm/mon[2]					111	174	183	165	143			
P_e mm/mon[3]					12	13	72	82	16			
IN_l mm/mon[4]					99	161	111	83	127			

Step 4: Calculate the average monthly irrigation need INav.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
IN_e mm/mon				98	150	179	102	59				
IN_l mm/mon					99	161	111	83	127			
IN_{av} mm/mon				49	125	170	107	71	64			

Step 5: Determine SINnet in litres per second for each month with the following formula:

$$SIN_{net} = \frac{IN_{av}\ (mm / month) \times Area\ (ha)}{260}\ (l / s)$$

For example, if April's INav equals 49 mm, then the SINnet equals 49 mm times the area (60 ha) divided by 260, or

$$\frac{49\text{mm} \times 60\text{ha}}{260} = 11\text{l/s}$$

The same calculation should be made and recorded on the schedule below for the months of May, June, July, August and September.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SIN_{net} l/s				11	29	39	25	16	15			

Please note the variations for SINnet for each month in the above example. It is interesting to compare the results with the ones obtained by the approximate method. With the approximate method, only a single value for SINnet can be obtained. If INnet is assumed to be 1 l/s/ha, SINnet for 60 ha is 60 l/s, which is about 50% greater than the peak water need (39 l/s for June) calculated above.

Farm or Scheme irrigation need for a one multiple crop cropping system

On a farm or an irrigation schemes more than one kind of crop is grown at the same time, and over the course of a year. It is therefore often necessary to calculate irrigation needs for a multiple cropping system. Once the irrigation need for a single cropping pattern has been estimated, the irrigation need for a scheme with more than one crop can be determined by adding up the irrigation requirements for each month. The way this is done is much the same as with the calculation for a simple cropping pattern, following the three steps outlined below.

Step 1: Draw the multiple cropping system diagram, as explained in Section 3.3.
Step 2: Determine the scheme irrigation need for each crop separately, following the steps explained in Section 3.4.1. Use Data Sheet 1.
Step 3: Add up each month's calculated irrigation needs. The total scheme irrigation need should be expressed in litres per second.

SAMPLE PROBLEM: Determine the scheme irrigation need based on the following assumed data.

Assumptions:

	Crop 1	**Crop 2**	**Crop 3**
Name:	onions	cotton	potatoes
Area:	60	75	30
Planting period	1 April – 30 April	1 Jul-15 Aug	1 Oct-30 Oct
Growing period	150 days	190 days	120 days

Potential Evapotranspiration (ET_0) in the example location:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ET_0 (mm/day)	4.7	5.1	5.2	5.6	5.7	6.1	5.8	5.5	5.6	5.2	4.3	4.6

Effective rainfall (P_e) in the example place:

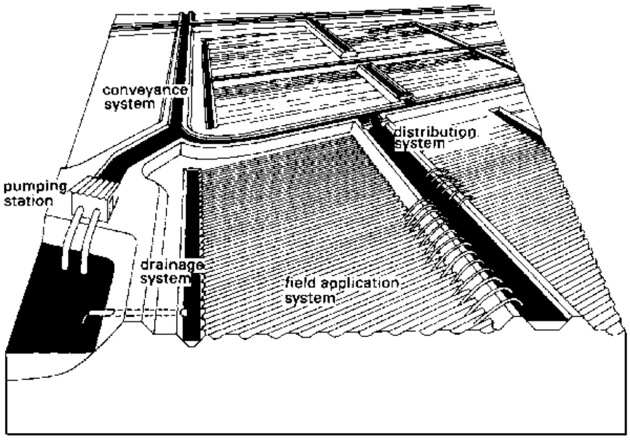
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P_e (mm/mon)	1	3	7	10	12	13	72	82	16	7	1	0

Step 2: The determination of the irrigation needs for the three different crops is done as explained. The results are copied onto the data sheet.
Step 3: The net scheme irrigation need is found by simply adding up monthly irrigation needs for each crop.

2.7 COMPONENTS OF AN IRRIGATION AND DRAINAGE SYSTEM (I&DS)

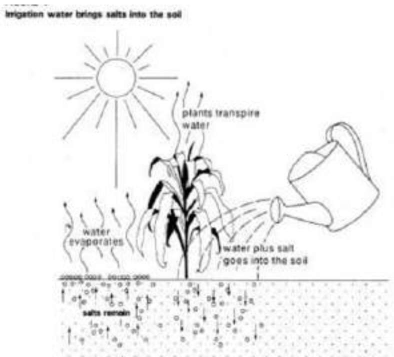
The components of an Irrigation and Drainage system (I&DS) are:

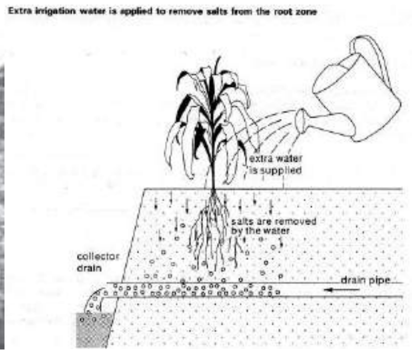
- **Main intake structure and pumping station:** directs water from the source of supply, such as a reservoir or a river, into the irrigation system. In some cases, the irrigation water source lies below the level of the irrigated fields. Then a pump must be used to supply water to the irrigation system
- assures the transport of water from the **Conveyance and distribution system:** main intake structure or main pumping station up to the field ditches.
- **Field application systems:** The distribution system assures the transport of water through field ditches to the irrigated fields. The field application system assures the transport of water within the fields.
- **Drainage system:** removes the excess water (caused by rainfall and/or irrigation) from the fields.



If and adequate drainage is not provided to an irrigation system, its absence can result in loss of agricultural production and potential failure of the scheme. Drainage is needed:

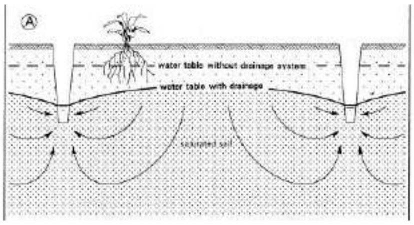
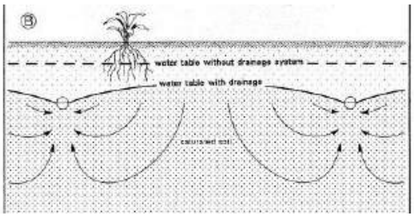
- to make new lands available for agriculture;
- to remove excess surface water following irrigation or rainfall; (improved aeration of the soil, permitting optimum agricultural production)
- to prevent or reduce waterlogging;(improved soil structure resulting from drier soils)
- to control salinity levels, leaching of unwanted salts from the root zone.





There are three main types of drainage system:

- surface drainage: open drains to remove excess irrigation or rainfall;
- subsurface drainage, (horizontal buried pipes set at 1–2 m below the surface and connected to deep open drains); designed to prevent the groundwater table rising into the crop's root zone;
- pumped drainage, in which deep tube wells are used to draw down the groundwater, and saline water from tube wells is discharged into open surface drains.

 Field drain for surface drainage	  	A Subsurface drainage with open drains  B Subsurface drainage with open drains

2.8 FIELD APPLICATION SYSTEMS (OR IRRIGATION METHODS) BROUWER ET ALL, 1985 (3)

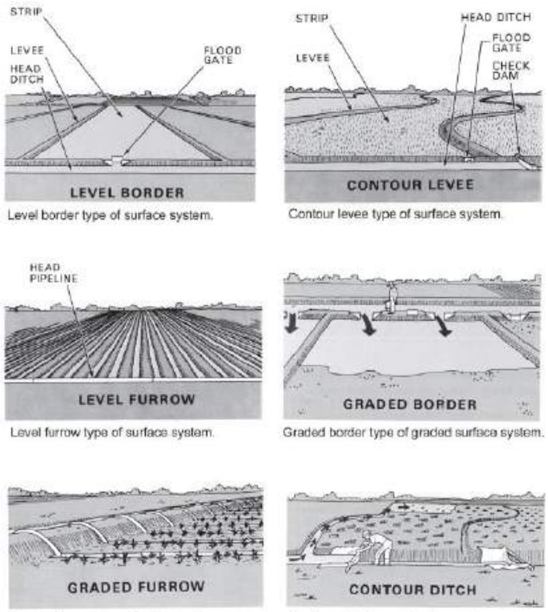
There are four principal methods

1. Surface irrigation:
2. Sprinkler irrigation.
3. Trickle (drip) irrigation
4. Subsurface irrigation.

Each of these irrigation methods has its own advantages and disadvantages, and is suited to particular physical conditions such as crop type, soils, land slope, water availability, availability of funds, labour costs, labour availability, etc.

Surface irrigation: oldest and most widely used method of water application.

