TRAINING PACKAGE ON IRRIGATION WATER MANAGEMENT

TECHNICAL MANUAL

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Table of contents

MODULE 1: BASIC INFORMATION

The predominant agricultural system is based on smallholder production and the sub-sector for crop production is entirely dependent on rain-fed agriculture with very limited areas currently developed under irrigation. The agriculture sector is facing a great challenge of not fulfilling the food requirement of the nation and the country is forced to depend on foreign food aid in order to feed its people. Unpredictable climate change coupled with widespread land degradation and accelerated erosion diminishes the productivity of both cultivable and grazing rain-fed land. Especially vulnerable to climatic instability and frequent droughts are semi-arid areas. At the same time, depletion and pollution of limited fresh water resources and competing demands for water-among upstream and downstream users and different sectors within an area constrain the further expansion of irrigation. The problem of food security is aggravated by rapid population growth and hence of the demand for food.

Irrigation can and should play an important role in raising and stabilizing food production especially in semi-arid areas where there is relatively better land potential suitable for irrigation. There are however many obstacles to the rapid development of irrigation. Large parts of the semi-arid area have only limited freshwater resources. In other areas, potential resources are insufficiently known to permit reliable planning. Even where water resources are known to be substantial, other conditions may not be conducive to irrigation development. Such conditions include unfavorable topography and soils, distant markets and inadequate infrastructure (mainly roads), lack of information and other services to farmers. The other major production constraints that impede the development of the irrigation sub- sector among others are predominantly primitive nature of the overall existing production system, shortage and increase in the price of agricultural inputs and limited availability of improved irrigation technologies, limited trained manpower, inadequate capacity and skills in the area of irrigation, inadequate extension services, particularly in irrigated agriculture. Therefore, the importance of irrigation development, particularly in the peasant sub-sector needs prime consideration to raise production to achieve food self-sufficiency and ensure food security at household level in particular and at country level at large. The irrigated agriculture can also play a vital role in supplying with sufficient amount and the required quality of raw materials for domestic agro-industries and increase export earnings.

Irrigation supports successful crop growing and stabilizes crop yields. Irrigation is required in most of places that have an uncertainty and uneven distribution of rainfall, particularly in semi- arid and arid regions. Irrigation, however, involves high capital investment for its exploitation and to supply to crop fields. Precipitation, atmospheric waters other than precipitation (such as dew, fog, cloud and atmospheric humidity), ground water and floodwater are natural sources of water for crop production. However, their contribution to crops varies depending on their amount and availability throughout the season. Irrigation water, in general, is obtained mainly from two sources: surface water and ground water.

Rain, melting snow, rivers, lakes, reservoirs, water tanks and ponds are the main sources of surface water. However, in the Ethiopian context, melting snow is not considered as part of the main source of surface water. The surface water provides the largest quantity of irrigation water. Dams are constructed across rivers and water is diverted to agricultural fields through canals and distributed by gravity flow. Streams are also developed and the water is led to fields under gravity to irrigate crops. Ground water is also an important source of irrigation water. Rain and melting snow are the principal sources for recharging ground water. However, rain is considered as the main source for recharging ground water in Ethiopian. The average annual rainfall for the country is estimated about 800 mm, varying from about 2,000 mm over some pocket areas in southwest Ethiopia to less than 100 mm over the Afar lowlands in the northeast of the country. The rainfall, generally, characterized with erratic nature and uneven distribution throughout the crop-growing period. In addition to rainfall, seepage water from canals, reservoirs and lakes, rivers drainage and percolating floodwater also recharge the ground water. Ground water is an ideal water source provided that there is an adequate recharging potential.

Ethiopia has a vast water resource potential and the Ethiopian highlands are the source of many of international rivers like that of the Blue Nile and Wabe Shebelle draining into the neighboring countries. The country has 12 major river basins, two of which are dry (Aysha and Ogaden) and several lakes and wetlands. Integrated development master plan studies and related river basin surveys of the 1990s indicate that the total surface water resource potential of the country is about 122 billion cubic meters (m^3). Most of these surface water resources are draining out to the territory of the neighboring countries as run- off, which is benefiting them significantly and only 8- 10% of the available surface water remains within the country. Only about 4 to 5% of the potential of the surface water resource is used for irrigation. The second main source of water is ground water, which is estimated at 2.6 billion m^3. This source of water is not yet exploited fully. Ethiopia has several lakes (about 7, 000 km^2), a number of saline and crater lakes as well as several wetlands. Most of the lakes, except Lake Tana, which is located in the northwestern part of the country, are located within the Rift valley. Among these lakes only Ziway has fresh water, which is suitable for irrigation, while others are saline. Considering the water potential of the country, promotion of both small- scale and large- scale irrigation can a play major role in the development of the agriculture sector in particular and the national economy at large.

Labor availability is very vital for running irrigation activities effectively and efficiently in order to fulfill operational activities at optimum time and establish a more profitable enterprise to get the maximum benefit out of it. In this regard, the required labor forces for the successful production exist in Ethiopia when compared to other countries. This can be considered as one of the attractive elements that could be taken into account with regards to investment in the irrigation sub-sector.

The irrigation potential of the country is estimated to be about 3.7 million hectares, of which about 20 to 23% is currently utilized (PASDEP, 2009/10, MoA). There is no consistent inventory with regards to the developed area under both traditional and modern irrigation schemes. In recent years there are a large number of small- scale irrigation schemes that have been developed in different parts of the country by the Government and support of different funding agencies. However, due to different environmental and management factors, most of these small-scale irrigation schemes are not being exploited fully and irrigation, in general is not contributing its share to the overall economic development of the country as required. Hence, the irrigation sub- sector has to be given a top priority in the overall development plans of the country with the ultimate objective of enhancing agricultural production and sustain crop production in order to alleviate food insecurity problems.

The lion's share of the agricultural produce of Ethiopia originates from rain-fed agriculture. However, globally most originates from irrigated agriculture. Also reports indicates that huge improvement in productivity of agricultural produce in the past several decades largely originate from irrigated fields compared to rain-fed one. One of the most important factors for this improvement is enhanced irrigation water management.

The history of irrigation in Ethiopia dates back several centuries, while the "modern" irrigation development was started by the commercial irrigated farms established in the early 1950s through the joint venture of the Government of Ethiopia and a Dutch company in the Awash valley. Most of the irrigated land is supplied from surface water sources, while ground water use has just been started on pilot phases in east Amhara, Southern Tigray and in the Rift valley areas. Surface irrigation methods are dominated throughout. However, a sprinkler irrigation system is being practiced on about 2% of the irrigated area for sugarcane production in Fincha State farms, in Southern Tigray and Eastern Amhara under subsistence farmers. Similarly, it is being introduced in localized areas in the Rift valley (Oromia). Drip irrigation technologies are also being promoted in Southern Tigray, Eastern Amhara, Rift valley areas and under commercial farms within the Rift valley areas. Local factories are coming up and actively engaged in manufacturing irrigation technologies and improved farm implements, which could be considered as a promising step in strengthening the irrigation sub- sector in the near future.

However, there are drawbacks as a result of poor irrigation water management. For instance the rise of the ground water table from 13m below the ground level before development of irrigation project to around 1.5 m in recent years is another problem in some irrigated areas of Awash basin. Also the salinity problem in the irrigated banana fields in Hare irrigation project nearby Arbaminch is another case. You can mention several cases of conflict associated with irrigation water resources due to lack of appropriate irrigation water management practices.

The purpose of this technical manual on irrigation water management is to provide technical backup to wereda experts and eventually to farmers on how to make appropriate and reasonable irrigation scheduling, how irrigation water is applied efficiently, how water is transported from source to target efficiently, and what are the options for management of drainage water.

MODULE 2: SOIL, PLANT AND WATER RELATIONSHIPS

Soil- plant- water relationships are related to the properties of soil and crop plants that affect the movement, retention and use of water. The soil water both in content and potential plays an important role in sustaining agricultural production. Soil provides the room for water and soil nutrients, which are taken up by plants through their roots located in the same medium. Water contains a large amount of dissolved nutrients, which are essential for successful growth and development of crop plants. If rainfall is not adequate for plant growth during the growing period of a crop, additional water should be supplied to the soil for plant use in the form of irrigation. Therefore, the entry of water into the soil and its retention, movement, and availability to plant roots should be well known for the efficient management of irrigated agriculture.

The rate of infiltration of water into the soil, its retention, movement and availability to plant roots are all physical phenomena, related to the physical properties of soils. Hence, it is important to know the physical properties of soils in relation to water for efficient management of irrigated agriculture and maximize the benefit for increased crop production and productivity.

2.1 Soil physical properties influencing movement and retention of water

Soil is a three phase system comprising of the solid phase made of mineral and organic matter and various compounds, the liquid phase called the soil moisture and the gaseous phase called the soil air. The main component of the solid phase is the soil particles, the size and shape of which give rise to pore spaces of different geometry.

These pore spaces are filled with water and air in varying proportions, depending on the amount of soil moisture present. The volume compaction of the three main constituents in the soil system varies widely. In general, a good agricultural soil must have a texture, or tilth that allows moisture and oxygen in adequate proportions to reach the root zone that stores water and nutrients and allows excess water to drain away. It must be workable to facilitate cultural practices such as tilling and weeding. As a general rule, when taken on volumetric basis, an average soil in good tillage will consist of 50 percent of soil minerals including humus and air and water in equal proportions of 25 percent each respectively. In addition to the three basic components of soil described above, soil usually contains numerous living organisms such as bacteria, fungi, algae, protozoa, insects and small animals, which directly or indirectly affect soil structure and plant growth.

The most important soil properties influencing irrigation are: Infiltration characteristics and water-holding capacity of the soil. Other soil properties such as soil texture, soil structure, capillary conductivity, soil profile conditions and depth of water table are also important soil physical properties influencing the irrigation regime and need to be given prime consideration in the management of irrigation water. The soil properties that have influence in irrigated agriculture are discussed in more details hereunder.

2.1.1 Soil profile

A soil profile is a succession of soil layers in a vertical position down into loose weathered rock from which the soil was formed. The soil layers are different in colour and composition. The nature of the soil profile greatly influences the growth of roots, recycling of organic materials, the storage of moisture, and the supply of plant nutrients. Soils range in depth, with some being very shallow and not able to support rain-fed crops because there is insufficient soil for storing water or available nutrients. The depth of the effective system (root zone) depends on both the crop and soil-profile characteristics. In general terms a simplified soil profile can be described as follows:-

- **The plough layer**: This layer has a depth of 20 to 30 cm thick, which is rich in organic matter and contains many live plant roots. This is actually the layer, which is subject to land preparation and often has a dark colour, due to high organic matter content (brown to dark).
- **The deep plough layer**: This contains much less organic matter and relatively reduced live plant 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.
- **The subsoil layer**: This has hardly any organic matter or live plant roots. It is not very important for plant growth, as only a few plant roots will reach it.
- **The parent rock layer**: This layer consists of rock, from which the soil is formed. This rock is sometimes called parent material.

However, the depth of the different layers varies greatly and even some layers may be missing altogether.

2.1.2 Soil texture

The majority of agricultural soils are composed of particles of minerals, which include large coarse fragments, gravel, and particles of sands of varying sizes, silt and clay. In addition, there are also materials of organic matter in all stages of decomposition. The fine soil particle is silty clay and clay. Thus, the term “silty clay” describes a soil in which the clay characteristics are outstanding and which also contains a substantial quantity of silt.

The texture of a soil determines its water-holding capacity, which in its turn plays an important role to hold sufficient or inadequate soil moisture for plant use. If the texture of the soil dominated with more sand in its content, the soil has less water holding capacity and the moisture available for plant use is less. Significant amount of water will be lost through deep percolation beyond the active root zone, which is not available for further uptake by the crop roots.

2.1.3 Soil structure

Soil structure describes the arrangement of individual particles of soil with respect to each other into a pattern or aggregates. Such aggregates may be held together by biological or chemical bonds such as clay, organic matter, microbial glue and mineral cementing materials like aluminum and iron oxides present in the soil. The chemical bonding, particularly in tropical zones are often held together by electrical forces, using positively charged oxides of iron and aluminum with that of the negatively charged silicate clay minerals. The basic types of soil aggregate arrangements are granular, blocky, prismatic and massive structures. Granular structure occurs normally only in sands and silts of low organic matter content and facilitates aeration and capillary movement of soil moisture. Massive structure is similar to single grained structure, except that it is coherent. The presence of the massive structure in the topsoil blocks the entrance of water and 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 water in the soil is predominantly vertical and side flow is critically affected. Therefore, in prismatic structure the supply of water to the plant roots is usually poor, due to the uptake of water and soil nutrients are affected. Unlike texture, soil structure is not permanent. Through cultivation practices (ploughing, ridging, etc.), the farmer tries to obtain a granular topsoil structure for his fields to improve water entry and good seed germination.

Soil structure plays an important role in plant growth as it influences the amount and nature of porosity and regulates the proportion of water, air and heat regimes in the soil, besides affecting mechanical properties of soil. Massive structure slows the entry and movement of water into the soil and hinders free drainage. But crumb and granular structures provide the most favourable physical properties (infiltration, water-holding capacity, porosity and bulk density) of soil for plant growth. Therefore, from crop production point of view granular and crumb structures are more suitable and have better water holding capacity, which hold sufficient amount of available moisture to crop plants. The stability of soil aggregates against disintegrating forces of water and physical action is most vital in structural behaviors of soil. Soils high in water- stable aggregates are more permeable to water and air, while soil tends to puddle when stable aggregates are less. Puddling of soil as in wetlands destroys all soil structures and makes it difficult to prepare a good tilth for the crops to be planted. Therefore, capillary system formations, water-holding capacity, aeration, drainage, erosion and penetration of roots are affected by the soil structure.

Thus, the management of soil aims at obtaining soil structures favourable for plant growth and yield, besides ensuring soil conservation and good infiltration and movement of water in soils. Common methods of soil structure management include addition of organic matter and adoption of suitable tillage practices, soil conservation and cropping practices. Growing legumes, mulching, ensuring proper irrigation and drainage, occasional use of soil conditioners and application of balanced and optimum levels of fertilizers help in development of good physical conditions of soils. Tillage practices can be damaging to soil productivity when they are carried out with sub-optimal soil conditions, since they can destroy the physical condition of fine textured soils when the soil is too wet. In such cases, the naturally occurring soil aggregates, become fractured and thus, lose their water stability and consequently develop into hard clods. Such conditions produce an inferior seedbed as larger soil aggregates only loosely surround the seed reducing contact with soil moisture. Excessive tillage or wrongly timed tillage can also cause changes to the physical properties of the soil, notably compaction, particularly fine textured soils are prone to compaction when tilled wet or by excessive passage of animals, tractors and implements over the soils.

2.1.4 Soil bulk density

For irrigation purposes it is always preferable to express the moisture content on a volumetric basis. Bulk volume consists of the volume of the soil particles (solid phase) and the volume of the pores or pore space. The weight of the bulk volume consists of the weight of the soil particles (solid phase) and the weight of the soil moisture. Porosity is defined as the ratio of pore space to total bulk volume. To convert the moisture content from weight basis to volumetric basis, the bulk density of the soil is required, which refers to the weight of a unit volume of dry soil, which includes the volume of solids and pore space (kg/m3). Thus, the bulk density is determined by weighing the soil contained in a certain volume. This is the reason for sampling cores of soil. The following expression provides the bulk density:

Equation

$$Ds = \frac{\text{Mass (weight) of dry soil}}{\text{Bulk volume of soil}}$$

Where:
Ds = Soil bulk density

To convert the percentage of moisture from weight to volume basis the following equation is used:

Equation

$$SMv = SMw \times \frac{Ds}{Dw}$$

Where:
SMv = Soil moisture by volume
SMw = Soil moisture by weight
Ds = Soil bulk density
Dw = Water density

Since Dw = 1, the equation is simplified to:

$$SMv = SMw \times Ds$$

Uniform plant root development and water movement in soil occur when soil profile bulk density is uniform; a condition that seldom exists in the field. Generally, soil compaction occurs in all soils where tillage implements and wheel traffic are used. Compaction decreases pore space, thus decreasing root development, oxygen content, water movement and availability. Other factors that affect bulk density include plant root growth and decay, wormholes and organic matter. Sandy soils generally have bulk densities greater than clayey soils.

Having determined the moisture content at FC and PWP, the water-holding capacity of the soil or the total available soil moisture on a volumetric basis can be provided through the following expression:

Equation

$$SMta\text{-}v = SMv\ (0.1\text{-}0.3\ \text{bar}) - SMv\ (15\ \text{bar})$$

Where:
SMta-v = Water-holding capacity by volume (%)
SMv (0.1-0.3 bar) = Soil moisture by volume at FC (pF ≈ 2) (%)
SMv (15 bar) = Soil moisture by volume at PWP (pF = 4.2) (%)

The SMta expressed in % can be expressed in mm/m by multiplying the SMv percent by 10. Often Soil Moisture Tension (SMT) is indicated in pF, where pF is the negative logarithm (cm water column) and 1 000 cm water column is 1 atmosphere. A specific pore size distribution of a given soil determines the specific relationship between its pF values and the corresponding moisture contents by volume, since at each pF level all pores wider than the corresponding critical EPD are empty.

Example

A soil has a soil bulk density of Ds of 1.2. After drying 120 grams of wet soil in an oven at 105-110°C for 24 hours, this soil lost 20 grams of moisture.

– What would be the moisture volumetric content of the soil?

– What would be the corresponding water depth in mm/m?

SMw = (120 - (120-20))/100) x 100 = 20%

SMv = 20 x 1.2 = 24%

Water depth = (24/100) x 1000 = 24 x 10 = 240 mm/m

Uniform plant root development and water movement in the soil occur when soil profile bulk density is uniform; a condition that seldom exists in the field. Generally, soil compaction occurs in all soils where tillage implements and wheel traffic are used. Compaction decreases pore space, thus decreasing root development, oxygen content, water movement and availability. Other factors that affect bulk density include plant root growth and decay, wormholes and organic matter. Sandy soils generally have bulk densities greater than clayey soils.

2.1.5 Porosity

Porosity of a soil is defined as the ratio of the volume of voids (a space filled with air and water) to the total volume of soils and is expressed in percent of pore spaces between the particles of soil. Depending on the pore sizes existing in general, capillary pores and non-capillary pores or large pores induce drainage and aeration. As a general rule, coarse textured, stony and sandy soils have a lower proportion of total pore space than fine textured clays and clay loams.

The amount of pore space has a direct impact on the productive value of soils because of its influence on the water-holding capacity, the movement of air, water, root penetration and nutrients through the soil. Compaction of soil affects the porosity of the soil by reducing the amount of pore spaces. In this regard, a 10% reduction in porosity that might be caused as a result of an excessive tillage can have drastic consequences on the plant growth, due to greatly reduced porosity that can affect the movement of water and nutrients within the soil profile. A porosity of about 50 % is generally, considered ideal for most agricultural soils, however, its determination is difficult, since their size, number, shape and orientation vary greatly. A more practical method is to examine the development of existing plant roots in the soil prevailing. A well- developed plant root system would be a good indicator of a well-aerated soil of good porosity.

Porosity is influenced by textural characteristics of soil and ranges from 35 to 50 % in sandy soils and from 40 – 60 % in clayey soil. It increases with an increase in fineness of particles, looseness of soils and amount of soil aggregates. Thus, a sandy soil has more non- capillary pores, and is characterized by good drainage and aeration and low water-holding capacity, while the clayey soil has more capillary pores that is characterized by high water-holding capacity, but by poor drainage and aeration.

2.2 Entry of water into the soil

Infiltration is the process of entry of water and its downward movement from the surface into the soil. Water enters the soil through pores, cracks, wormholes, decayed-root holes, and cavities introduced by tillage. The infiltration characteristics of soil are one of the dominant variables influencing irrigation. The rate at which water enters soil is called intake rate or infiltration rate. The infiltration rate of a soil is at a maximum as soon as the water enters the soil when applied at its surface. Infiltration rate is very rapid at the start of irrigation or rain but it decreases rapidly with the advance of time and eventually approaches a constant value. The constant value that is reached after some time from the start of irrigation is termed as the basic infiltration rate. The actual rate at which water enters the soil at any given time is called infiltration velocity.

When water is applied at the surface, it enters the soil as fast as it is supplied as long as the supply rate is less than the intake rate of the soil. However, when the supply rate exceeds the intake rate, water ponds over the area or moves down the slope as runoff. Therefore, when irrigating, it is very important to control flow stream size as not to proceed over the intake rate of the soil.

Factors influencing infiltration rate

The infiltration rate is influenced by different factors. The major factors governing the rate of infiltration of water into the soil are conditions and characteristics of the soil surface, tillage and crop management practices, vegetation cover, duration of irrigation and the level of water table. Conditions and characteristics of the soil surface primarily involved in the process of irrigation are the initial soil water content, soil texture, soil structure, soil compaction, soil organic matter content, soil depth, depth of water table, soil surface sealing or forming crust, presence of cracks in soil surface and soil hydraulic conductivity.

Organic matter improves soil aggregates and increases macro-pores and porosity. As a result it increases infiltration and hence soil moisture content. A soil with higher proportion of sand allows water intake at a higher rate than that with more of silt and clay. A deep soil with good permeability allows greater infiltration than a shallow soil. As far as infiltration rate is concerned the soil surface with vegetation cover favors a greater infiltration than a bare soil, as vegetative cover encourages slow movement of water and this in turn gives more time for the water to infiltrate into the soil by minimizing surface run-off. Furthermore, infiltration rates reduce over the irrigation season, particularly when the irrigation water deposits fine soil particles in the irrigated fields. The soil water content and looseness of the soil surface exert a profound influence on the initial rate of the infiltration. When the soil water content is high and the soil is compacted, the rate and amount of infiltration is low. Soil tillage and crop management practices increase the looseness of soil and thereby increase infiltration.

2.3 Soil moisture

Soil moisture is one of the most important soil ingredients and dynamic properties of soil. Soil moisture intensely affects many physical and chemical reactions of the soil as well as plant growth. Only part of the soil moisture or water stored in the root zone of a crop can be available and utilized by the crop for its transpiration and building up of plant tissues. The remaining soil moisture is lost either through leaching beyond the active root zone of crop plants and/or lost into the atmosphere in the form of evapo-transpiration.

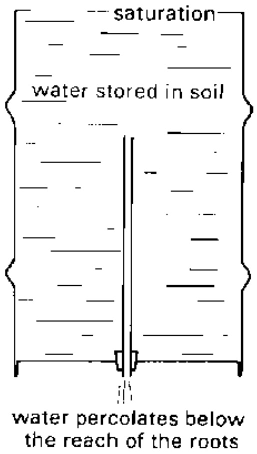
Various forms of moisture occur in the soil. Small pores are required for moisture storage, medium- sized pores for water movement and large pores for aeration. The three main classes of soil water are:

- **Gravitational water**: This is the water that occupies the larger pore spaces and drains away from the root zone of a crop under the influence of gravity, unless prevented by impervious layer of soil, rock or a high water table. Its upper limit is when the pores are completely filled with water, when the soil is saturated. Depending on the soil type the rate at which the water drains downwards from the root zone will take less than a day in coarse sandy soils to more than 3 days in heavy clays.
- **Capillary water**: This is the water held by surface tension forces in pore spaces between soil particles. Its upper limit is when all the gravitational water has drained away and when the soil is said to be at field capacity. This is the main source of water to crop plants.
- **Hygroscopic water**: This is held as a very thin film round the particles of soil being held to firmly that in most circumstances it is unavailable to the plant.

Soils vary in their capacity to hold soil moisture according to their texture and physical structures. Fine soils such as clay soils can store much more water than coarser textured soils, such as sand soils. According to soil water availability to plants and drainage characteristics various forms of moisture occur in the soil:

a) **Saturation:** the soil can be compared to a water reservoir for the plants. When the soil is saturated, the reservoir is full. Saturation capacity is reached when all pores of the soil are completely filled with water. It is then equal to the porosity of the soil.

Fig. 1. Saturation

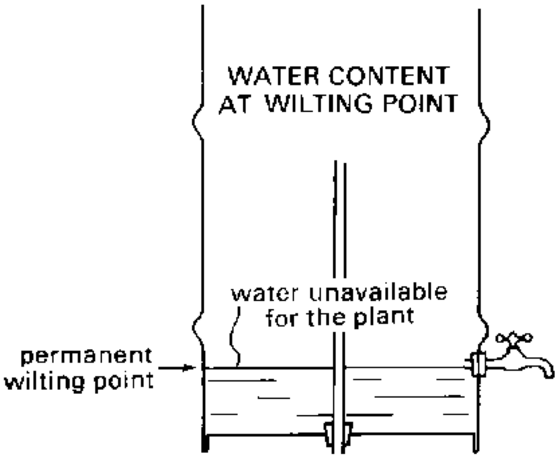


b) **Field capacity (FC)**: After saturation some water drains rapidly below the root-zone before the plant can use it. The remaining water is the amount of water a soil holds after “free or gravitational” water has drained from a saturated soil because of gravity. When this water has drained away, the soil is at field capacity. The plant roots draw water from what remains in the reservoir (see Fig. 2 below).

This free or gravitational water can drain from coarse-textured (e.g. sandy) soils in a few hours from the time of rainfall or irrigation, from medium-textured (e.g., loamy) soils in about 24 hours, and from fine-textured (e.g., clay) soils in several days. Soil properties that affect field capacity are texture, structure, bulk density, and strata within the soil profile that restrict water movement.

At this moisture capacity, the soil water is retained by the soil at a tension or suction pressure of 1/3 atmosphere.

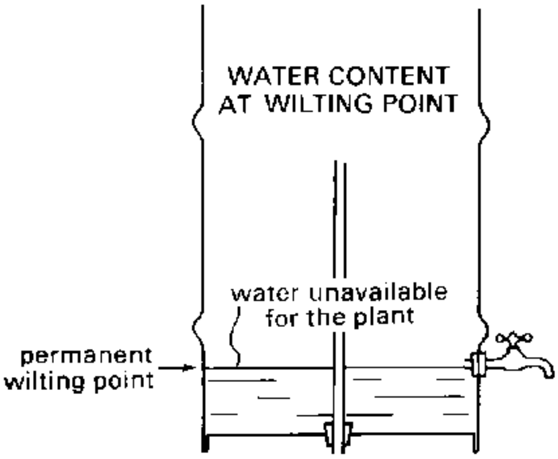
Fig. 2. Field capacity



c) **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.

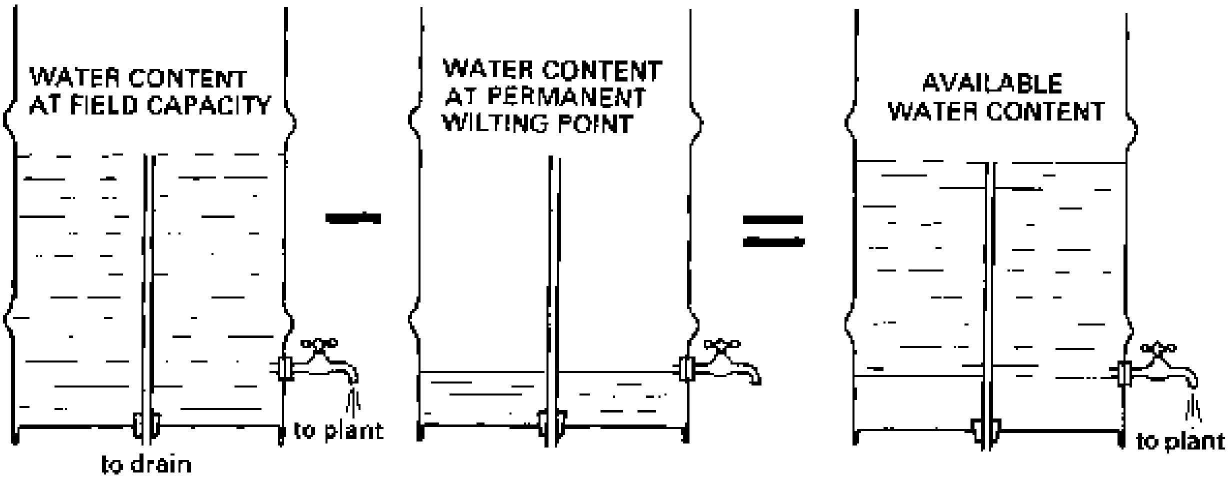
The dryer the soil becomes, the more tightly the remaining water is retained and the more difficult it is for the plant roots to extract it. At a certain stage, the uptake of water is not sufficient to meet the plant's needs. The plant looses freshness and wilts; the leaves change colour from green to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

Fig. 3. Permanent wilting point



d)Available soil water (AW): 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. 4 below.

Fig. 4. The available soil moisture or water content



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

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.

e) Readily available soil water (RAW):, the beneficial soil water content that is between FC and moisture content higher than the PWP level. This range of moisture content is called readily available soil water (RAW) which is less than AW. The RAW is the maximum amount of soil water that can be removed by the plant from the soil before irrigation is needed to avoid undesirable crop water stress. The RAW is usually expressed as percentage of AW. However, determination of RAW is very difficult.

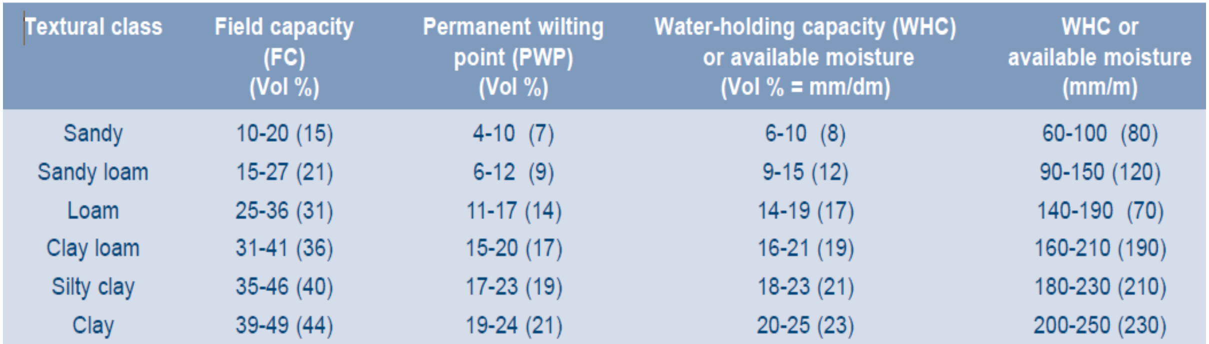
Therefore, based upon yield and product quality objectives, growers decide how much water to allow plants to remove from the soil before irrigation and they call this amount as Management Allowable Depletion (MAD). It is expressed as a percentage of the available water-holding capacity. The MAD is another way of expressing RAW and it varies for different crops and irrigation methods. As a general rule of thumb, MAD is 50%. Smaller MAD values result in more frequent irrigations, may be desirable where micro-irrigation is practiced, when saline water is used, for shallow root zones, and in cases where the water supply is uncertain. Large MAD values might be desirable when hand-move and hose- pull sprinklers are used, where furrows are long and for some crops that need to be stressed on heavy soil for physiological reasoning.