- uncontrolled flooding,
    - wild flooding;
- controlled flooding;
    - basin or level border,
    - contour levee,
    - graded border or border strip,
    - furrow,
    - corrugation (small furrows pressed in the soil for cereals.
- Characteristics:
- not recommended for highly permeable soils or steep slopes.
- Least expensive of the possible systems, though costs rise if land-forming or land levelling are required.
- land preparation is relatively straightforward,
- easy to operate and maintain,
- not affected by wind conditions,
- low energy costs,



Level border type of surface system. Contour levee type of surface system. Level furrow type of surface system. Graded border type of graded surface system. Graded furrow type of graded surface system. Contour ditch type of graded surface system.

- can be highly efficient (up to 60%) but require more skilled operation to apply water uniformly to the land surface without undue losses.
- The efficiency of the water application is highly dependent on the knowledge and skill of the farmer.
- It is often thought that farmers are very experienced in surface irrigation methods simply because they have been practicing them for years. However, it is rare for farmers to evaluate their irrigation application by assessing the soil moisture status in the root zone before and after irrigation. It is therefore difficult to know if an excessive quantity of water has been applied and lost to deep percolation below the root zone; a farmer may well have been over-irrigating for many years without knowing it.
- Significant improvements in water-use efficiency and productivity can be gained through assessment of farmers' actual application practices followed by training.

BASIN IRRIGATION

Basins are flat areas of land, surrounded by low bunds. The bunds prevent the water from flowing to the adjacent fields. Basin irrigation is commonly used for rice grown on flat lands or in terraces on hillsides. Other crops which are suited to basin irrigation include:

- pastures, e.g. alfalfa, clover;
- trees, e.g. citrus, banana;
- crops which are broadcast, such as cereals;
- to some extent row crops such as tobacco

In general, the basin method is suitable for crops that are unaffected by standing in water for long periods (e.g. 12-24 hours).

Suitable land slopes and soils: The flatter the land surface, the easier it is to construct basins. It is also possible to construct basins on sloping land, but should be constructed like the steps of a staircase and these are called terraces. Loamy soils are preferred for basin irrigation so that waterlogging (permanent saturation of the soil) can be avoided. Coarse sands are not recommended for basin irrigation as, due to the high infiltration rate, percolation losses can be high. Also soils which form a hard crust when dry (capping) are not suitable.

Shape and size of basins: They are mainly determined by the land slope, the soil type, the available stream size (the water flow to the basin), the required depth of the irrigation application and farming practices.

Table 2-18 Approximate values for the maximum basin or terrace width (m)

Slope %	Maximum width (m)	
	average	range
0.2	45	35-55
0.3	37	30-45
0.4	32	25-40
0.5	28	20-35
0.6	25	20-30
0.8	22	15-30
1.0	20	15-25
1.2	17	10-20
1.5	13	10-20
2.0	10	5-15
3.0	7	5-10
4.0	5	3-8

BASIN WIDTH: The main limitation on the width of a basin is the land slope. If the land slope is steep, the basin should be narrow, otherwise too much earth movement will be needed to obtain level basins.

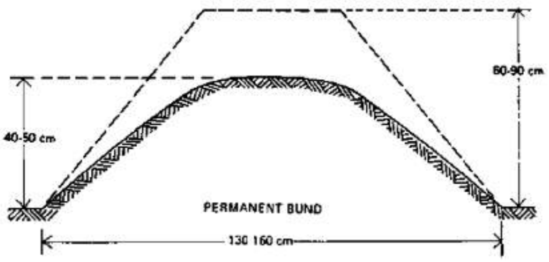
Three other factors which may affect basin width are:

- depth of fertile soil, If the topsoil is shallow, there is a danger of exposing the infertile subsoil when the terraces are excavated. This can be avoided by reducing the width of basins and thus limiting the depth of excavation
- method of basin construction, Basins can be quite narrow if they are constructed by hand labour but will need to be wider if machines are used so that the machines can easily be moved around
- agricultural practices. If hand or animal powered tillage is used, then basins can be much narrower than if machines are used for cultivation.

The size of basins depends not only on the slope but also on the soil type and the available water flow to the basins. The relationship between soil type, stream size and size of the basin is given in Table 2.18. Values are based on practical experience, and have been adjusted in particular to suit small-scale irrigation conditions.

Table 2-19 Suggested maximum basin areas (m2) for various soil types and available stream sizes (l/sec)

Stream size (l/sec)	Sand	Sandy loam	Clay loam	Clay
5	35	100	200	350
10	65	200	400	650
15	100	300	600	1000
30	200	600	1200	2000
60	400	1200	2400	4000
90	600	1800	3600	6000



BASINS SHOULD BE SMALL IF THE:

1. slope of the land is steep
2. soil is sandy
3. stream size to the basin is small
4. required depth of the irrigation application is small
5. field preparation is done by hand or animal traction.

BASINS CAN BE LARGE IF THE:

1. slope of the land is gentle or flat
2. soil is clay
3. stream size to the basin is large
4. required depth of the irrigation application is large
5. field preparation is mechanized.

Shape and dimensions of bunds: Bunds are small earth embankments which contain irrigation water within basins. They are sometimes called ridges, dykes or levees.

Irrigating Basins and wetting patterns: There are two methods to supply irrigation water to basins:

- The direct method: water is led directly from the field channel into the basin through siphons, spiles or bundbreaks The cascade method: on sloping land, where terraces are used, the irrigation water is supplied to the highest terrace, and then allowed to flow to a lower terrace and so on.

For good crop growth it is very important that **the right quantity** of water is supplied **to the root zone** and that the root zone **is wetted uniformly**.

If crops receive too little water, they will suffer from drought stress, and yield may be reduced. If they receive too much water, then water is lost through deep percolation and, especially on clay soils, permanent pools may form, causing the plants to drown. How much irrigation water should be supplied to the root zone - in other words "the net irrigation depth" - has been discussed. How the irrigation water can be evenly distributed in the root zone is explained below.

Ideal wetting pattern

To obtain a uniformly wetted root zone, the surface of the basin must be level and the irrigation water must be applied quickly. Figure 17 shows an ideal wetting pattern: the basin is level and the right quantity of water has been supplied with the correct scream size. As can be seen from Figure 17, it is not possible to have the wetting pattern and root zone coincide completely. The part of the basin near the field channel is always in contact with the irrigation water longer than the opposite side of the basin. Therefore, percolation losses will occur near the field channel, if sufficient water is supplied to the opposite side of the basin.

Poor wetting patterns can be caused by:
- unfavourable natural conditions, e.g. a compacted subsoil layer, or different soil types within one basin;
- poor layout, e.g. a poorly levelled surface;
- poor management, e.g. supplying incorrect stream size, applying too little or too much water.

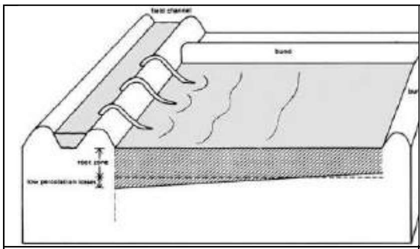
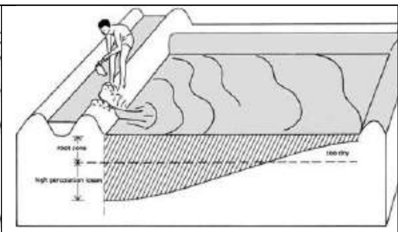
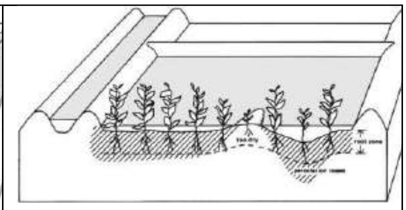
		
ideal wetting pattern: wetting pattern and root zone does not coincide completely. The first part of the basin gets more water than the opposite side of the basin	if the basin is irrigated too slowly, by using a small stream size the first part of the basin receives too much water. And the other end of the basin remains too dry.	if the soil surface is not level, some parts of the root zone receive too little water and in the lower parts water may pond or be lost through deep percolation.

Table 2-20 Basins wetting pattern

FURROW IRRIGATION

Furrows are small, parallel channels, made to carry water in order to irrigate the crop. The crop is usually grown on the ridges between the furrows.

Furrow irrigation is suitable for many crops, especially row crops. Crops that would be damaged if water covered their stem or crown should be irrigated by furrows, such us:

- row crops such as maize, sunflower, sugarcane, soybean;
- crops that would be damaged by inundation, such as tomatoes, vegetables, potatoes, beans;
- fruit trees such as citrus, grape;
- broadcast crops (corrugation method) such as wheat.