The water-holding capacity of a soil or the available moisture is defined as the difference between field capacity (FC) and permanent wilting point (PWP).The determination of the available moisture requires the determination of the FC and the PWP. They are both determined in the laboratory using the standard pressure plate technique. Cores of soil are wetted to saturation. Pressure would then be exerted until no more drainage water is measurable. In the case of FC, the pressure would be 0.1 atmospheres for light soils, 0.15 for medium soils and 0.3 for heavy soils. In the case of PWP, the pressure will be 15 atmospheres. At the end of the test, the wet soil cores are weighed and oven dried at 105°C for 24 hours and then reweighed. The moisture content is then expressed as percent of the dry weight of the soil:

Equation
SMw = Wet mass (weight) - Oven dry mass
(weight) x 100) .
Oven dry mass (weight)
Where:
SMw = Weight moisture content

The quantity of available soil water varies depending on the soil texture and structure. The following table gives the various ranges of available soil moisture /Aw/ expressed in millimeter - mm of water per meter of soil for various soil types.

Table 1. Range of average moisture contents for different soil types (Source: Euroconsult, 1989)



Textural class	Field capacity (FC) (Vol %)	Permanent wilting point (PWP) (Vol %)	Water-holding capacity (WHC) or available moisture (Vol % = mm/dm)	WHC or available moisture (mm/m)
Sandy	10-20 (15)	4-10 (7)	6-10 (8)	60-100 (80)
Sandy loam	15-27 (21)	6-12 (9)	9-15 (12)	90-150 (120)
Loam	25-36 (31)	11-17 (14)	14-19 (17)	140-190 (70)
Clay loam	31-41 (36)	15-20 (17)	16-21 (19)	160-210 (190)
Silty clay	35-46 (40)	17-23 (19)	18-23 (21)	180-230 (210)
Clay	39-49 (44)	19-24 (21)	20-25 (23)	200-250 (230)

Often, irrigation engineers find it convenient to use tables rather than waiting for the laboratory test on the values of FC and PWP. Such an approach should, however, be avoided. The range of available moisture within each textural class, as shown in Table 1, is too large to provide an accurate design basis. The tables should be used only exceptionally and such tables should have been derived from previous within-country tests. This can be more greatly appreciated by comparing the figures in Table 1 with those in Table 2.

Table 2: Available moisture for different soil types (Source: Withers and Vipond, 1974)

Soil type	Available moisture (mm/m)
Sand	55
Fine sand	80
Sand loam	120
Clay loam	150
Clay	135

The differences are especially big with the heavy and light soils.

2.3.1 Factors influencing infiltration rate

The infiltration rate is influenced by different factors. The major factors governing the rate of infiltration of water into the soil are conditions and characteristics of the soil surface, tillage and crop management practices, vegetation cover, duration of irrigation and the level of water table. Conditions and characteristics of the soil surface primarily involved in the process of irrigation are the initial soil water content, soil texture, soil structure, soil compaction, soil organic matter content, soil depth, depth of water table, soil surface sealing or forming crust, presence of cracks in soil surface and soil hydraulic conductivity.

Organic matter improves soil aggregates and increases macro-pores and porosity. As a result it increases infiltration and hence soil moisture content. A soil with higher proportion of sand allows water intake at a higher rate than that with more of silt and clay. A deep soil with good permeability allows greater infiltration than a shallow soil. As far as infiltration rate is concerned the soil surface with vegetation cover favors a greater infiltration than a bare soil, as vegetative cover encourages slow movement of water and this in turn gives more time for the water to infiltrate into the soil by minimizing surface run-off. Furthermore, infiltration rates reduce over the irrigation season, particularly when the irrigation water deposits fine soil particles in the irrigated fields. The soil water content and looseness of the soil surface exert a profound influence on the initial rate of the infiltration. When the soil water content is high and the soil is compacted, the rate and amount of infiltration is low. Soil tillage and crop management practices increase the looseness of soil and thereby increase infiltration.

2.3.2 The removal of soil moisture by plants

The amount of water that is available for plant growth is that portion of water that is between field capacities, i.e. when all the gravitational water has drained away and that amount of soil moisture, which is held mainly as hygroscopic water, which the plant is unable to utilize quickly enough to maintain its normal growth. This lower limit is known as the permanent wilting point, because under such moisture conditions, plant leaves become permanently wilted.

Temporary wilting point may occur in many crops on hot windy day, but the plants recover during the cooler portion of the day. The amount of available water depends on the texture and structure of soils and the amount of organic matter content present in the soil. Sandy soils drain readily, while clayey soils drain very slowly. The field capacity can be measured by determining the moisture content of a soil after a heavy irrigation and drainage of the gravitational water. Samples from the soil profile are taken and then the moisture content determined by drying for at least 24 hours in an oven at 105 0c.

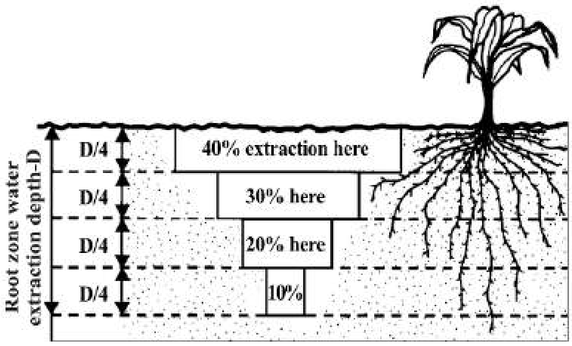
As a general rule, it is necessary to start irrigating when the soil moisture is about half way between field capacity and permanent wilting, the 50% rule. However, in the case of heavy clay soils, such as vertisols which have characteristics of swelling and cracking and generally have a low infiltration rate after they have swelled; the movement of water through them is largely facilitated by their shrinkage forming large deep cracks for the water to infiltrate. This occurs when most of the moisture has been depleted and if the 50% rule was followed, plants would suffer of moisture stress. Therefore, it is advised to start irrigating when the soil moisture depletion rate is at 60%.

2.3.3 Plant root growth and rooting depth

The volume of water absorbed by a plant depends largely on the growth of root systems. Root development is most important for a better plant growth and ultimately increased yield. It dictates the amount of water that could be explored by plants from different layers of soils. Soil water of course, decides the depth of root penetration and their lateral and relative growth, and the same goes for shoots. Roots grow more towards the moist soil and follow the water when they are in direct contact or close to it. With greater availability of water, roots grow increasingly with shoots. Roots provide the water absorbing surface and soils serve as the reservoir of water. Under, favorable conditions for root growth, the depth of rooting increases during the vegetative and flowering period, if there is no hard pan, rock or other impediment to root penetration of the soil. As a general rule, the hotter the climate or the longer the growing period, the deeper the roots will penetrate the soil. Thus, crops such as lettuce, phaseolus beans, which require three months to mature, do not penetrate the soil more than 30- 70 cm. In the contrary, longer maturing crops such as 6 months of maize, cotton and local cultivars of sorghum, which mature in some 8 months, penetrate the soil as much as 2m depth. Therefore, availability of water in the effective root zone is very crucial for root development.

The designated water extraction depth of a crop is the soil depth from which the crop meets most of its water needs. As a general rule, given a homogenous soil, the greater part of root development takes place in the upper layer of the soil, with some 40% of the root growth occurring in the 1st quarter of the rooting zone, 30% from the 2nd quarter and 20% from the 3rd and a more 10% from the last quarter.

Fig. 5. A soil water extraction pattern in soils of adequate soil moisture and without restrictive layer in the root zone



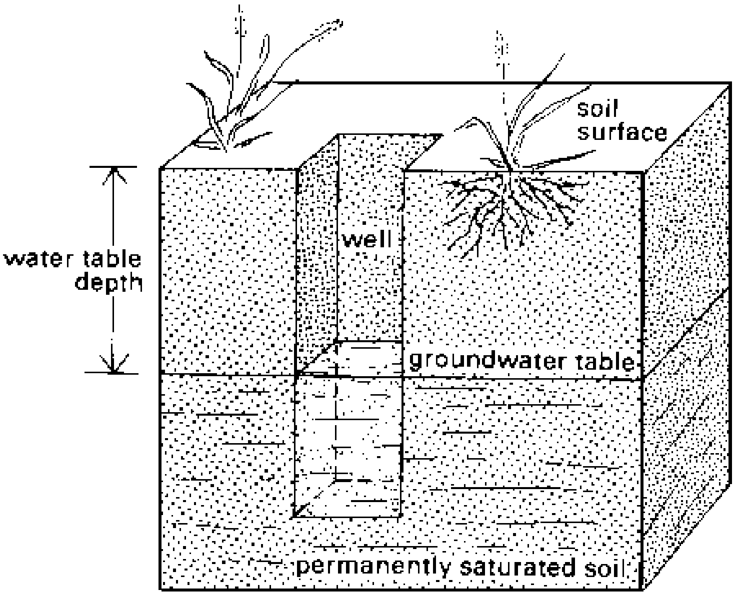
Thus, in order to obtain a fair estimate of the moisture status of the soil, it is necessary to make measurements of soil moisture at a minimum of two different soil depths.

By contrast, the soil is not homogenous and it has layers of different permeability. Hence, the rooting and, therefore, moisture extraction pattern is different. This can be quite dramatic where there is a clay pan, or plough pan, which impedes both root development and the passage of water through the normal rooting zone of a crop. If there is a problem of plough pan, various remedial measures can be taken to alleviate such a problem, such as breaking up of the plough pan by deep cultivation using a single tined sub- soiler or by growing tress and other deep rooted crops whose roots are capable to penetrate such pans. If these remedial measures are not taken, then crops with very shallow root system can be grown with controlled water application to avoid water-logging.

2.4 Ground water table

Part of the water applied to the soil surface drains below the root-zone and feeds deeper soil layers which are permanently saturated; the top of the saturated layer is called groundwater table or sometimes just water table (see Fig. 6 below).

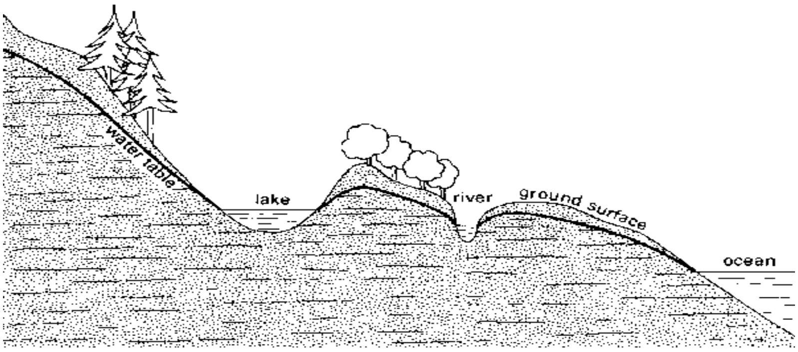
Fig. 6. The groundwater table



2.4.1 Depth of the groundwater table

The depth of the groundwater table varies greatly from place to place, mainly due to changes in topography of the area (see Fig. 7 below).

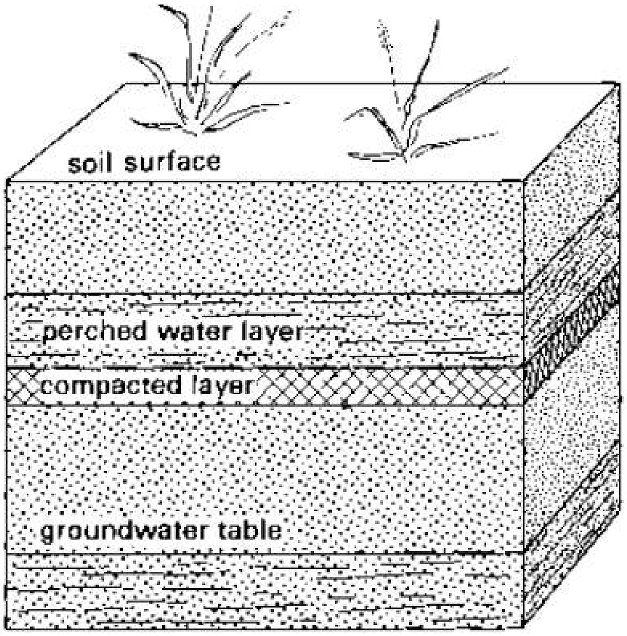
Fig. 7. Variations in depth of the groundwater table



In one particular place or field, the depth of the groundwater table may vary in time.
Following heavy rainfall or irrigation, the groundwater table rises. It may even reach and saturate the root-zone. If prolonged, this situation can be disastrous for crops which cannot resist "wet feet" for a long period. Where the groundwater table appears at the surface, it is called an open groundwater table. This is the case in swampy areas. The groundwater table can also be very deep and distant from the root-zone, for example following a prolonged dry period. To keep the root-zone moist, irrigation is then necessary.

2.4.2 Perched groundwater table

A perched groundwater layer can be found on top of an impermeable layer rather close to the surface (20 to 100 cm). It covers usually a limited area. The top of the perched water layer is called the perched groundwater table. The impermeable layer separates the perched groundwater layer from the more deeply located groundwater table (see Fig. 8 below).
Fig. 8. A perched groundwater table



Soil with an impermeable layer not far below the root-zone should be irrigated with precaution, because in the case of over irrigation (too much irrigation), the perched water table may rise rapidly.

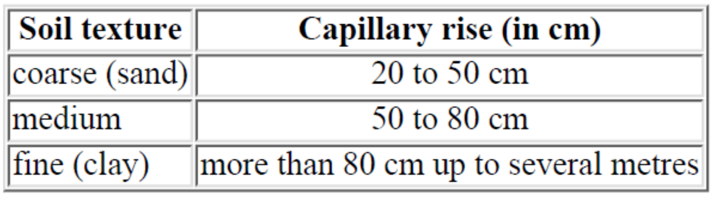
2.4.3 Capillary rise

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 (Fig. 9 below), the water is sucked upward by the tissue.

Fig. 9. Upward movement of water or capillary rise

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 3: Capillary rise in different types of soil



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

MODULE 3: DEFINITION AND IMPORTANCE OF IRRIGATION

3.1 Definition of irrigation

Irrigation is defined as an artificial application of water to irrigated crop fields to supplement the natural sources of water to satisfy the crop water requirements and increase crop yields on sustainable basis without causing damage to the land and soils. The natural supply of water to agricultural land for crop production purpose is usually received from natural sources such as precipitation /rain/, other atmospheric water, ground water and floodwater. The natural rainfall may be insufficient and untimely, and the ground water may be too deep in the soil profile beyond the active root zone, which is unavailable to the plant roots. This is a common phenomenon in drought- prone areas of the country and successful crop production in these areas is only possible with the support of irrigation.

Irrigation itself is a key input for successful and sustainable crop production. Irrigation water management is strictly combined with improved agronomic practices for increased yields of irrigated crops. In this context, irrigation agronomy is simply defined as a branch of agriculture and biology that explores the principles and concepts of plants- soils- water relationships combined with other improved crop management practices to optimize production on a sustainable basis without causing damage to the environment. Therefore, the maximum benefit of using improved crop production technologies such as high yielding varieties, optimum fertilizer use, establishing multiple cropping systems, improved cultural practices and appropriate plant protection measures can only be achieved when an adequate supply of water is assured.

3.2 The need and importance of irrigation

Irrigation is considered necessary when the natural supply of water is not sufficient to satisfy the crop water requirements for sustaining crop production. Therefore, the water deficit should be supplied by supplemental or full irrigation. Inadequate and uneven distribution of rainfall, with adequate but uneven distribution throughout the growing season, the need to sustain the practice of double cropping in the dry season, and ensuring of growing high value crops are among the factors that necessitate irrigation.

Irrigation plays an important role in the development of the agriculture sector and contributes much in the national economic development of the country. Therefore, irrigation ensures production of high value crops, ensures protection of crop failures due to drought; ensures cultivation of suitable multiple cropping practices in a season, maximizes the value of land and farmers may become prosperous and their living standards could be raised. It also creates the opportunity of introducing aquaculture to farmers that will improve their diet by supplementing with a protein source and can be used as an additional income source. In addition, irrigation water can be used for domestic and industrial water supplies for nearby areas. Irrigated agriculture requires increased farm labours and this creates employment opportunities for the rural population.

3.3 Ill-effects of irrigation

Irrigation is useful only when it is properly managed and controlled. Faulty and careless irrigation water management practices do harm to crops and damage the land and ultimately reduce crop yields. Besides, excess watering is a waste of the valuable and scarce water resource. Traditionally farmers in Ethiopia and elsewhere are usually tempted to over- irrigate their lands when water is available in excess amounts, without being conscious of the harmful effects of over- watering on their fields. Therefore, the following are some harmful effects of faulty and excess irrigation practices:

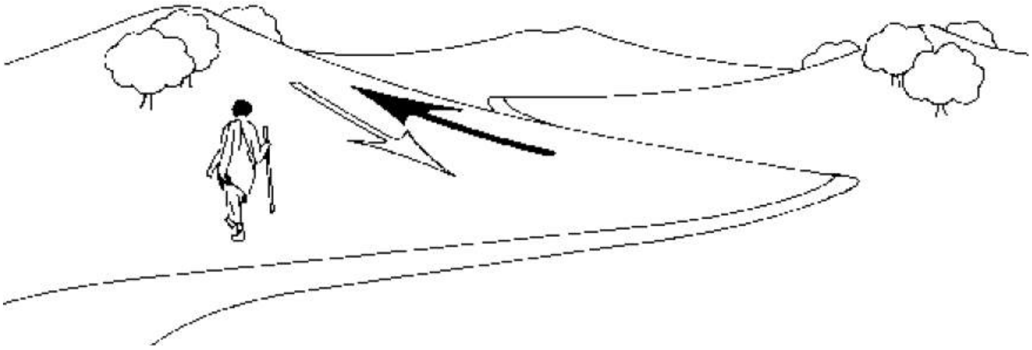
- **Creates poor soil aeration:-** Excess irrigation fills the pores with water expelling soil air completely and this leads to deficiency of oxygen, which affects the root respiration and normal growth of crop plants.
- **Creates increased nutrient toxicity levels for crops:-** In excess water application nutrients such as manganese and iron become more soluble and their increased availability may be toxic to plants.
- **Creates physiological imbalance in plants:-** Physiological activities of plants will seriously be affected due to lack of adequate oxygen in poorly aerated soil.
- **Restricts the root system**:- lack of adequate oxygen, restricts the root development. Roots do not grow well in wet soil conditions and usually remain shallow. This affects the nutrient uptake of plants that ultimately affect crop growth and results in reduced crop yields.
- **Increases soil erosion and leads to degradation of soil fertility status:-** Heavy irrigation in areas of sloping and undulating lands may cause erosion of surface soil. The stream size and amount of irrigation water applied should be decided based on the water intake rate, hydraulic conductivity, textural class and water retentive capacity of the soil, land slope and soil water depletion status in order to minimize the likely erosion hazard and leaching of nutrients beyond the active root zone.
- **Rise of water table:-** Faulty or over- irrigation of a farm, if continued for a long period, leads to a rise of the water table. The rise of water table restricts root development and limits the feeding zones of crops. Growing of fruit trees and deep-rooted crops is not suitable in areas where the water table rises high up and gets near the soil surface. Instead, shallow rooted- crops are recommended to be cultivated in such conditions.
- **Creates water logging:-** When irrigation is done with a large stream size and if not turned off at the proper time, excess water accumulates in the lower part of the field and causes water logging. The water logging further destroys the crumb structure and soil aggregates and encourages the development of platy structure, which is not suitable for crop production. Therefore, controlling of the stream size and constructing of drainage systems is essential to drain off excess water and create favorable conditions for normal growth and development of crop plants.
- **Affects activities of micro- organisms:-** Useful aerobic bacteria such as ammonifying, nitrifying and nitrogen fixing bacteria cannot function well with a deficiency of oxygen. As a result, decomposition of organic matter, atmospheric nitrogen fixation and availability of nutrients to plants are hampered. On the other hand, anaerobic bacteria are activated causing loss of nitrogen in the form of gas and evolution of harmful gases which encourage incidence of plant diseases.
- **Increases incidence of malaria and other water borne diseases:-** waterlogged areas are ideal sites for breeding of mosquitoes and enhance the outbreak of malaria and water borne diseases. Therefore, basic knowledge and skills are required for efficient water management practices.

MODULE 4: ELEMENTS OF TOPOGRAPHY

4.1 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. 10, black arrow). Go downhill; this is a falling slope (see Fig. 10, white arrow).

Fig.10. 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".

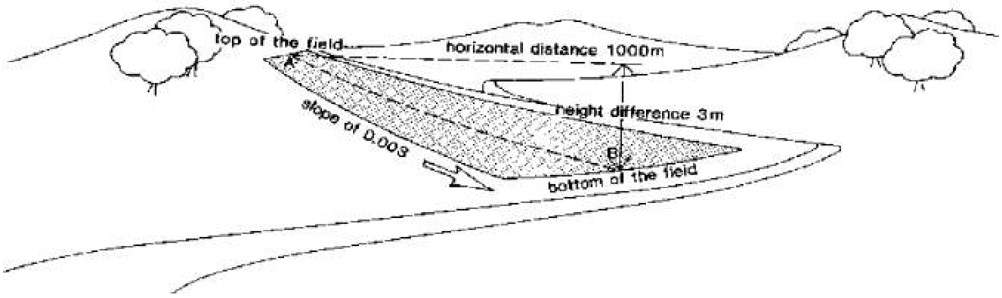
4.1.1 Method of expressing slopes

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 (see Fig. 11 below).

The formula is:

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

Fig. 11. The dimension of a slope



The slope for point A above in the drawing can also be expressed in percent; the formula used is then:

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

The slope for point B above can also be expressed in percent; the formula used is then:

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

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

Finally, the slope can be expressed in per mil; 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:

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

NOTE:

Slope in ‰ = slope in % x 10

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

$$\text{Field slope in \%} = \frac{\text{height difference (metres)}}{\text{horizontal distance (metres)}} \times 100 = \frac{1.5}{200} \times 100 = 0.75\%$$

Field slope in ‰ = field slope in % x 10 = 0.75 x 10 = 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

$$\text{Field slope} = 2‰ = 0.002 = \frac{\text{height difference (m)}}{\text{horizontal distance (m)}} = \frac{\text{height difference (m)}}{300\ \text{m}}$$

thus: height difference (m) = 0.002 x 300 m = 0.6 m.

Table 4: 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

4.1.2 Cross slopes

Place a book on a table and lift one side of it 4 centimetres from the table (Fig. 12a. A steep slope). Now, tilt the book sideways (6 cm) so that only one corner of it touches the table (Fig. 12b. a flat slope).

The thick arrow indicates the direction of what can be called the main slope; the thin arrow indicates the direction of the cross slope, the latter crosses the direction of the main slope.

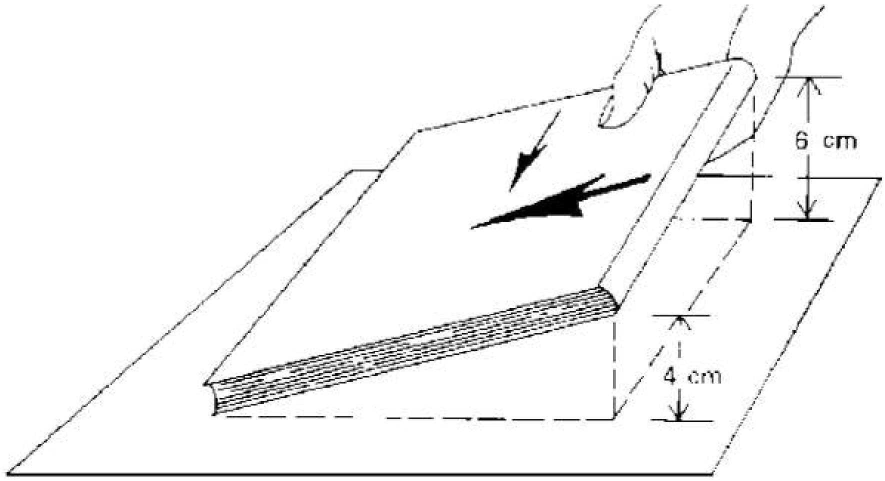
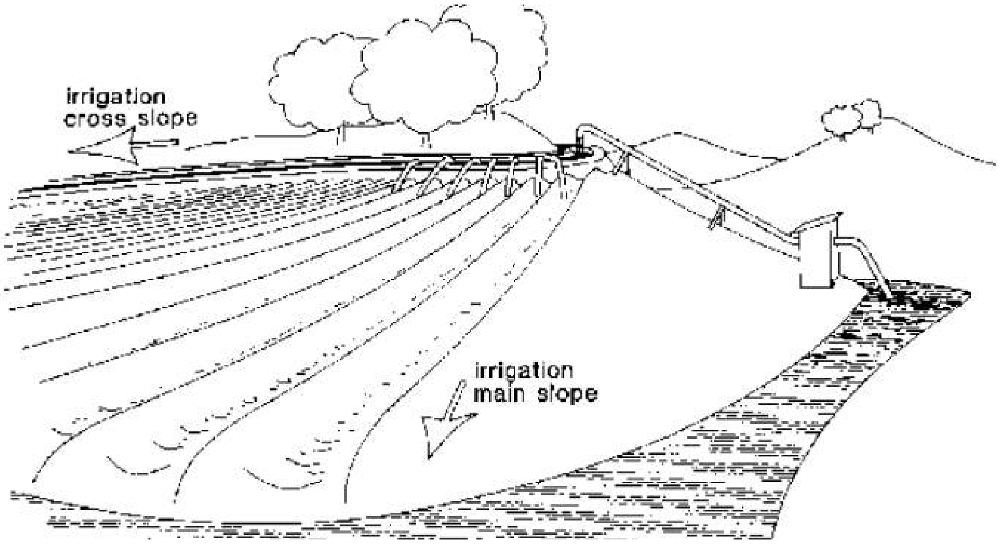


Fig. 13. The main slope and cross slope of an irrigated field

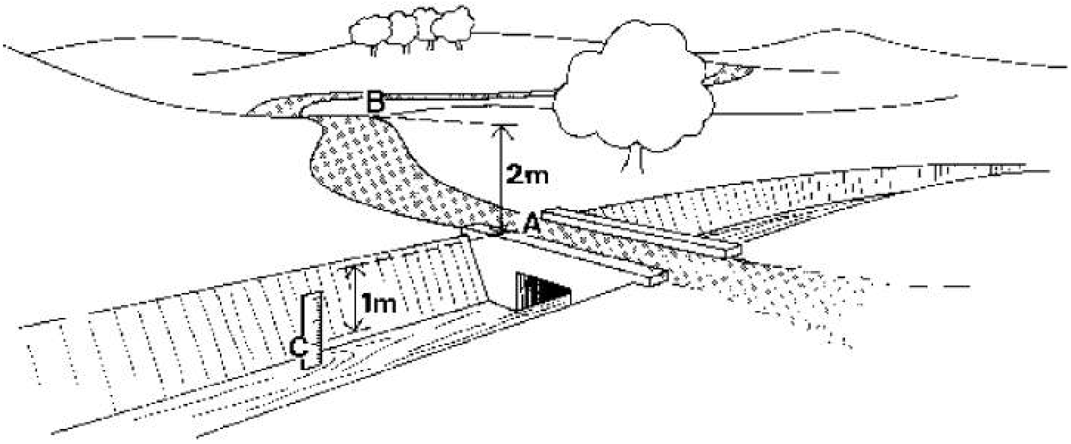


4.2 *Elevation of a point*

4.2.1 Definition

In Fig. 14 below, point A is at the top of a concrete bridge. Any other point in the surrounding area is higher or lower than A, and the vertical distance between the two can be determined. For example, B is higher than A, and the vertical distance between A and B is 2 m. Point C, is lower than A and the vertical distance between A and C is 1 m. If point A is chosen as a reference point or datum, the elevation of any other point in the field can be defined as the vertical distance between this point and A.

Fig**.** 14. Reference point or datum "A"



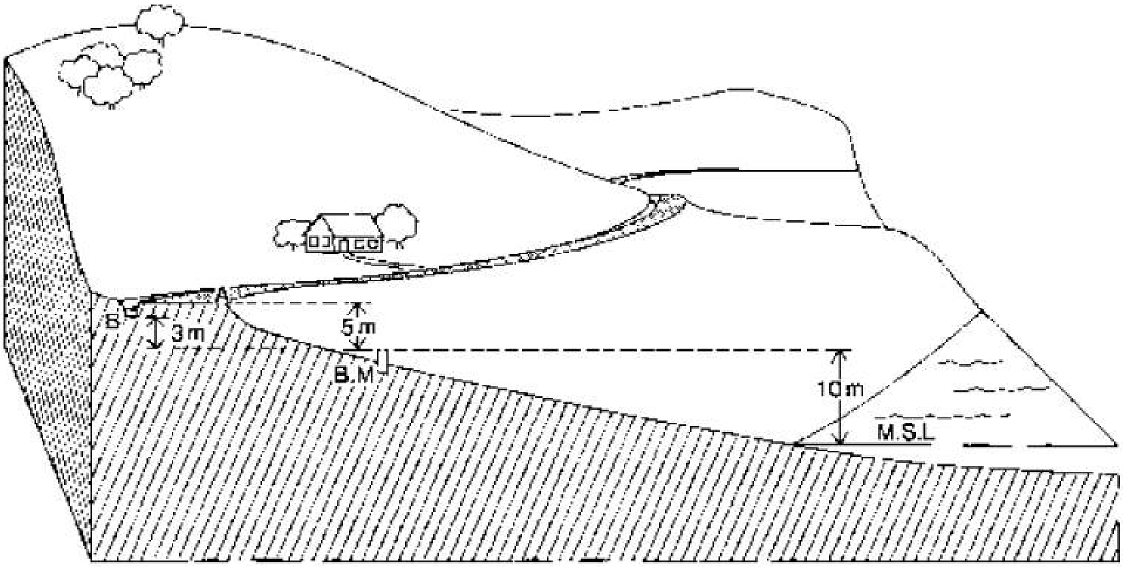
Thus, the height or elevation of B, in relation to the datum A, is 2 m and the elevation of C, also related to the datum A, is 1 m. As a reminder that a point is above or below the datum, its elevation is prefixed by the sign + (plus) if it is above the datum, or - (minus) if it is below the datum. Therefore, in relation to the datum A, the elevation of B is +2 m and the elevation of C is -1 m.