Corrugation irrigation is a special type of furrow irrigation (corrugations are small hills pressed into the soil surface) used for broadcast crops.

Suitable land slopes and soils:

- the maximum recommended furrow slope is 0.5% to avoid soil erosion
- the minimum furrow slope is provided up to 0.05% to assist drainage following irrigation or excessive rainfall with high intensity.

On undulating land furrows should follow the land contours. Furrows can be used on most soil types. However, as with all surface irrigation methods, very coarse sands are not recommended as percolation losses can be high. Soils that crust easily are especially suited to furrow irrigation because the water does not flow over the ridge, and so the soil in which the plants grow remains friable. In sandy soils water infiltrates rapidly. Furrows should be short (less than 110 m), so that water will reach the downstream end without excessive percolation losses. In clay soils, the infiltration rate is much lower than in sandy soils. Furrows can be much longer on clayey than on sandy soils.

Furrow Layout: The shape, length and spacing of furrows are determined by the natural circumstances, i.e. slope, soil type and available stream size. However, other factors may influence the design of a furrow system, such as the irrigation depth, farming practice and the field length.

Furrow length
Furrows can be longer when the land slope is steeper. Furrows can also be level and are thus very similar to long narrow basins.

Soil type: furrows should be short (less than 110 m), so that water will reach the downstream end without excessive percolation losses. In clay soils, the infiltration rate is much lower than in sandy soils. Furrows can be much longer on clayey than on sandy soils.

Stream size: Normally stream sizes up to 0.5 l/sec will provide an adequate irrigation provided the furrows are not too long. When larger stream sizes are available, water will move rapidly down the furrows and so generally furrows can be longer. The maximum stream size that will not cause erosion will obviously depend on the furrow slope; in any case, it is advised not to use stream sizes larger than 3.0 l/sec.

Irrigation depth: applying larger irrigation depths usually means that furrows can be longer as there is more time available for water to flow down the furrows and infiltrate.

Cultivation practice: when the farming is mechanized, furrows should be made as long as possible to facilitate the work. Short furrows require a lot of attention as the flow must be changed frequently from one furrow to the next. However, short furrows can usually be irrigated more efficiently than long ones as it is much easier to keep the percolation losses low.

Field length: It may be more practical to make the furrow length equal to the length of the field, instead of the ideal length. Furrow lengths are made to fit the field boundaries.

Table 2-21 Practical values of maximum furrow lengths

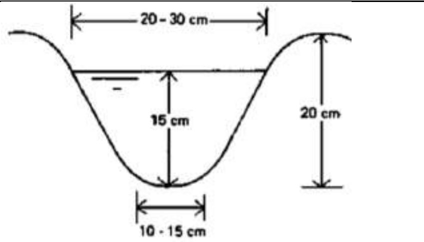
Furrow slope (%)	Maximum stream size (l/s) per furrow	Clay		Loam		Sand	
		Net irrigation depth (mm)					
		50	75	50	75	50	75
0.0	3.0	100	150	60	90	30	45
0.1	3.0	120	170	90	125	45	60
0.2	2.5	130	180	110	150	60	95
0.3	2.0	150	200	130	170	75	110
0.5	1.2	150	200	130	170	75	110

Furrows can be longer in larger scale, fully mechanized conditions.

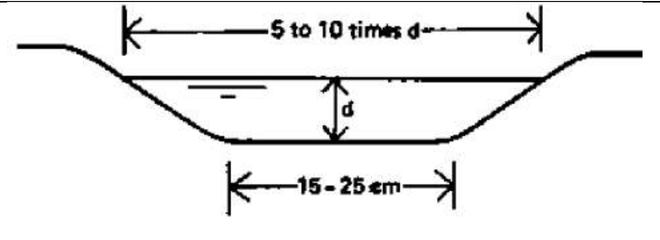
Important:
This table only provides approximate Information relating furrow slope, soil type, stream size and irrigation depth to furrow lengths. This should only be used as a guide as the data are based primarily on field experience and not on any scientific relationships. Maximum values of furrow length are given for reasonably efficient irrigation. However, furrow lengths can beeven shorter than those given in the table and in general this will help to improve irrigation efficiency. Only by Installing a furrow system, following the guidelines, and then evaluating its performance can an appropriate system be developed for a given locality. Furrows can be longer in larger scale, fully mechanized conditions.

Furrow shape: The shape of furrows is influenced by the soil type and the stream size.

Soil type: In sandy soils, water moves faster vertically than sideways (= lateral). Narrow, deep V-shaped furrows are desirable to reduce the soil area through which water percolates. However, sandy soils are less stable, and tend to collapse, which may reduce the irrigation efficiency. In clay soils, there is much more lateral movement of water and the infiltration rate is much less than for sandy soils. Thus a wide, shallow furrow is desirable to obtain a large wetted area to encourage infiltration.



A deep, narrow furrow on a sandy soil



A wide, shallow furrow on a clay soil

Figure 2-39 Furrows shapes according to soil types

Stream size: In general, the larger the stream size the larger the furrow must be to contain the flow.

Furrow spacing: the spacing of furrows is influenced by the soil type and the cultivation practice.
Soil type

- Sandy soils: spacing 30 and 60 cm, i.e. 30 cm for coarse sand and 60 cm for fine sand.
- Clay soils, spacing 75-150 cm. On clay soils, double-ridged furrows - sometimes called beds - can also be used.

Cultivation practice: In mechanized farming a compromise is required between the machinery available to cut furrows and the ideal spacings for crops. Mechanical equipment will result in less work if a standard width between the furrows is maintained, even when the crops grown normally require a different planting distance. This way the spacing of the tool attachment does not need to be changed when the equipment is moved from one crop to another. However, care is needed to ensure that the standard spacings provide adequate lateral wetting on all soil types.

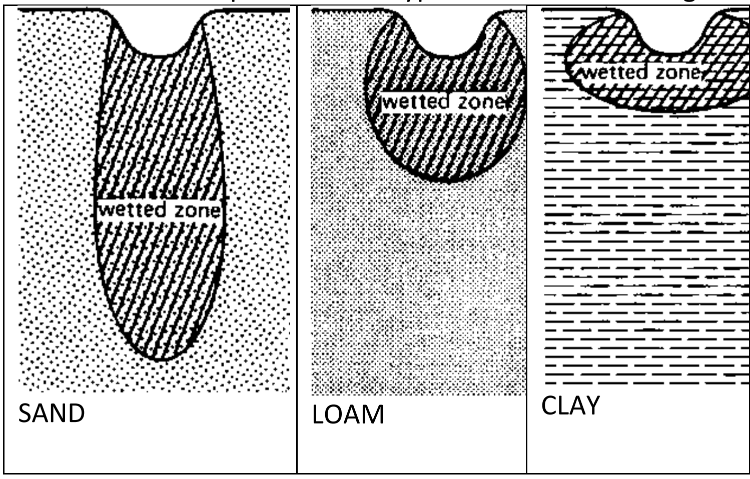
Irrigating Furrows and wetting patterns:

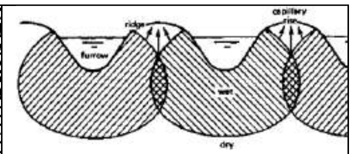
Depending on the available flow in the farm channel, several furrows can be irrigated at the same time. When there is a water shortage, it is possible to limit the amount of irrigation water applied by using 'alternate furrow irrigation'. This involves irrigating alternate furrows rather than every furrow. Thus, the crop receives some water every T/2 days instead of a large amount every T days.

Runoff at the ends of furrows can be a problem on sloping land. This can be as much as 30 percent of the inflow, even under good conditions. Therefore, a shallow drain should always be made at the end of the field, to remove excess water. When no drain is made, plants may be damaged by waterlogging. Excessive runoff can be prevented by reducing the inflow once the irrigation water has reached the end of the furrows. This is called cut-back irrigation.

In order to obtain a uniformly wetted rootzone, furrows should be properly spaced, have a uniform slope and the irrigation water should be applied rapidly.

As the root zone in the ridge must be wetted from the furrows, the downward movement of water in the soil is less important than the lateral (or sideways) water movement. Both lateral and downward movement of water depends on soil type as can be seen in Figure 2.41.





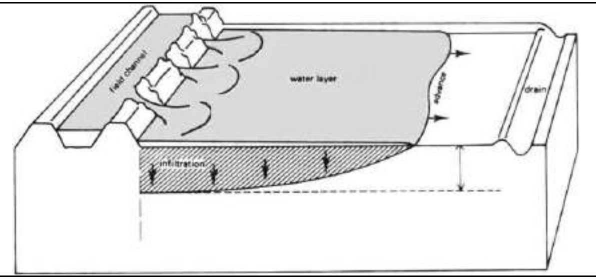
In an ideal situation adjacent wetting patterns overlap each other, and there is an upward movement of water (capillary rise) that wets the entire ridge (see Figure 39), thus supplying the root zone with water.