4.2.2 Bench mark and mean sea level

A bench mark is a permanent mark established in a field to use as a reference point. A bench mark can be a concrete base in which an iron bar is fixed, indicating the exact place of the reference point. A bench mark can also be a permanent object on the farm, such as the top of a concrete structure.

In most countries the topographical departments have established a national network of bench marks with officially registered elevations. All bench mark heights are given in relationship to the one national datum plane which in general is the mean sea level (MSL) (see Fig. 15 below).

Fig. 15. A bench mark (B.M.) and mean sea level (M.S.L.)



EXAMPLE

In Fig. 15, the elevation of point A in relation to the bench mark (BM) is 5 metres. The BM elevation relative to the mean sea level (MSL) is 10 m. Thus, the elevation of point A relative to the MSL is 5 m + 10 m = 15 m and is called the reduced level (RL) of A.

QUESTION

What is the reduced level of point B in Fig.15.

ANSWER

The elevation of B relative to BM = 3 m

The elevation of BM relative to MSL = 10 m

Thus, the reduced level of B = 3 m + 10 m = 13 m

QUESTION

What is the difference in elevation between A and B? What does it represent?

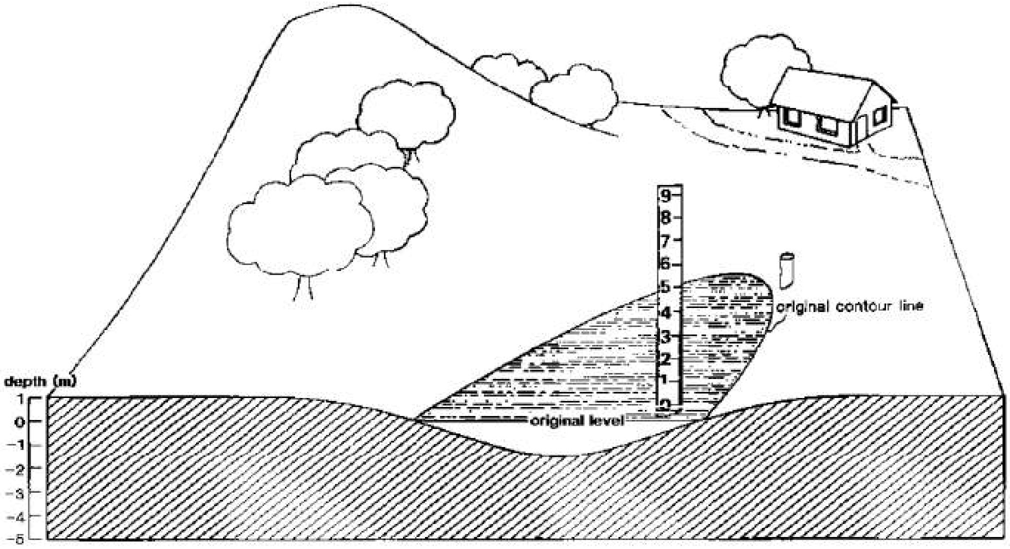
ANSWER

The difference in elevation between A and B is the reduced level of A minus the reduced level of B = 15m - 13 m = 2 m, which represents the vertical distance between A and B.

4.3 Contour lines

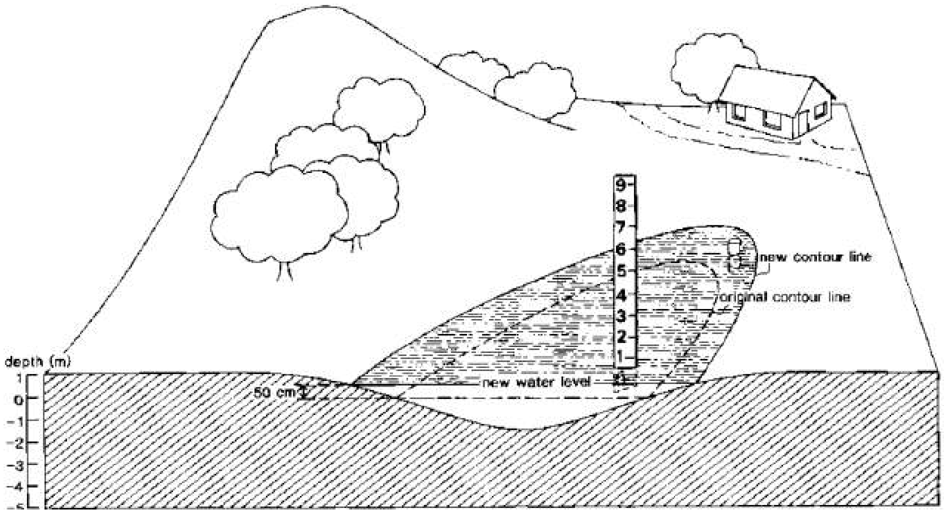
A contour line is the imaginary horizontal line that connects all points in a field which have the same elevation. A contour line is imaginary but can be visualized by taking the example of a lake. The water level of a lake may move up and down, but the water surface always remains horizontal. The level 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 (see Fig. 16a below).

Fig. 16a. The shore line of the lake forms a contour line



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 (see Fig. 16b below).

Fig. 16b. When the water level rises, a new contour line is formed



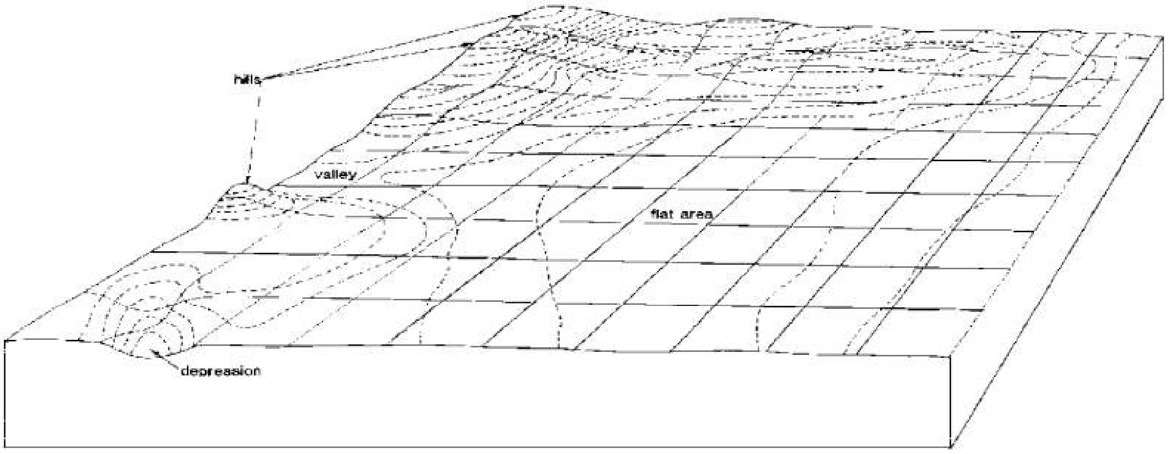
Suppose the water level of the lake rises 50 cm above its original level. The contour line, formed by the shore line, changes and takes a new shape, by joining all the points 50 cm higher than the original lake level.

4.4 Maps

4.4.1 Description of a map

Fig. 17 below represents a three-dimensional view of a field with its hills, valleys and depressions; the contour lines have also been indicated.

Fig. 17 A three-dimensional view

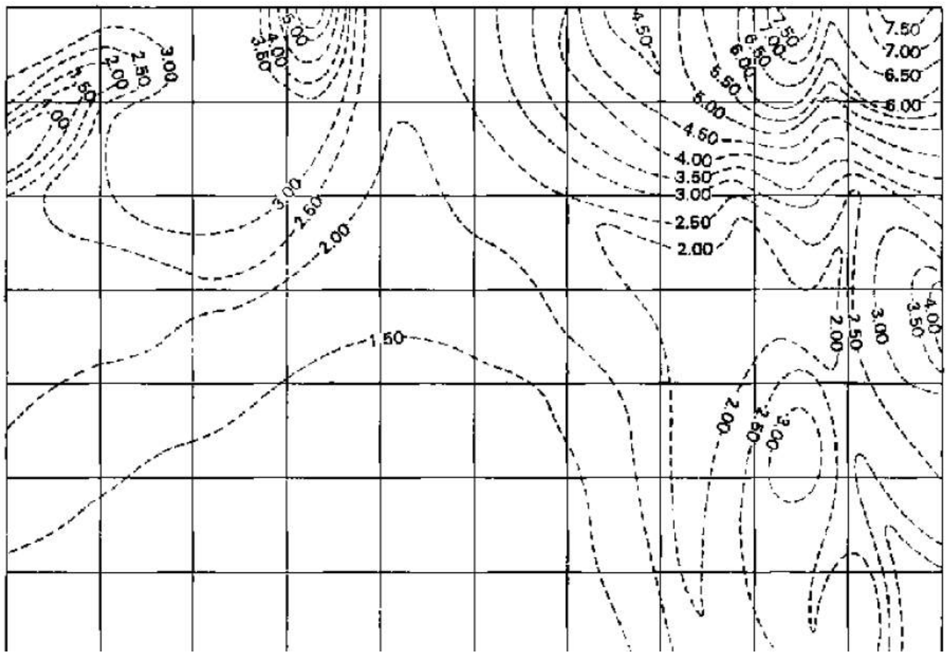


Such a representation gives a very good idea of what the field looks like in reality. Unfortunately, it requires a lot of skill to draw and is almost useless for the designing of roads, irrigation and drainage infrastructures. A much more accurate and convenient representation of the field, on which all data referring to topography can be plotted, is a map (see Fig. 18 below). The map is what you see when looking at the three-dimensional view (Fig. 17) from the top.

4.4.2 Interpretation of contour lines on a map

The arrangement of the contour lines on a map gives a direct indication of the changes in the field's topography (Fig. 18).

Fig.18. A two-dimensional view or map

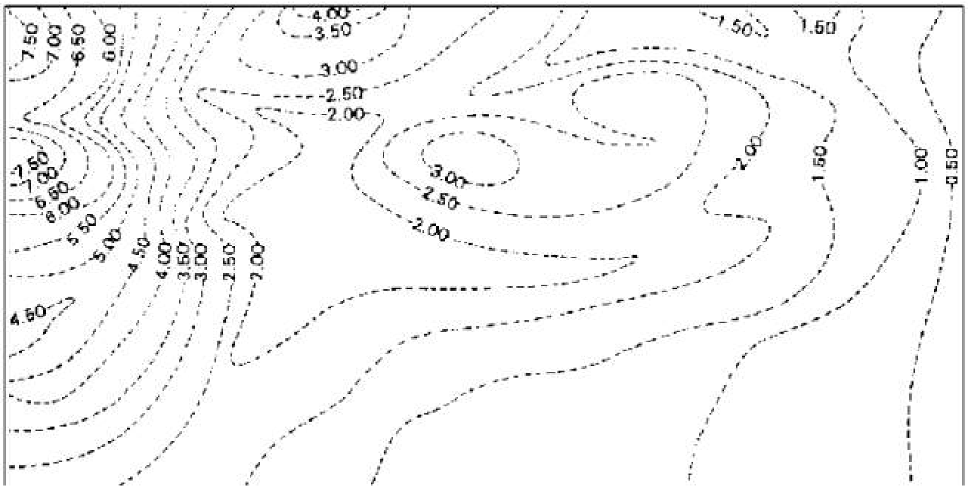


In hilly areas, the contour lines are close together while they are widely apart on flat slopes. The closer the contour lines the steeper the slope. The wider the contour lines the flatter the slopes. On a hill, the contour lines form circles; whereby the values of their elevation increase from the edge to the centre. In a depression, the contour lines also form circles; the values of their elevation, however, decrease from the edge to the centre.

4.4.3 Mistakes in the contour lines

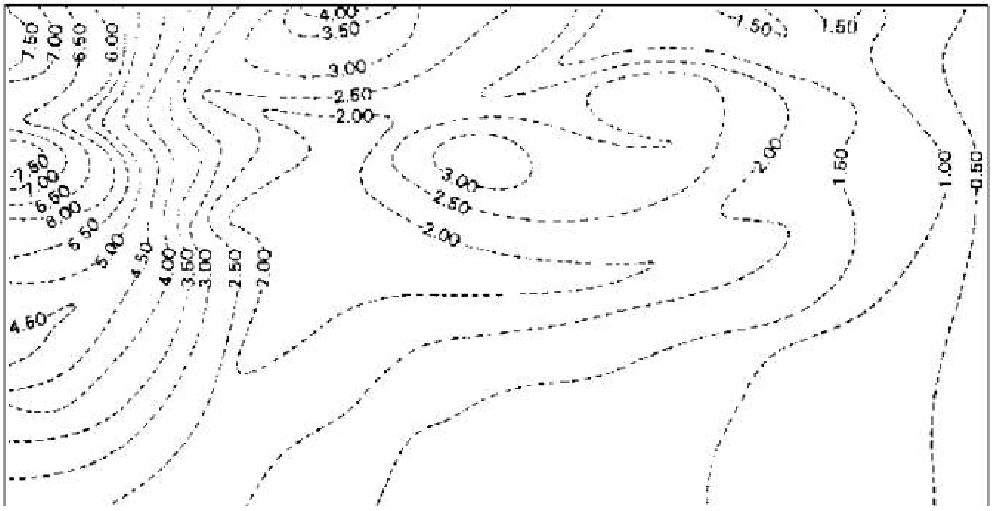
Contour lines of different heights can never cross each other. Crossing contour lines would mean that the intersection point has two different elevations, which is impossible (see Fig. 19 below).

Fig.19. WRONG; crossing contour lines



A contour line is continuous; there can never be an isolated piece of contour line somewhere on the map, as shown in Fig. 20 below.

Fig.20. WRONG; an isolated piece of contour line



4.4.4 Scale of a map

To be complete and really useful, a map must have a defined scale. The scale is the ratio of the distance between two points on a map and their real distance on the field. A scale of 1 in 5000 (1:5000) means that 1 cm measured on the map corresponds to 5000 cm (or converted into metres, 50 m) on the field.

QUESTION
What is the real distance between points A and B on the field when these two points are 3.5 cm apart on a map whose scale is 1 to 2 500?

ANSWER
The scale is 1:2 500, which means that 1 cm on the map represents 2 500 cm in reality. Thus, 3.5 cm between A and B on the map corresponds to 3.5 x 2 500 cm = 8 750 cm or 87.5 m on the field.

MODULE 5: IRRIGATION WATER REQUIREMENT

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. 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 ground water-table and an undesirable saturation of the root zone. 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 water requirement needs to be determined for proper design of the irrigation system and for the establishment of the irrigation schedules. There are different factors that affect the irrigation water requirement of the crop. These are rainfall, evapotranspiration, type of the crop, weather, type of soil etc

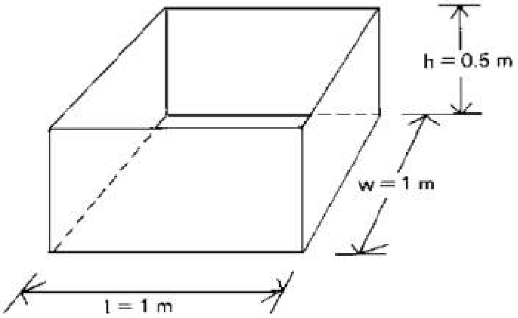
5.1 Rainfall

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.

5.1.1 Amount of rainfall

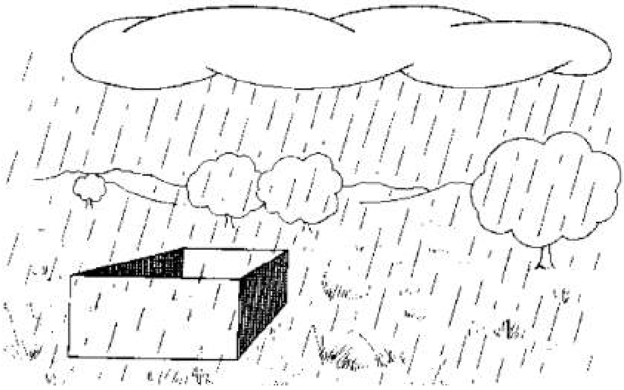
Imagine an open square container; 1 m wide, 1 m long and 0.5 m high (see Fig. 21a below).

Fig. 21a. An open container to collect rainwater



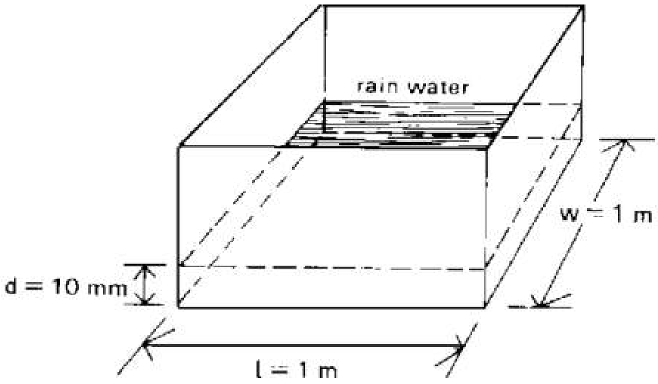
This container is placed horizontally on an open area in a field (see Fig. 21b below).

Fig. 21b. Container placed in the field



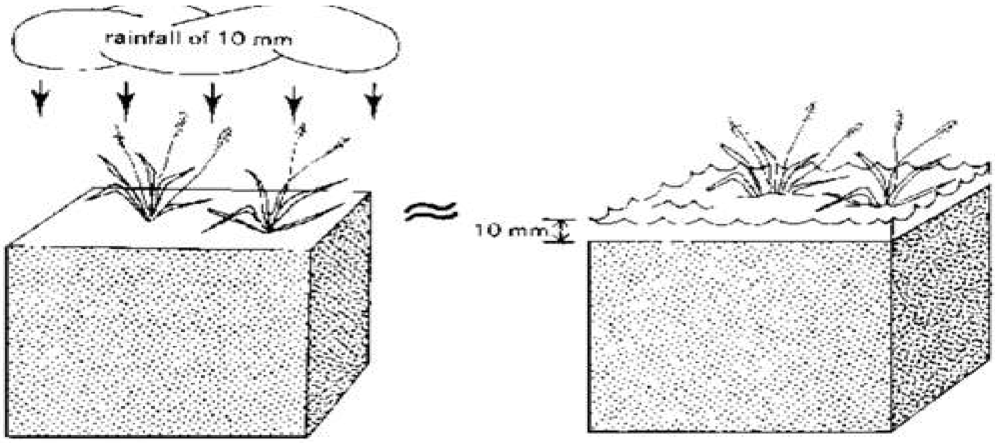
During a rain shower, the container collects the water. Suppose that when the rain stops, the depth of water contained in the pan is 10 mm (see Fig. 21c below).

Fig 21c.10 mm rainwater collected in the container



The volume of water collected in the pan is:
V (m3) = l (m) x w (m) x d (m) = 1 m x 1 m x 0.010 m = 0.01 m3 or 10 litres
It can be assumed that the surrounding field has also received a uniform water depth of 10 mm (see Fig. 21d below).

Fig.21d.10 mm rainfall on the field



In terms of volume, with a rainfall of 10 mm, every square metre of the field receives 0.01 m, 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 10000 litres.
QUESTION
What is the total amount of water received by a field of 5 ha under a rainfall of 15 mm?
ANSWER
Each hectare (10 000 m2) receives 10 000 m2 x 0.015 m = 150 m3 of water. Thus the total amount of water received by the 5 hectares is: 5 x 150 m3 = 750 m3.

5.1.2 Rainfall intensity

Rainfall is often expressed in millimetres per day (mm/day) which represents the total depth of rainwater (mm), during 24 hours. It is the sum of all the rain showers which occurred during these 24 hours.

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

For example, a rain shower lasts 3.5 hours and supplies 35 mm of water. The intensity of this shower is

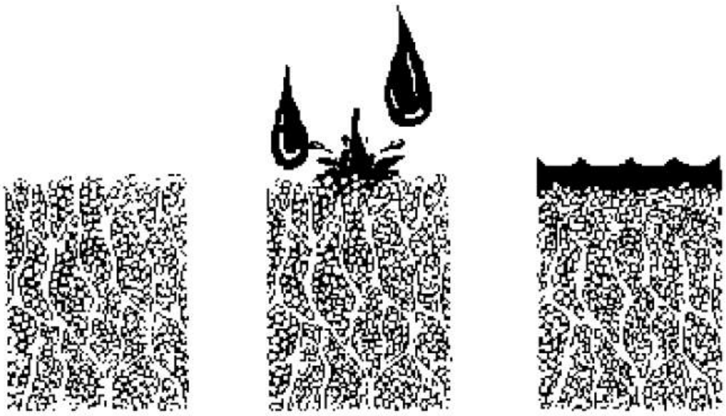
$$\frac{35\text{ mm}}{3.5\text{ hours}} = 10\text{ mm/hour}$$

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

$$\frac{35\text{ mm}}{1\text{ hour}} = 35\text{ mm/hour}$$

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. 22 below). The infiltration is then reduced, and surface runoff increases.

Fig. 22. Sealing of the soil surface by raindrops



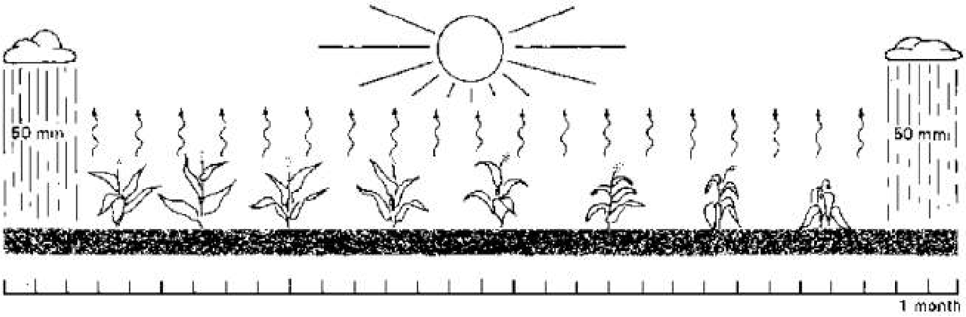
The low intensity rainfall has finer drops. The soil surface is not sealed, the rainwater infiltrates more easily and surface runoff is limited.

5.1.3 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.

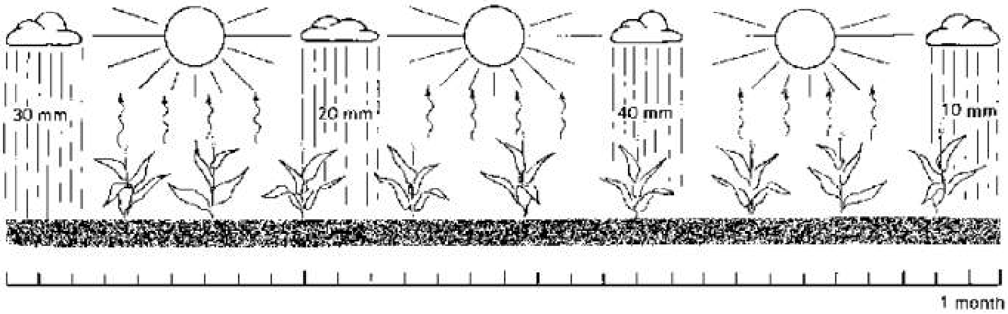
Suppose that the rainwater falls during two showers of 50 mm each, one at the beginning of the month and the other one at the end of the month (see Fig. 23a below). In between these two showers, the crop undergoes a long dry period and may even wilt. Irrigation during this period is then required.

Fig. 23a. 100 mm rainfall, poorly distributed over one month



On the other hand, if the rainwater is supplied regularly by little showers, evenly distributed over the month (see Fig. 23b), adequate soil moisture is continuously maintained and irrigation might not be required.

Fig. 23b.100 mm rainfall, evenly distributed over one month



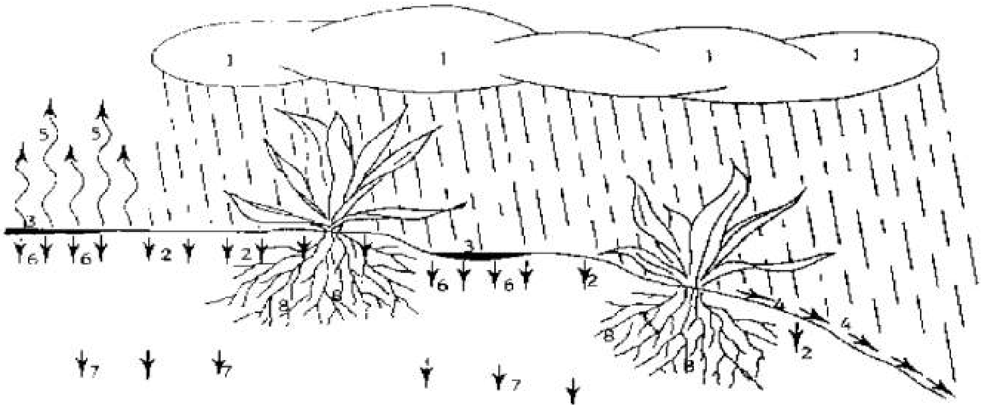
Not only is the rainfall distribution within a month is important, but it is also important to look into the rainfall distribution over the years. Suppose that in a certain area the average rainfall in May is 150 mm and that this amount is just sufficient to satisfy the water need of the crops during 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.

5.1.4 Effective rainfall

i. Introduction

When rain water ((1) in Fig. 24 below) 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 root zone (7), while the rest remains stored in the root zone (8).

Fig. 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.

ii. 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).

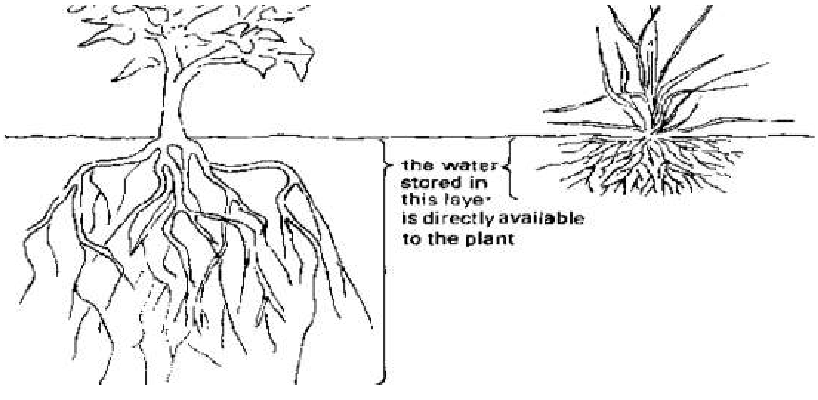
a. Climate:- The climate determines the amount, intensity and distribution of rainfall which have direct influence on the effective rainfall.

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

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.).

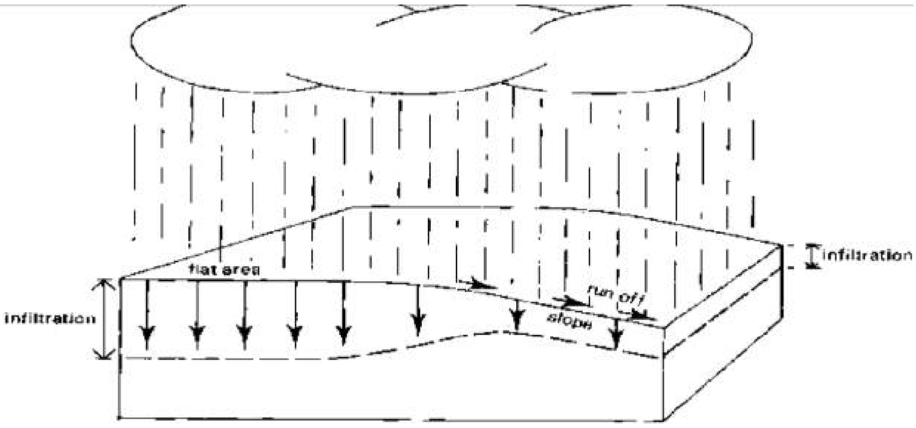
d. Depth of the root-zone:- Soil water stored in deep layers can be used by the plants only when roots penetrate to that depth. The depth of root penetration is primarily dependent on the type of crop, but also on the type of soil. The thicker the root-zone, the more water available to the plant. (see Fig. 25 below).

Fig. 25. Effective rainfall and depth of the root-zone



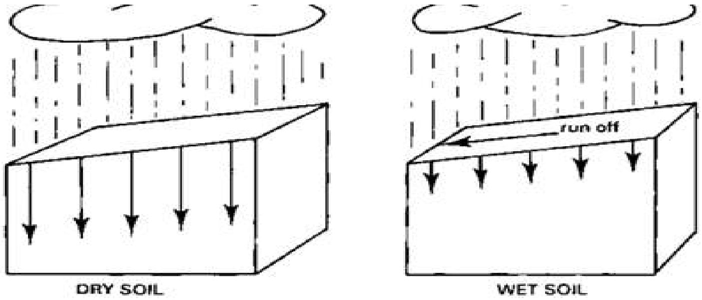
e. Topography:- On steep sloping areas, because of high runoff, the water has less time to infiltrate than in rather flat areas (see Fig. 26). The effective rainfall is thus lower in sloping areas.

Fig.26. Effective rainfall and topography



f. Initial soil moisture content:- 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. 28 below).