Figure 2-40 Different wetting patterns in furrows, depending on the soil type and ideal wetting pattern

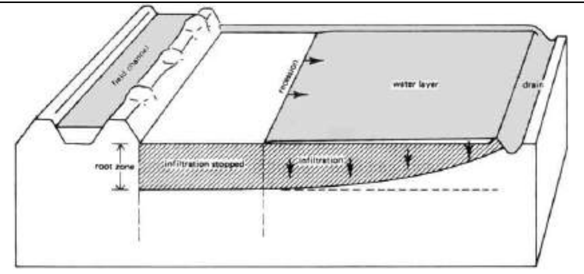
To obtain a uniform water distribution along the furrow length, it is very important to have a uniform slope and a large enough stream size so that water advances rapidly down the furrow. In this way large percolation losses at the head of the furrow can be avoided. The quarter time rule is used to determine the time required for water to travel from the farm channel to the end of the furrow, in order to minimize percolation losses.

QUARTER TIME RULE AND IRRIGATION TIME

In surface irrigation water is supplied to the field from the supply channel. From the side of the supply channel the water flows to the opposite side of the field; this is called the advance of the water front. When the water supply is stopped, the water on the field gradually infiltrates into the soil and moves away from the field channel; this is called the recession of the water front.

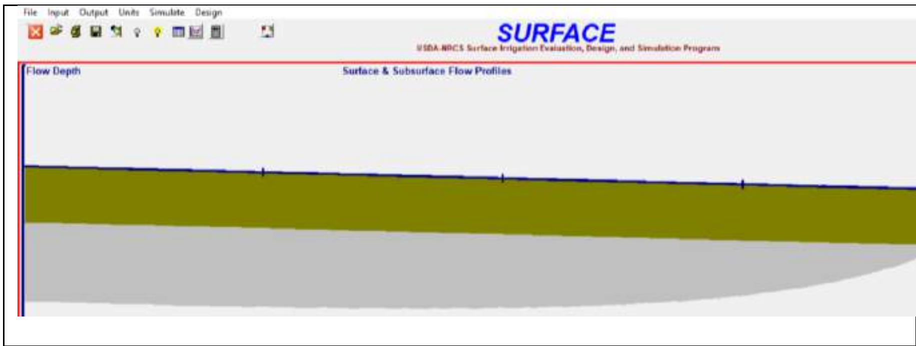


Advance of the water front

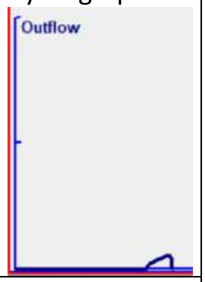


Recession of the water front

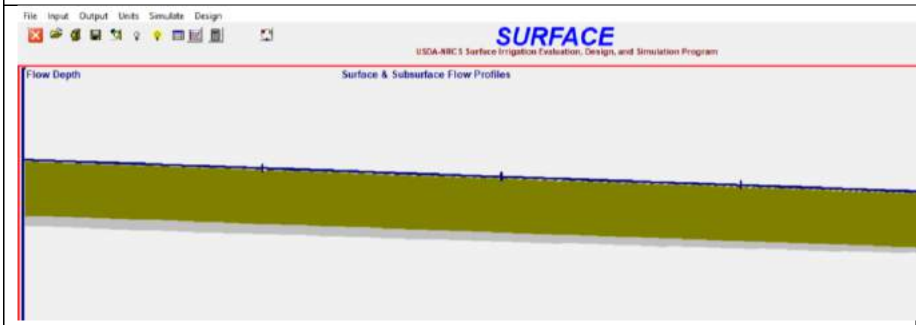
Ideally the advance of the water front should be the same as the recession; this would result in a uniform infiltration of water over the entire field. Usually, however, the advance and recession are not the same: the advance is often slower than the recession. The result is that the side of the field near the supply channel receives more water than the opposite side of the field. This is especially true if the water supply to the field is too small.



Run-off hydrograph



on a sandy soil a small stream size is applied to a large field, it will take a long time before the water reaches the far end of the field; the water infiltrates rapidly into the sandy soil. The side of the field near the supply channel receives too much water and the opposite side of the field receives too little water



Run-off

hydrograph

When the stream size is increased, the distribution of the water will improve. The water, of course, infiltrates at the same rate, but the water front will reach the opposite side of the field sooner. So also this side will receive a fair share of the water, albeit always less than the side near the supply channel

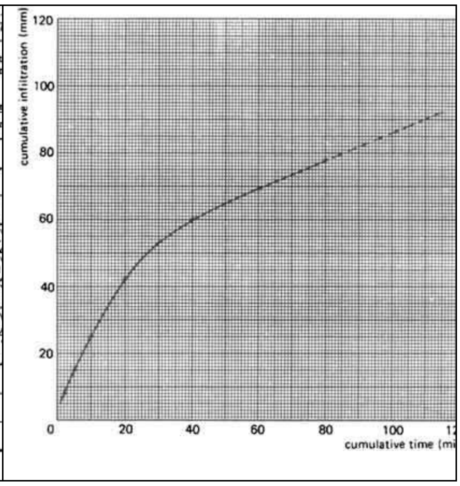
In order to choose an appropriate stream size, the following "rule of thumb" called quarter time rule is used. The quarter time rule says that the stream size should be large enough for the water to reach the end of the field (furrow irrigation) or for the water to cover the entire field (basin irrigation) in a quarter of the time needed to fill the root zone with sufficient water (the contact time). The contact time is the time needed to infiltrate the required amount of water. The contact time can be determined from the infiltration test curve.

Example:
Given the following infiltration test results:

Site location: EXAMPLE Soil type: Loam Test date: 5. DEC. 198?

1 Reading on the clock (hr min sec)	2 Time difference (min)	3 Cumulative time (min)	4 Water level readings before filling (mm)	4 Water level readings after filling (mm)	5 Infiltration (mm)	6 Infiltration rate (mm/min)	7 Infiltration rate (mm/hour)	8 Cumulat infiltr (mm)
14 05 0	start = 0	start = 0		100				start
14 07 0	2	(0+2) 2	92	100	(100-92) 8	(8/2) 4.00	240	(0+8)
14 10 0	3	(2+3) 5	93	99	(100-93) 7	(7/3) 2.33	140	(8+7)
14 15 0	5	(5+5) 10	89	101	(99-89) 10	(10/5) 2.00	120	(15+10)
14 25 0	10	(10+10) 20	84	100	(101-84) 17	(17/10) 1.70	102	(25+17
14 35 0	10	(20+10) 30	89	102	(100-89) 11	(11/10) 1.10	66	(42+11
14 45 0	10	(30+10) 40	95	101	(102-95) 7	(7/10) 0.70	42	(53+7
15 05 0	20	(40+20) 60	92	100	(101-92) 9	(9/20) 0.45	27 *	(60+9)
15 25 0	20	(60+20) 80	91		(100-91) 9	(9/20) 0.45	27 *	(69+9

* basic infiltration rate



Suppose it has been determined that 70 mm of water has to be supplied to a basin. From the curve it can be observed that to Infiltrate 70 mm would take approximately 74 minutes. This means that when applying the quarter time rule, the basin must be covered with water in 74/4 - 18 to 19 minutes. So the stream size must be chosen in such a way that indeed the field is covered with water within some 18 or 19 minutes. If it takes longer, the distribution of water in the root zone is poor. If it is for some reason not possible to Increase the stream size and it takes longer than 18 or 19 minutes to cover the field, then it will be necessary to reduce the size of the basin such that it is possible to cover the field within 18 or 19 minutes.

IRRIGATION TIME

The irrigation time (in minutes or hours) is the time needed to supply the required irrigation depth (in mm). The irrigation time depends on: the stream size (l/sec), the required irrigation depth (mm) and the size of the field to be Irrigated (ha). The following formula is used to determine the irrigation time:

$$\text{Irrigation time (hours)} = \frac{2.78 \times \text{irrigation depth (mm)} \times \text{field size(ha)}}{\text{stream size (l/sec)}}$$

Example:

If for example the required irrigation depth is 50 mm, the available stream size is 20 l/sec and the size of the field is 75 x 50 m, the irrigation time is calculated as follows:
Step 1: Determine the field size in hectares.
The size is 75 m x 50 m = 3 750 m2 = 3750/10 000 = 0.375 ha
Step 2: Determine the irrigation time
Irrigation time (hours) = 2.6 hours = 156 minutes

Applying the quarter time rule it would mean that the water has to reach the end of the furrow or cover the basin in 156/4 39 minutes. If it takes longer the stream size per furrow or basin has to be increased or the furrow length or basin size reduced.

Poor wetting patterns can be caused by:
- unfavourable natural conditions, e.g. a compacted layer, different soil types, uneven slope;
- poor layout, e.g. a furrow spacing too wide;
- poor management: supplying a stream size that is too large or too small, stopping the Inflow too soon.

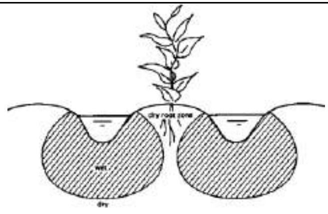
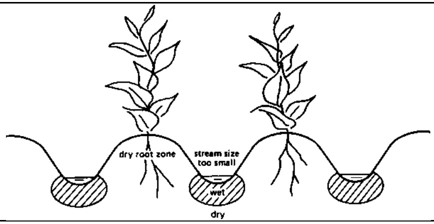
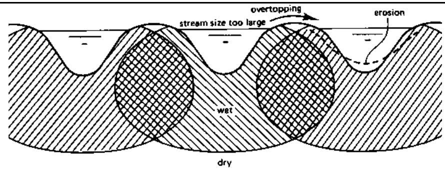
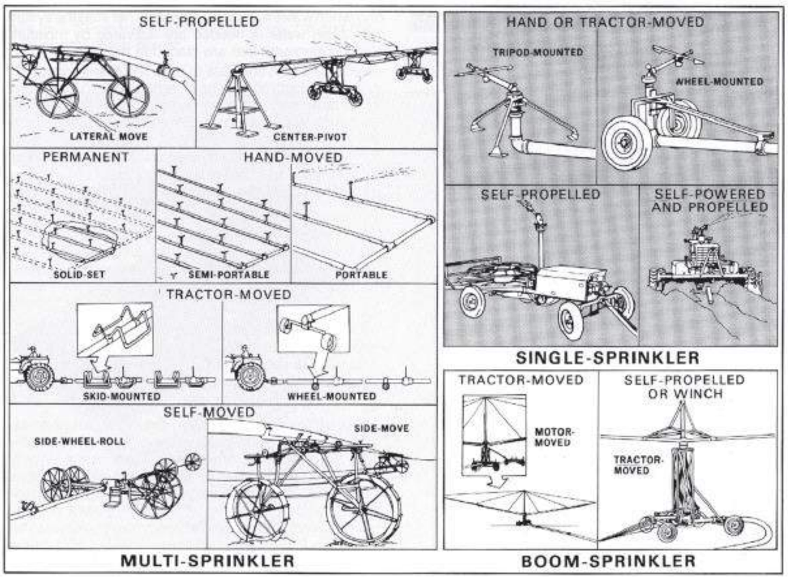
		
Furrow spacing too wide: • the root zone will not be adequately wetted	Stream size too small: • inadequate wetting of the ridges. • poor water distribution along the furrow. Slow advance. High looses at the head of the furrow.	stream size is too large • on flat slopes, overtopping of the ridge may occur • On steeper slopes erosion of the bed and sides of the furrow

Figure 2-41 Poor wetting patterns in furrows

SPRINKLER IRRIGATION:

(5% of the irrigated land worldwide). (up to 75% application efficiency)
- suit most soil types and terrains,
- does not function well under windy conditions.
- can be used for frost protection, fertilizers and pesticides application.
- High initial cost of the equipment and the energy costs required for pumping.
- Need for good-quality water, particularly with sodium and chloride
- PRICE: rootcrops, (1.600-2.300 Eur/ha), potato, rice, tobacco, cabage (3.100-3.500 Eur/ha). 40-50% reduction if the systems are without second filtration



There are different sprinkler devices: revolving head, multiple-nozzle, fixed head, etc. According to their mobility, they can be classified in Permanent, semi portable, portable, (hand moved, tractor moved, self-moved, lateral moved (center pivot, side move), Mobile raingun systems (hose-pull system; hose-reel system), etc.

Sprinkler irrigation is a method of applying irrigation water which is similar to natural rainfall. Water is distributed through a system of pipes usually by pumping. It is then sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground. The pump supply system, sprinklers and operating conditions must be designed to enable a uniform application of water.

Suitable crops: Sprinkler irrigation is suited for most row, field and tree crops and water can be sprayed over or under the crop canopy. However, large sprinklers are not recommended for irrigation of delicate crops such as lettuce because the large water drops produced by the sprinklers may damage the crop.

Suitable land slopes and soils: Sprinkler irrigation is adaptable to any farmable slope, whether uniform or undulating. The lateral pipes supplying water to the sprinklers should always be laid out along the land contour whenever possible. This will minimize the pressure changes at the sprinklers and provide a uniform irrigation.

Sprinklers are best suited to sandy soils with high infiltration rates although they are adaptable to most soils. The average application rate from the sprinklers (in mm/hour) is always chosen to be less than the basic infiltration rate of the soil so that surface ponding and runoff can be avoided. Sprinklers are not suitable for soils which easily form a crust. If sprinkler irrigation is the only method available, then light fine sprays should be used. The larger sprinklers producing larger water droplets are to be avoided.

Suitable irrigation water: a good clean supply of water, free of suspended sediments, is required to avoid problems of sprinkler nozzle blockage and spoiling the crop by coating it with sediment.

Sprinkler System Layout
A typical sprinkler irrigation system consists of the following components:

- Pump unit
- Mainline and sometimes submainlines
- Laterals
- Sprinklers

The mainline and sub-mainlines are pipes which deliver water from the pump to the laterals. In some cases, these pipelines are permanent and are laid on the soil surface or buried below ground. In other cases, they are temporary, and can be moved from field to field. The laterals deliver water from the mainlines or submainlines to the sprinklers. They can be permanent but more often they are portable and made of aluminium alloy or plastic so that they can be moved easily.

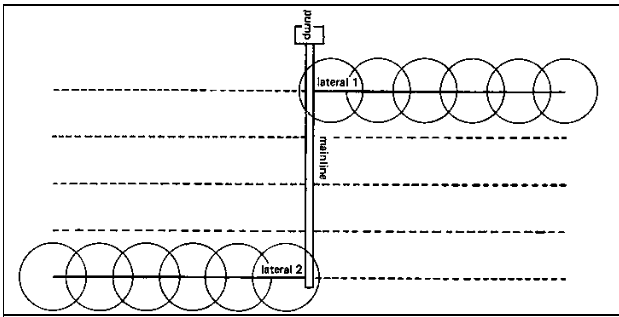
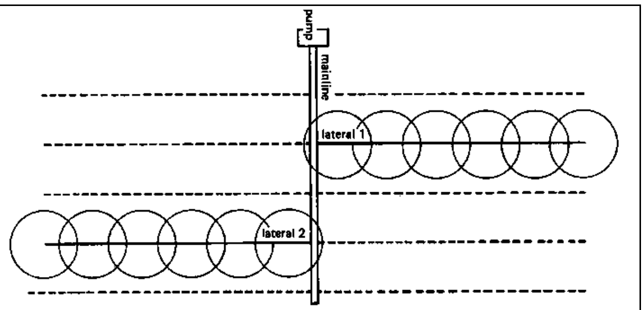
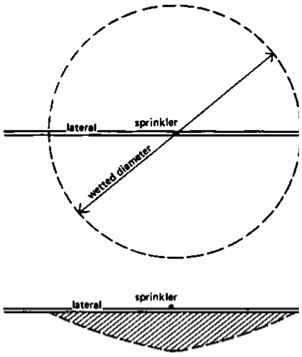
	
Hand-moved sprinkler system using two laterals (Laterals 1 and 2 in position 1)	Hand-moved sprinkler system using two laterals (Laterals 1 and 2 in position 2)

Figure 2-42 Most common type of sprinkler system layout

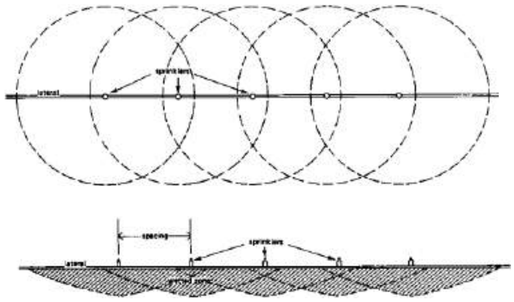
The most common type of sprinkler system layout is shown in Figure 2.44. It consists of a system of lightweight aluminium or plastic pipes which are moved by hand. The rotary sprinklers are usually spaced 9-24 m apart along the lateral which is normally 5-12.5 cm in diameter. This is so it can be carried easily. The lateral pipe is located in the field until the irrigation is complete. The pump is then switched off and the lateral is disconnected from the mainline and moved to the next location. It is re-assembled and connected to the mainline and the irrigation begins again. The lateral can be moved one to four times a day. It is gradually moved around the field until the whole field is irrigated.