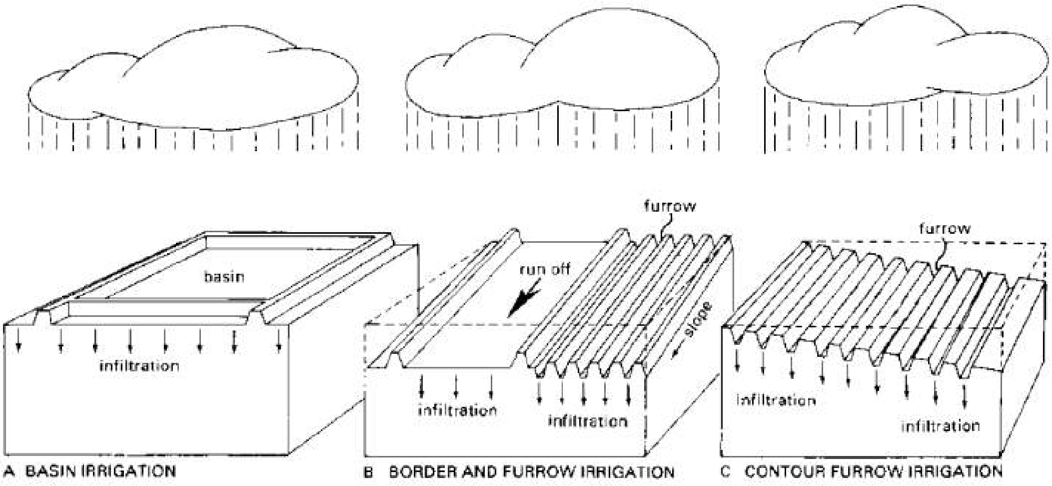
Fig. 27. Effective rainfall and initial soil moisture content



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 (see Fig. 28a below).

In graded **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 (see Fig. 28b below). 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 result in a relatively high effective rainfall, compared to inclined border or furrow irrigation (see Fig. 28c below).

Fig. 29a + b + c. Effective rainfall and irrigation methods



5.2 Evapo-transpiration and consumptive use

In a cropped field water can be lost through two processes:-

a) Water can be lost from the soil surface and wet vegetation through a process called **evaporation (E)**, whereby liquid water is converted into water vapor and removed from the evaporating surface.

b) The second process of water loss is called **transpiration (T),** whereby liquid water contained in plant tissues vaporizes into the atmosphere through small openings in the plant leaf, called stomata. The soil water content and the ability of the soil to conduct water to the roots also determine the transpiration rate, as do water-logging and soil salinity. Crop characteristics, environmental aspects and cultivation practices also have an influence on the transpiration.

The combination of these two separate processes is called *evapotranspiration* (ET).

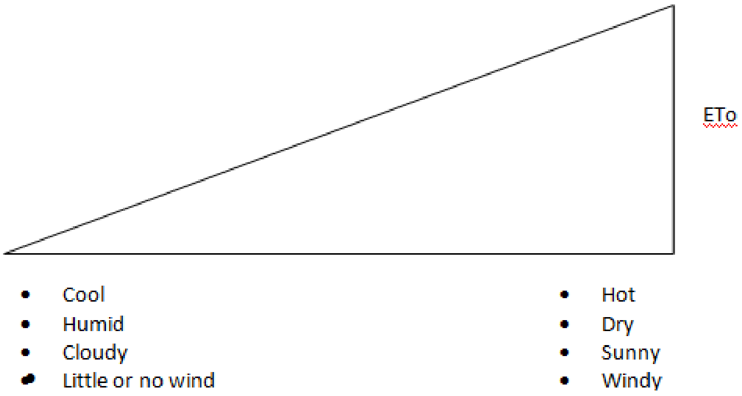
- **Evapotranspiration (ET):** This is the amount of water, which evaporates from wet soils and plant surfaces together with the plant transpiration.
- **Reference evapotranspiration** (**ETo**) or **Potential evapotranspiration** (**PET**): Since it is difficult to measure the amount of ET directly for irrigation scheduling a commonly practice is to estimate the Reference Evapotranspiration (ETo) from a *representative surface area* in response to the climatic demand. ETo purely reflect the climatic demand and depends on climatic factors such as temperature, humidity, relative humidity, solar radiation (obtained from sunshine hours) and wind. The representative surface area is described as large area covered by green grass which grows actively, completely shading the ground and not short of water. Sometimes ETo is considered similar to potential evapotranspiration (PET). However, their similarity ends up through series of research and development in irrigation when the representative surface is described with specific characteristics and the use of PET abandoned. Since 1990 the standard reference surface is defined as "a hypothetical reference crop with an assumed crop height of 12 cm, a fixed surface resistance of 70 s/m and an albedo of 0.23."

- In order to convert it in to the desired crop evapotranspiration (ETc) the ETo is multiplied by a factor called crop coefficient (Kc). This type of approach to estimate the ETc is called dual step approach. The direct measurement of ETc is restricted to research purpose because it requires special instrument/device and strict follow-up.

5.3 Factors influencing evapo-transpiration

Many factors influence the evapo-transpiration (ETo) of the crop. The main ones are associated with climate and crop. In connection with climate the highest value of ETo is found in areas which are hot, dry, windy and sunny whereas the lowest values are observed in areas where it is cool, humid and cloudy with little or no wind (see Fig. 29 below). It is expressed as a mean value in mm per day over a period of 10-30 days.

Fig. 29. Variation of ETo with climate



5.4 Methods of estimating crop evapo-transpiration (ETo)

A number of empirical methods have been developed to estimate reference evapotranspiration from different climatic variables. To accommodate users with different data availability, four methods are presented to calculate the reference crop evapo-transpiration (ET_o): the pan evaporation methods, Blaney-Criddle, radiation, and Penman methods. Table 5 below shows the available methods and data requirements of each.

Table 5: Methods for Estimating ETo and Data Requirements

Method	**Temp**	**Humidity**	**Wind speed**	**Sunshine**	**Radiation**	**Evaporation**
Blaney-Criddle	M	E	E	E		
Pan		E	E			M
Penman	M	M	M	M	(m)	
Radiation	M	E	E	M	(m)	

E: Estimated data

M: Measured data

(m): If available but not essential

5.4.1 Pan evapo-transpiration

The evaporation rate from pans filled with water is easily obtained. In the absence of rain, the amount of water evaporated during a period (mm/day) corresponds with the decrease in water depth in that period. Pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. The standard pan, which is used to measure evaporation rate, is Class A pan of the US Weather Bureau. It has a diameter of 120.7 cm, a depth of 25 cm. The pan is mounted on a wooden open frame platform, which is 15 cm above ground level. There is also another pan evaporation method known as the Colorado sunken pan. The Colorado sunken pan is 92 cm square and 46 cm deep, made of 3 mm thick iron, placed in the ground with the rim 5 cm above the soil level.

The pan method makes use of the evaporation data (Epan) which is measured with evaporation pan. In order to compute ETo , from the Epan data, a pan factor (kp) is used. kp varies between 0.35 and 0.85. If the precise pan factor is not known, the average value, 0.7, can be used for Class A pan and 0.8 for Colorado sunken pan. The formula for estimating ETo is: ETo = kp x Epan

Example: Given the daily evaporation data for the first week of July for a Class A pan installed in a green area surrounded by short irrigated field crops: 8.2, 7.5, 7.6, 6.8, 7.6, 8.9 and 8.5 mm/day. In that period, the mean wind speed is 1.9 m/s and the daily mean relative humidity is 73%. Determine the 7-day average reference evapo-transpiration.

Table 6: Worked Example

Description	**Calculation/Condition**	**Result (mm/day)**
Wind speed is light	u< 2 m/s	
Relative humidity is high	RH_{mean} >70%	
Average Epan	(8.2 + 7.5 + 7.6 + 6.8 + 7.6 + 8.9 + 8.5)/7	7.9
Average reference (ETo)	ETo= Kp x Epan = 0.7 x 7.9	5.53

5.4.2 Blaney-Criddle method

This method is suggested for areas where only air temperature and general levels of relative humidity, sunshine hours and wind speed are available and is recommended for periods of one month or longer.

$$T_{mean} = \frac{T_{\max} + T_{Min}}{2} \quad \text{(Equation 1)}$$

$$T_{max} = \frac{\text{Sum of all Tmax values during the month}}{\text{number of days of the month}} \quad \text{(Equation 2)}$$

$$T_{min} = \frac{\text{Sum of all Tmin values during the month}}{\text{number of days of the month}} \quad \text{(Equation 3)}$$

$$f = [p(0.46.T_{mean}+8)] \quad \text{(Equation 4)}$$

$$ETo = cf \quad \text{(Equation 5)}$$

Where,

p = Mean daily percentage of annual daily time hours for a given month and altitude(Table 7)

c = Adjustment factor which depends on minimum relative humidity, sunshine hours and daytime wind speed estimates

The value of p for an area can be obtained from Table 7, knowing the latitude of the area. The above ETo value needs to be corrected by an adjustment factor (c) which takes into the wind speed, relative humidity and sunshine hours. Adjusted ETo is provided by FAO in Publication No 24, “Irrigation and Drainage” Paper and is reproduced in Figure 3.

Table 7: Mean Daily Percentage of Annual Daytime Hour for Different North Latitudes

Latitude	North	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Degree (°)	South	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
60		0.15	0.20	0.26	0.32	0.38	0.41	0.40	0.34	0.28	0.22	0.17	0.13
55		0.17	0.21	0.26	0.32	0.39	0.36	0.38	0.33	0.28	0.23	0.18	0.16
50		0.19	0.23	0.27	0.31	0.34	0.36	0.35	0.32	0.28	0.24	0.21	0.20
45		0.20	0.23	0.27	0.30	0.34	0.35	0.34	0.32	0.28	0.24	0.21	0.20
40		0.22	0.24	0.27	0.30	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21
35		0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.30	0.28	0.25	0.23	0.22
30		0.24	0.25	0.27	0.29	0.31	0.32	0.31	0.30	0.28	0.26	0.24	0.23
25		0.24	0.26	0.27	0.29	0.30	0.31	0.31	0.30	0.28	0.26	0.25	0.24
20		0.25	0.26	0.27	0.28	0.29	0.30	0.30	0.29	0.28	0.26	0.25	0.25
15		0.26	0.26	0.27	0.28	0.29	0.29	0.29	0.29	0.28	0.27	0.26	0.25
10		0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.28	0.28	0.27	0.26	0.26
5		0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.27	0.26
0		0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27

5.4.3 Modified Penman-Monteith method

The FAO Penman-Monteith method is recommended as the sole ETo method for determining reference evapotranspiration. Penman-Monteith method is considered to be the most accurate method for estimating ETo but it requires relatively more data than others. The method is considered to offer the best results with minimum possible error in relation to a living grass reference. This method overcomes the shortcomings of all other previous empirical and semi-empirical methods and provides ETo values that are more consistent with actual crop water use data in all regions and climates.

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.32u_2)}$$

Where,

ETo = Reference evapotranspiration (mm/day)

Rn = Net radiation at the crop surface (MJ/m^2 per day)

G = Soil heat flux density (MJ/m^2 per day)

T = Mean daily air temperature at 2 m height (°C)

u_2 = Wind speed at 2 m height (m/sec)

e_s = Saturation vapour pressure (kPa)

e_a = Actual vapour pressure (kPa)

e_s - e_a = Saturation vapour pressure deficit (kPa)

As indicated above, Penman-Monteith method not only required many data but is also complicated for manual calculation. To solve this problem, FAO developed software known as CROPWAT which runs with windows. The software estimates ETo, net and irrigation requirements as well as determines irrigation scheduling.

5.4.4 Choice of methods

Each method of estimating ETo has specific pros and cons and regions/conditions where to apply. The choice among these methods is based on the available data and the degree of accuracy desired. Manual calculation of ETo using Penman-Monteith is a long and tedious procedure, and the risk of making arithmetical errors is fairly high. If some of the required weather data for input into the FAO Penman-Monteith Equation are missing or cannot be calculated, it is strongly recommended that the missing climatic data be estimated with appropriate method.

In the absence of measured data, approximate values of ETo shown in Table 8 can be used. The table indicates the average daily water needs of this reference grass. The daily water needs of the grass depend on the climatic zone (rainfall regime) and daily temperature.

Table 8: Indicative Values of ETo (mm/day)

Climatic zone	**Mean daily Temperature**		
	Low(<15°)	Medium (15-25°C)	High (>25°)
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

5.5 Irrigation water requirement

Crop water requirements (CWR) encompass the total amount of water used in evapotranspiration. FAO (1984) defined crop water requirements as 'the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment'. CWR is equal to ETc. The use of computer programmes for the estimation of ETc or CWR is explained in different reference materials.

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.

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 needs (see Fig. 30 below)

Fig. 30. Estimation of irrigation water needs

EXAMPLE

Suppose a tomato crop grown in a certain area has a total growing season of 150 days and the following monthly crop water needs: Feb Mar Apr May June Total Crop water need (mm/month) 69 123 180 234 180 786. This means that in February the tomatoes need 69 mm of water, in March 123 mm of water, etc. The water need of tomatoes over the total growing season (February-June: 150 days) is 786 mm. Suppose the following rainfall data for the area where the tomatoes are grown have been obtained from the Meteorological Service or Ministry of Agriculture. Feb Mar Apr May June Total Rainfall: P (mm/month) 20 38 40 80 16 194. This means that the average rainfall for February is 20mm, for March 38 mm, etc. The rainfall over the total growing season of tomatoes (February-June: 150 days) is 194 mm. Only part of this rainfall is effective, and the effective rainfall is estimated using Table 9 below.

Table 9. Effective rainfall given on monthly basis

	Feb	Mar	Apr	May	June	Total
Rainfall: P (mm/month)	20	38	40	80	16	194
Effective rainfall: Pe (mm/month)	2	13	14	39	0	68

This means that the effective rainfall during February is only 2 mm, during April 13 mm, etc. The effective rainfall during the total growing season of tomatoes (February-June: 150 days) is 68 mm. Now the Irrigation water need for the tomatoes can be calculated on a monthly basis, as follows (see Table 10 below):

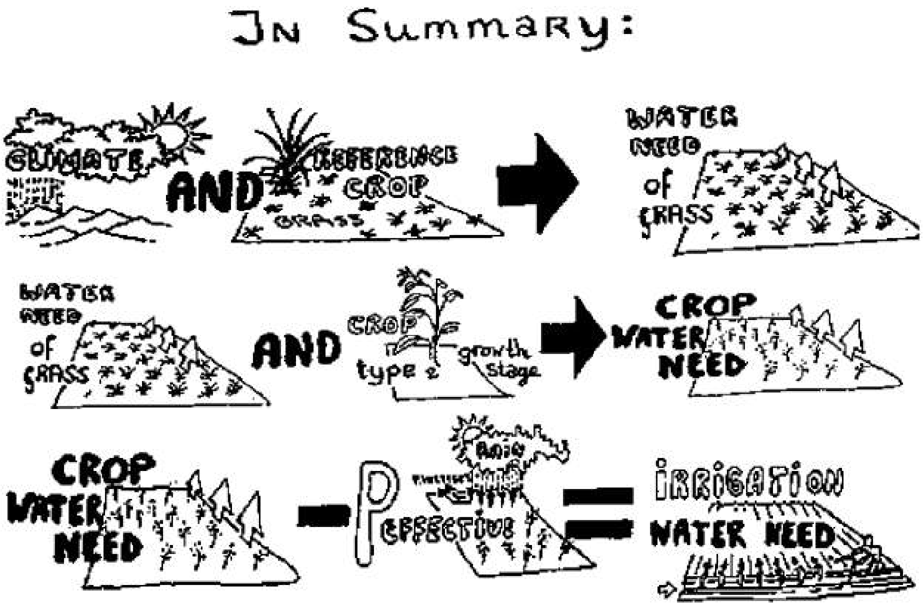
Table 10. Calculation of irrigation water needs

	Feb	**Mar**	**Apr**	**May**	**June**	**Total**
Crop water need (mm/month)	69	123	180	234	180	786
Effective rainfall: Pe (mm/month)	2	13	14	39	0	68
Irrigation water need (mm/month)	67	110	166	195	180	718

Looking at the example for the month of March, it can be seen that tomatoes need 123 mm during March. Of this 123 mm, 13 mm is supplied by the rainfall. The remaining (123 -13 =) 110 mm have to be supplied by irrigation. The total water need of tomatoes over the entire growing season is 786 mm of which 68 mm is supplied by rainfall. The remaining quantity (786 - 68 = 718 mm) has to be supplied by irrigation.