Figure 2-43 Moving a lateral

A common problem with sprinkler irrigation is the large labor force needed to move the pipes and sprinklers around the In some places field. Such labor may not be available and may also be costly. To overcome this problem many mobile systems have been developed such as the hose reel raingun and the centre pivot. However, these systems go beyond the scope of this introduction to sprinkler systems.



Wetting patterns: The wetting pattern from a single rotary sprinkler is not very uniform (See fig. 2.47). Normally the area wetted is circular (see topview). The heaviest wetting is close to the sprinkler (see sideview). For good uniformity several sprinklers must be operated close together so that their patterns overlap (Fig. 2.46). For good uniformity the overlap should be at least 65% of the wetted diameter. This determines the maximum spacing between sprinklers.



The **uniformity** of sprinkler applications can be **affected by wind and water pressure**. Spray from sprinklers is easily blown about by even a gentle breeze and this can seriously reduce uniformity. To reduce the effects of wind the sprinklers can be positioned more closely together.

Sprinklers will only work well at the right operating pressure recommended by the manufacturer. If the pressure is above or below this, then the distribution will be affected. The most common problem is when the pressure is too low. This happens when pumps and pipes wear. Friction increases and so pressure at the sprinkler reduces. The result is that the water jet does not break up and all the water tends to fall in one area towards the outside of the wetted circle. If the pressure is too high, then the distribution will also be poor. A fine spray develops which falls close to the sprinkler.

Application rate

This is the average rate at which water is sprayed onto the crops and is measured in mm/hour. The application rate depends on the size of sprinkler nozzles, the operating pressure and the distance between sprinklers. When selecting a sprinkler system, it is important to make sure that **the average application rate is less than the basic infiltration rate of the soil**. In this way all the applied will be readily absorbed by the soil and there should be no runoff.

Sprinkler drop sizes

As water sprays from a sprinkler it breaks up into small drops between 0.5 and 4.0 mm in size. The small drops fall close to the sprinkler whereas the larger ones fall close to the edge of the wetted circle. Large drops can damage delicate crops and soils and so in such conditions it is best to use the smaller sprinklers.

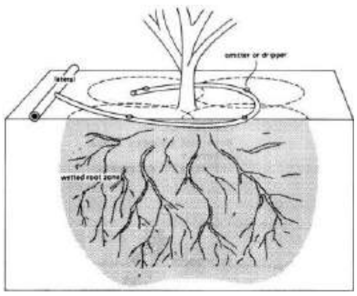
Drop size is also controlled by pressure and nozzle size. When the pressure is low, drops tend to be much larger as the water jet does not break up easily. So, to avoid crop and soil damage use small diameter nozzles operating at or above the normal recommended operating pressure.

TRICKLE (DRIP) IRRIGATION

0.1% of irrigated land. Up tp 90% efficiency. The method comprises trickling or dripping water onto the soil at very low rates (2-20 litres/hour) next to the plant, so almost all the water is absorbed into the soil, there is little or no runoff can be used to apply fertilizers.

- High equipment and setting up costs can be high,
- problems with blocking of the emitters from sand and silt, chemical precipitation and algae.

Water is applied close to plants so that only part of the soil in which the roots grow is wetted, unlike surface and sprinkler irrigation, which involves wetting the whole soil profile. With drip irrigation water, applications are more frequent (usually every 1-3 days) than with other methods and this provides a very favourable high moisture level in the soil in which plants can flourish.



Suitable crops

Drip irrigation is most suitable for row crops (vegetables, soft fruit), tree and vine crops where one or more emitters can be provided for each plant. Generally, only high value crops are considered because of the high capital costs of installing a drip system.

Suitable slopes

Drip irrigation is adaptable to any farmable slope. Normally the crop would be planted along contour lines and the water supply pipes (laterals) would be laid along the contour also. This is done to minimize changes in emitter discharge as a result of land elevation changes.

Suitable soils

Drip irrigation is suitable for most soils. On clay soils water must be applied slowly to avoid surface water ponding and runoff. On sandy soils higher emitter discharge rates will be needed to ensure adequate lateral wetting of the soil.

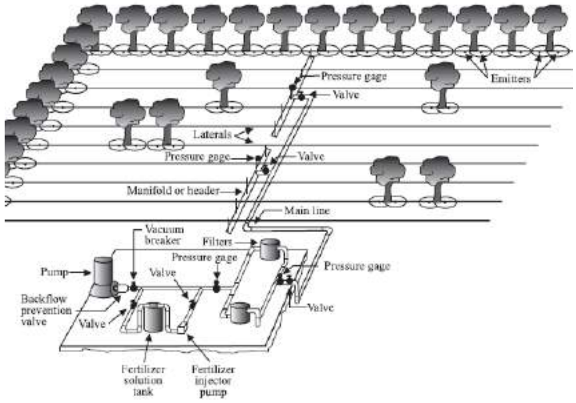
Suitable irrigation water

One of the main problems with drip irrigation is blockage of the emitters. All emitters have very small waterways ranging from 0.2-2.0 mm in diameter and these can become blocked if the water is not clean. Thus, it is essential for irrigation water to be free of sediments. If this is not so then filtration of the irrigation water will be needed.

Drip System Layout

A typical drip irrigation system is shown in Figure 61 and consists of the following components:

- Pump unit
- Control head
- Main and submain lines
- Laterals
- Emitters or drippers.



The **pump unit** takes water from the source and provides the right pressure for delivery into the pipe system.

The **control head** consists of valves to control the discharge and pressure in the entire system. It may also have filters to clear the water. Common types of filter include screen filters and graded sand filters which remove fine material suspended in the water. Some control head units contain a fertilizer or nutrient tank. These slowly add a measured dose of fertilizer into the water during irrigation. This is one of the major advantages of drip irrigation over other methods.

Mainlines, submains and laterals supply water from the control head into the fields. They are usually made from PVC or polyethylene hose and should be buried below ground because they easily degrade when exposed to direct solar radiation. Lateral pipes are usually 13-32 mm diameter.

Emitters or drippers are devices used to control the discharge of water from the lateral to the plants. They are usually spaced more than 1 metre apart with one or more emitters used for a single plant such as a tree. For row crops more closely spaced emitters may be used to wet a strip of soil. Many different emitter designs have been produced in recent years. The basis of design is to produce an emitter which will provide a specified constant discharge which does not vary much with pressure changes and does not block easily.

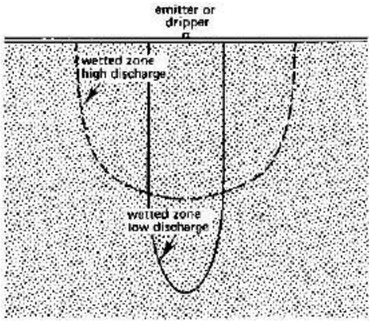
Operating Drip Systems

A drip system is usually permanent. When remaining in place during more than one season, a system is considered permanent. Thus, it can easily be automated. This is very useful when labour is scarce or expensive to hire. However, automation requires specialist skills and so this approach is unsuitable if such skills are not available.

Water can be applied frequently (every day if required) with drip irrigation and this provides very favourable conditions for crop growth. However, if crops are used to being watered each day they may only develop shallow roots and If the system breaks down, the crop may begin to suffer very quickly.

Wetting patterns

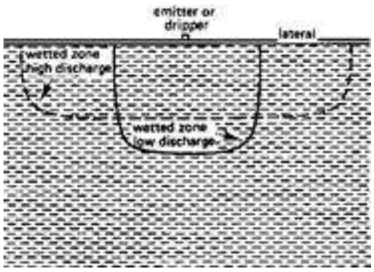
Unlike surface and sprinkler irrigation, drip irrigation only wets part of the soil root zone. This may be as, low as 30% of the volume of soil wetted by the other methods. The wetting patterns which develop from dripping water onto the soil depend on discharge and soil type. The fFigure shows the effect of changes in discharge on two different soil types, namely sand and clay.



SAND

Wetting patterns

Unlike surface and sprinkler irrigation, drip irrigation only wets part of the soil root zone. This may be as, low as 30% of the volume of soil wetted by the other methods. The wetting patterns which develop from dripping water onto the soil depend on discharge and soil type. Figures show the effect of changes in discharge on two different soil types, namely sand and clay.



CLAY

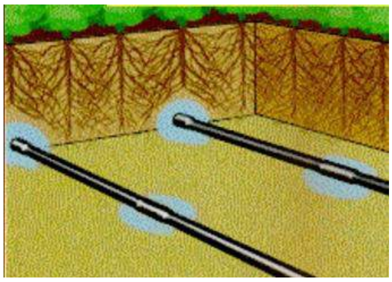
Although only part of the root zone is wetted it is still important to meet the full water needs of the crop. It is sometimes thought that drip irrigation saves water by reducing the amount used by the crop. This is not true. Crop water use is not changed by the method of applying water. Crops just require the right amount for good growth.

The water savings that can be made using drip irrigation are the reductions in deep percolation, in surface runoff and in evaporation from the soil. These savings, it must be remembered, depend as much on the user of the equipment as on the equipment itself.

Drip irrigation is not a substitute for other proven methods of irrigation. It is just another way of applying water. It is best suited to areas where water quality is marginal, land is steeply sloping or undulating and of poor quality, where water or labour are expensive, or where high value crops require frequent water applications.

Subsurface irrigation: irrigation water is applied below the ground surface, through buried pipes or drains. It is successfully practiced

- in some humid areas, for example in the Netherlands.
- in arid regions can cause serious salinity problems.



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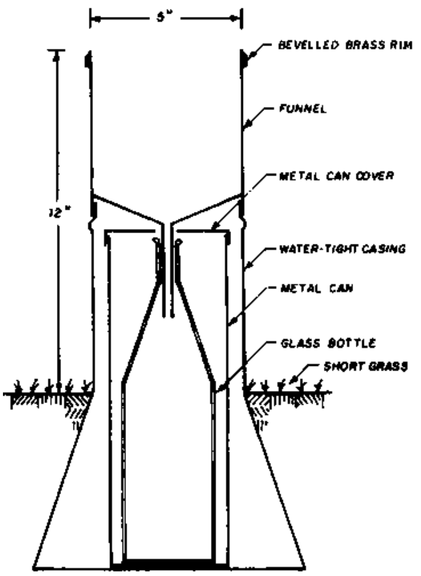
4 ANNEXES

4.1 ANNEX I: RAINFALL MEASUREMENT (DOORENBOS, 1976)

The total amount of rainfall over a given period is expressed as the depth of water which would cover a horizontal area if there is no runoff, infiltration and evaporation. This depth is generally expressed in millimetres.
Accuracy of rainfall measurement is mainly affected by wind, by the height of the gauge and exposure. Wind and exposure errors can be very large, even more than 50 percent. The catch of rainfall is a function of the height of the gauge; the more open the location the greater will be the difference in catch with height.

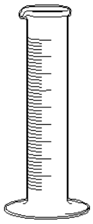
RAIN GAUGES
Rain gauges have a cylindrical form. The leak proof collector rim is placed above a funnel which leads to a receiver. The receiver should have a narrow neck into which the funnel fits to reduce evaporation loss.
The collector should have a receiving area of 200 to 500 cm2. The rim of the collector should have a sharp edge which falls away vertically inside. The collector is designed so that rain cannot splash out; the walls should therefore be sufficiently deep and the slope of the funnel sufficiently steep (more than 45°).
Rain gauges are made of non-corrosive metal, fiberglass or plastic. Since type, diameter of the collector, height and manner in which the gauge is exposed vary considerably from country to country, it is important that the type selected, and method of installation should be similar to any other rain gauge in the area in order to obtain comparable data. Normal height of exposure is usually 30 cm above ground level.
At greater height wind affects the accuracy of measurement. Where the rain gauge placement and particularly the siting are very different from local practice, a side by side comparison between the two rain gauges may be needed. The graduation of the gauging device (jar or rod) must, however, always be consistent with the size of the collecting area of the rain gauge. A number of rain gauge types are shown below.



The site must be level and the surrounding ground should be uniform. The ground should preferably be grassed or loose earth. No object such as another instrument, building or trees should be closer than four times their height. Very exposed sites, such as on the top of a hill, should be avoided. For very exposed sites without any natural shelter rain gauge shields are sometimes used. The rain gauge should be firmly mounted on a concrete base. The rim of the rain gauge must always be horizontal.

MEASUREMENTS

Measurements should be taken at the same time each morning. A graduated measuring cylinder or a graduated dipstick or rod should be used. The former is preferred. If it is raining at time of observation, measurements should be taken quickly to avoid loss of catch.



A measuring cylinder, standard for the instrument in use, should be of clear glass or plastic. The diameter of the measuring cylinder should not be more than one third of the diameter of the rim of the gauge. Graduations should be clearly engraved in 0.2 mm graduations. The measuring procedure is to pour the rain water from the storage contained into the measure and to read the value from the graduations. If there has been considerable rainfall, this may have to be done in two or more stages. The bottom of the water meniscus should be taken as the defining line. When reading, the cylinder should be held vertically. The empty storage vessel is then returned to the gauge and the collector replaced.

If no special graduated measure adapted to the rain gauge in use is available, a measure graduated in cm3 can be used. The procedure is the same, but the observed volume should be divided by the surface area of the collector of the gauge in cm2 to find the cm of rainfall. Errors using this type of measurement can be
greater.

OBSERVATIONS

Rainfall should be observed in units of 0.1 mm. Readings of less than 0.05 mm should be recorded as a "trace". A "trace" is also recorded when there is no sign of precipitation in the gauge but it is known for certain that slight rainfall has occurred since the last rain gauge reading.
It is conventional to allocate the 24 hours catch observed in the rain gauge before or at 09.00 hours to the previous day. For example, the catch measured at 08.00 hours on 1 December will be shown in the record dated 30 November and be included in the November totals. The hour of observation should, however, still coincide with local practice.

MAINTENANCE

Rain gauges should be checked for leakage; dust and leaves should be removed from the collector. The inside should be cleaned but should not be polished. The measuring cylinder should be clean, and should not be dented. A spare measuring cylinder should be available. Plant growth around and above the rain gauge should be kept out.

4.2 ANNEX II: IRRIGATION EFFICIENCIES

Not all water taken from a source (river, well) reaches the root zone of the plants. Part of the water is lost during transport through the canals and in the fields. The remaining part is stored in the root zone and eventually used by the plants. In other words, only part of the water is used efficiently, the rest of the water is lost for the crops on the fields that were to be irrigated.

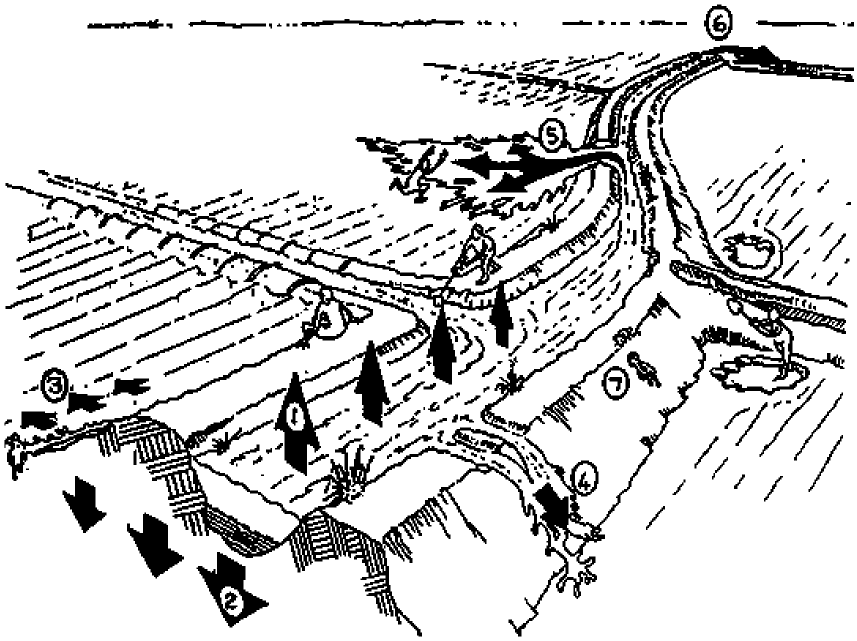


Figure 4-1 irrigation water losses in canals

Figure 4.1 shows the irrigation water losses in canals; these are due to:
1. Evaporation from the water surface
2. Deep percolation to soil layers underneath the canals
3. Seepage through the bunds of the canals
4. Overtopping the bunds
5. Bund breaks
6. Runoff in the drain
7. Rat holes in the canal bunds

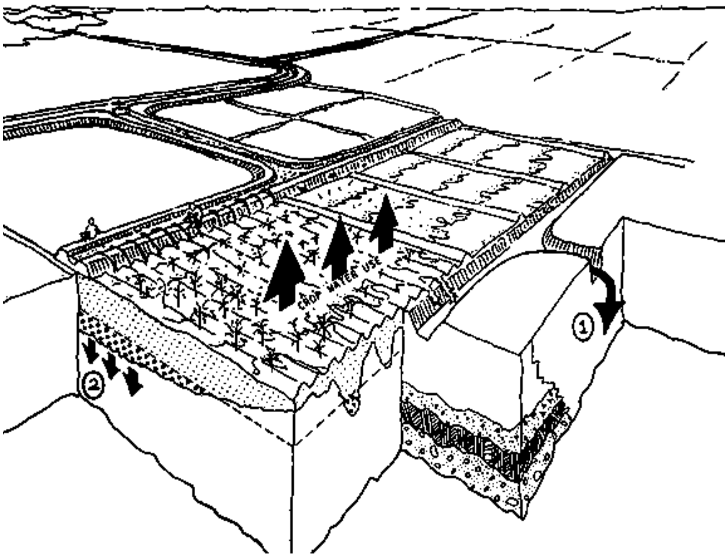


Figure 4-2 irrigation water losses in the field

Figure 4.2 shows the irrigation water losses in the field; these are due to:
1. Surface runoff, whereby water ends up in the drain
2. Deep percolation to soil layers below the root zone

To express which percentage of irrigation water is used efficiently and which percentage is lost, the term irrigation efficiency is used.
The scheme irrigation efficiency (e in %) is that part of the water pumped or diverted through the scheme inlet which is used effectively by the plants. The scheme irrigation efficiency can be sub-divided into:

- ✓ the conveyance efficiency (ec) which represents the efficiency of water transport in canals or conducts, and
- ✓ the field application efficiency (ea) which represents the efficiency of water application in the field.

The conveyance efficiency (ec) mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals.

In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils. When canals are lined with bricks, plastic or concrete, only very little water is lost. If canals are badly maintained, bund breaks are not repaired properly, and rats dig holes, a lot of water is lost.

Table 7 provides some indicative values of the conveyance efficiency (ec), considering the length of the canals and the soil type in which the canals are dug. The level of maintenance is not taken into consideration: bad maintenance may lower the values of Table 4.1 by as much as 50%.

Table 4-1 Indicative values of the conveyance efficiency (ec) for adequately maintained canals

	Earthen canals			Lined canals
Soil type	**Sand**	**Loam**	**Clay**	
Canal length				
Long (> 2000m)	60%	70%	80%	95%
Medium (200-2000m)	70%	75%	85%	95%
Short (< 200m)	80%	85%	90%	95%

The field application efficiency (ea) mainly depends on the irrigation method and the level of farmer discipline. Some indicative values of the average field application efficiency (ea) are given in Table 4.2 Lack of discipline may lower the values found in Table 4.2.

Table 4-2 Indicative values of the field application efficiency (ea)

Irrigation methods	Field application efficiency
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

Once the conveyance and field application efficiency have been determined, the scheme irrigation efficiency (e) can be calculated, using the following formula:

$$e = \frac{ec \times ea}{100}$$

with
e = scheme irrigation efficiency (%)
ec = conveyance efficiency (%)
ea = field application efficiency (%)

A scheme irrigation efficiency of 50-60% is good; 40% is reasonable, while a scheme Irrigation efficiency of 20-30% is poor.

4.3 ANNEX III: EVALUATION OF IRRIGATION PERFORMANCE

This section describes how to determine the performance of basin/furrow irrigation. It is assumed that the net irrigation water need of the crop is known (i.e. the net irrigation depth). This is compared with what happens during the actual irrigation practice. The field application efficiency thus obtained is a good measure for the evaluation of the performance.

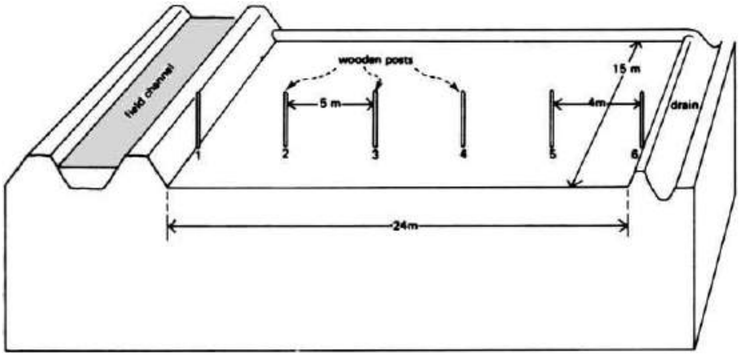


Figure 4-3 Place wooden posts at 5 a interval

Equipment needed
- Measuring tape (30 m)
- Infiltrometer
- Wooden posts or lathes
- Stopwatch or clock
- Data sheet

Method
Step 1:
Identify a typical basin or furrow, which can be considered representative of the local situation in terms of size, soil type and crop. Measure the basin size or furrow length with the tape. Record the site data on the data sheet:
Example:
Date of test: 4 December 1987
Basin size: 24 (m) x 15 (m) - 360 (m2)
Crop: Groundnuts Required net irrigation depth: 45 mm

Step 2:
Place wooden posts at 5 to 10 m intervals as shown in Figure 4.3. Record position of the posts on the data sheet (column 2).

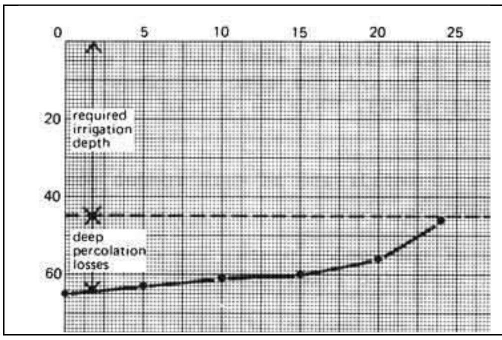
Step 3:
Carry out several infiltration tests (see Annex 3) and make an (average) infiltration curve. In this example, the curve of Annex 3 (Figure 76) is used.

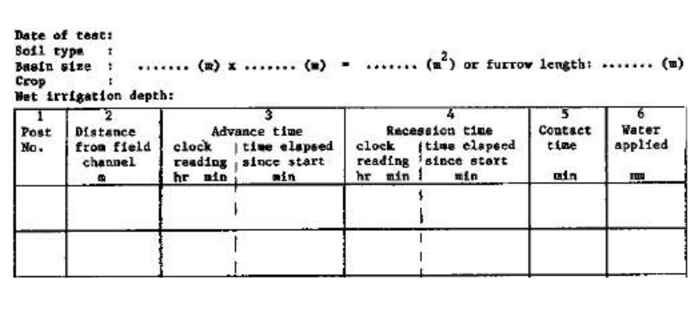
Step 4:
Now the irrigation starts. Use the same stream size and the same irrigation time as the irrigator normally uses. Record the time it takes for the water front to reach each wooden post (1 to 6). This is called the advance time: column 3.

Step 5:
Record the time it takes the water to infiltrate at each wooden post (1 to 6). This is called recession time: column 4.

Step 6:
Calculate the contact time at each of the wooden posts. The contact time is the difference between the advance and recession time: column 5.

Step 7:
Calculate at each of the wooden posts the amount of water applied (in column 6 of the following table), using the infiltration curve. All data are recorded on the data sheet as indicated in the example below.





Date of test:
Soil type :
Basin size : .... (m) x .... (m) = ... (m^2) or furrow length: .... (m)
Crop :
Net irrigation depth:

1	2	3		4		5	6
Post No.	Distance from field channel	Advance time		Recession time		Contact time	Water applied
		clock reading	time elapsed since start	clock reading	time elapsed since start		
	m	hr min	min	hr min	min	min	mm

Step 8:
Determine the field application efficiency. The field application efficiency is the fraction of the applied water that is used by the crop. Provided there are no runoff losses, the field application efficiency (%) is the required irrigation depth (mm), divided by the average applied irrigation depth (mm), multiplied by 100%.

Or:

$$\text{Field application efficiency (\%)} = \frac{\text{Required irrigation depth (mm)}}{\text{Ave. applied irrigation depth (mm)}} \times 100\%$$

:

The average irrigation depth applied (column 6) is:
(65 + 63 + 61 + 60 + 56 + 46):6 = 59 mm
The required net irrigation depth is 45 mm.
Thus the field application efficiency (%) = 45/59 x 100% = 76%
It means that the (average) deep percolation losses are 59 - 45 = 14 mm. This is shown in next table

1	2	3			4			5	6
Post No.	Distance from field channel	Advance time			Recession time			Contact time	Water applied
		clock reading		time elapsed since start	clock reading		time elapsed since start		
	m	hr	min	min	hr	min	min	min	mm
1	0	11	00	0	11	50	50	50	65
2	5	11	04	4	11	50	50	46	63
3	10	11	08	8	11	50	50	42	61
4	15	11	11	11	11	51	51	40	60
5	20	11	20	20	11	52	52	32	56
6	24	11	30	30	11	54	54	24	46
								Average	59 mm