When looking at the calculations above, it is obvious that the month of May is the month of peak irrigation water need (195 mm Irrigation water in May). If the tomatoes are the only crop grown on the Irrigation scheme, the canals would have to be designed in such a way that they allow a flow large enough to supply a net water layer of 195 mm to the whole area covered by tomatoes during the month of May. In other words, for designing an irrigation scheme, the month of peak water supply is the critical month.

Fig. 31. Summary of estimation of irrigation water needs

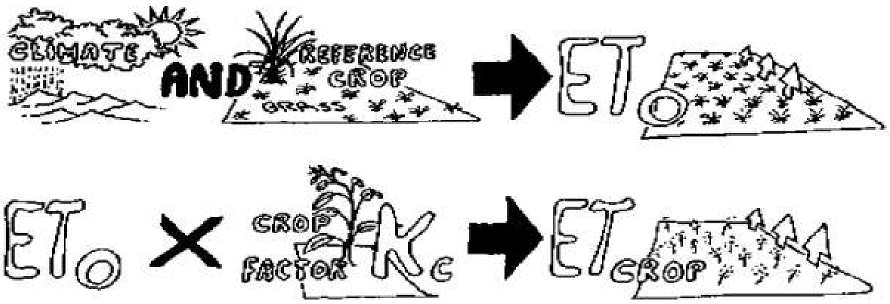


The **crop water needs,** or in other words the amount of water needed by a certain crop to grow optimally, mainly depends on:

- the climate: in a sunny and hot climate crops need more water per day than in a cloudy and cool climate
- the crop type: crops like rice or sugarcane need more water than crops like beans or wheat
- the growth stage of the crop: fully grown crops need more water than crops that have just been planted.

The amount of water needed can be supplied to the crops by rainfall, by irrigation, or by a combination of both. Usually the irrigation water supplements or adds to the rainwater. Only in desert or arid areas -or in the dry season - will all the water needed by the crops have to be supplied by irrigation.

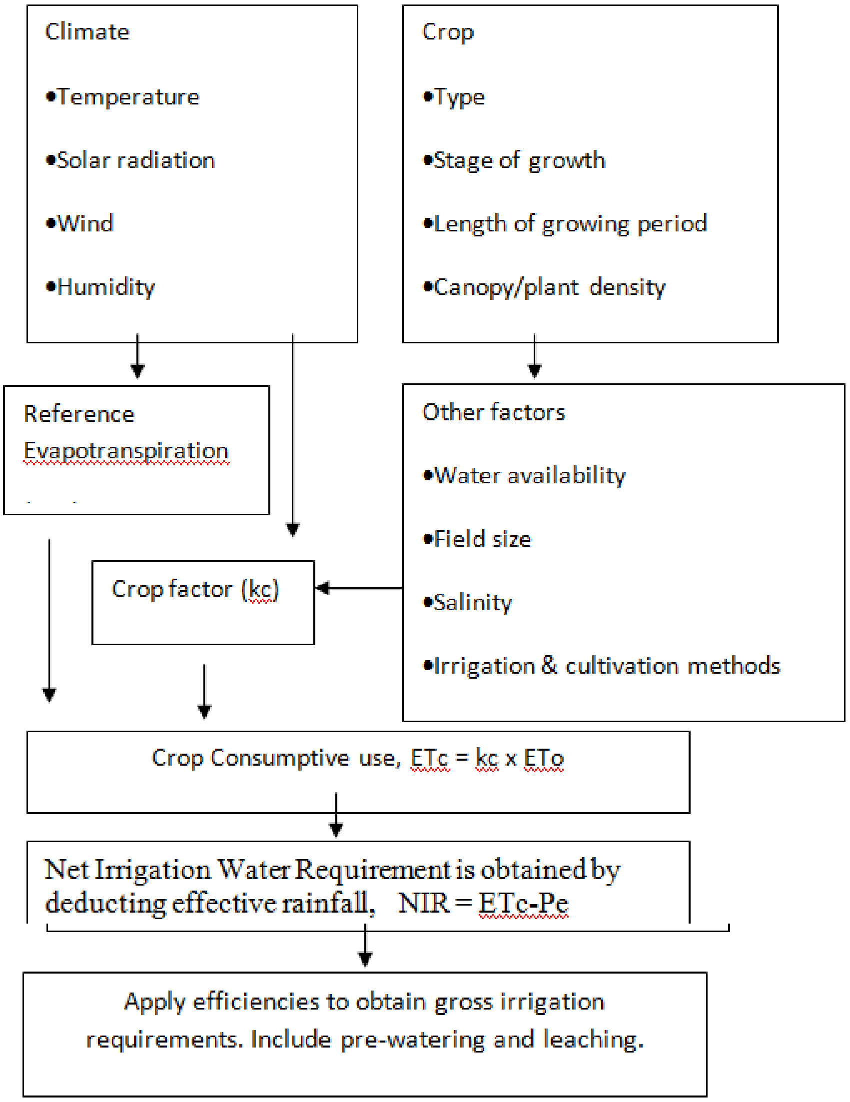
The irrigation water need is the difference between the crop water need and that part of the rainfall which can be used by the plants (effective rainfall). The irrigation water need calculation provides the basis for the determination of the irrigation schedule (usually by agronomists) and the design of the irrigation scheme, e.g. canal dimensions (usually by engineers). An overview of all the subjects that are dealt with in this manual is given.
Overview of the determination of the reference crop evapo-transpiration (ETo), the crop water need (ET crop) and the irrigation water need.



Crop water requirement

Crop water requirement (CWR) is the amount of water required by the plant to fulfil its consumptive use (ET) and is expressed in mm/day. Several factors influence irrigation water requirements (see Fig. 32 below).

Fig. 32: Factors Influencing Irrigation Water requirements



Crop water requirement (ETc) is determined by the crop coefficient approach whereby the effect of the various weather conditions is incorporated into ET_o and the crop characteristics into crop coefficient (kc). The crop coefficient depends on the crop area and its roughness, stage of growth, the growing season and the prevailing weather conditions. The effect of both crop transpiration and soil evaporation are integrated into a single crop coefficient.

Lengths of crop development stages may vary substantially from one area to another, with climate and cropping conditions, and with crop variety. Hence, we need to obtain appropriate local information.

Growing Stages	**Descriptions**
Initial stage	Germination and early growth, little of the soil (less than 10%) is covered with crop.
Crop development	Up to when the crop achieves full ground cover
Mid-season	From full cover is achieved to maturity, when leaves start to discolour or fall off. Flowering and fruit setting occurs during this phase.
Late	From mid-season until harvest.

The following fig (see Fig. 33 below) shows Kc curve for the crop growth stages.

Fig. 33. Crop Coefficient (Kc) Curve

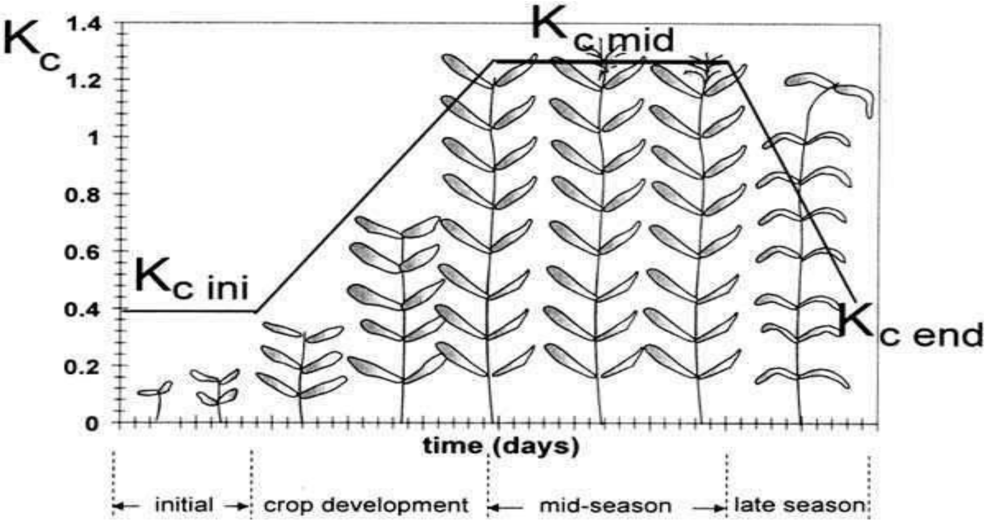


Fig. 34: Growth stages

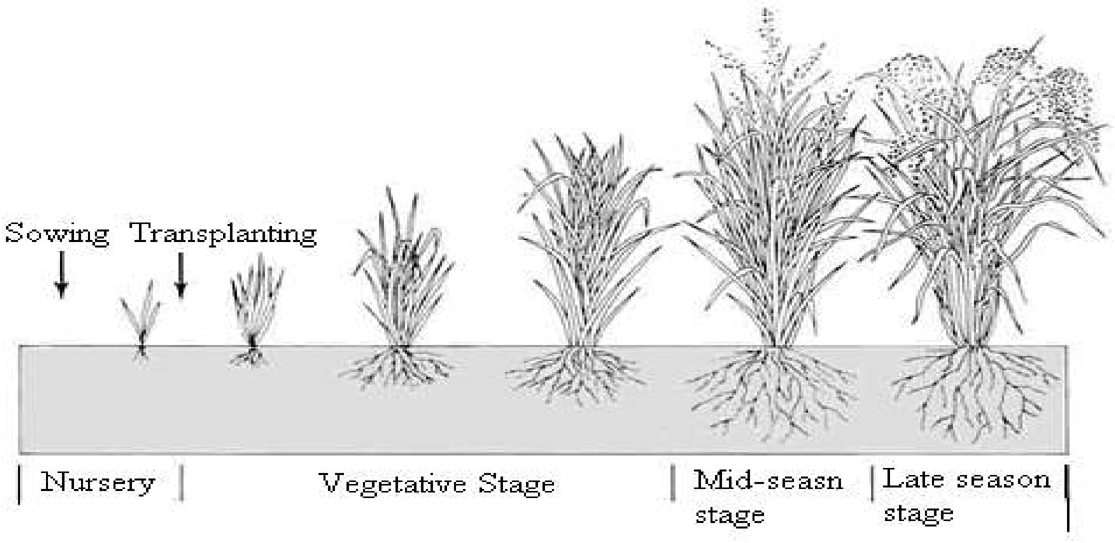


Table 11. Crop coefficient (Kc) values for different crops at various growth stages

Crops	**Initial**	**Crop development**	**Mid-season**	**Late & harvest**	**Depth of Root system (cm)**	**Depletion level (%)**
Seasonal						
• Bean (dry)	0.35 (20)	0.70 (30)	1.00 (40)	0.90 (20)	50-70	0.45
• Cabbage	0.45 (20)	0.75 (25)	1.05 (60)	0.90 (15)	40-50	0.45
• Carrot	0.45 (20)	0.75 (30)	1.05 (30)	0.90 (20)	50-100	0.35
• Cotton	0.45 (30)	0.75 (50)	1.15 (55)	0.75(45)	100-170	0.65
• Cucumber	0.45	0.7	0.90	0.75	70-120	0.50
• Groundnut	0.45 (25)	(35)	1.00 (50)	0.75 (20)	50-100	0.40
• Lettuce	0.45 (20)	0.60 (30)	1.00 (15)	0.90 (10)	30-50	0.30
• Maize	0.40 (20)	0.75 (35)	1.15 (40)	0.75 (30)	100-200	0.60
• Onion	0.50 (20)	0.75 (45)	1.05 (20)	0.85 (10)	30-50	0.25
• Pea	0.45 (20)	0.80 (25)	1.15 (35)	1.05 (15)	60-100	0.35
• Pepper	0.35 (30)	0.75 (35)	1.05 (40)	0.90 (20)	50-100	0.25
• Potato	0.45 (25)	0.75 (30)	1.15 (30)	0.75 (20)	40-60	0.25
• Sorghum	0.35	0.75 (30)	1.11	0.65 (30)	100-200	0.55

	(20)		(40)			
• Sugar beet	0.45 (25)	0.80 (45)	1.15 (60)	0.80 (45)	70-120	0.50
• Tomato	0.45 (25)	0.75 (40)	1.15 (40)	0.80 (25)	70-150	0.40
• Wheat	0.35 (15)	0.75 (30)	1.15 (65)	0.70 (40)	100-150	0.55
Permanent	Young	Mature				
• Alfalfa	0.35	0.85			100-200	
• Banana	0.50	1.1			50-90	
• Citrus	0.30	0.65			120-150	
• Sugar cane	0.45-0.85	1.15-0.65			120-200	

Source: FAO I & D paper 24 (1977) and I & D 33 (1979)

The calculation procedure for crop evapo-transpiration (ETc) consists of:

1. Select the type of crops to be grown;
2. Establish planting dates;
3. Identify the crop growth stages and determine their lengths;
4. Select kc values from Table 9 for each growing stage;
5. Adjust the selected k_c values for frequency of wetting or climatic conditions during the stage;
6. Construct the crop coefficient curve (allowing one to determine k_c values for any period during the growing period);
    - Plot kc values at midpoints of growing periods and connect them;
    - Construct a curve by connecting straight line segments through each of the four growth stages
    - Read kc values for any period during the growing stage
7. Calculate ET_c as the product of ET_o and k_c

Crops vary in their nature of growth, that some crops take short time to mature like peas, while others need long time (cotton). In the same manner, some crops need more water at full maturity than other onions. Hence, the amount of water required by each crop varies daily and seasonally.

Table 12: Example of calculation of ETc for Onion in Sewir Irrigation Scheme- North Shewa, Amhara

Crop	Onion	Pepper
Planting date	15 September	16 July
Harvesting date	30 December	25 December
Soil type	Clay	Clay

Table 13: Table showing ETo for Shewa Robit

Month	J	F	M	A	M	J	J	A	S	O	N	D
ETo (mm/day)	3.3	4.1	5.2	5.5	6.2	6.3	5.6	5.0	4.9	4.7	4.0	4.7
Rainfall (mm)	15.3	75	49.4	126.4	29.3	16.2	249.2	0	110	21.3	15.6	0

Step 1: Determine growth stages of the crops (column 2) of Table 9
Step 2: Indicate ETo Values with Growth Stages (Column 3)
ETo for Onion during initial and development stages:
ETo = 15x 4.9 + 5 x 4.7 = 97 mm and ETo = 25x 4.7 + 25 x 4 = 221.5 mm
Step 3: Select Kc values from Table 9 for each growing stage (column 4)

Table 14. Kc values for different Growth Stages

Crop	Growth Stages	Initial stage	Crop development stage	Mid-season stage	Late season stage	Total
Onion	Duration (days)	20	50	20	15	105
	Months	15 Sept-5 Oct	6 Oct-25 Nov	26 Nov-15 Dec	16-30 Dec	
	Kc values	0.5	0.75	1.05	0.85	0.8
	ETo (mm)	97	221.5	91.2	65.8	**475.5**
	ETc (mm)	48.5	166.1	95.8	55.9	**366.3**
Pepper	Duration (days)	40	45	50	25	160
	Months	16 Jul-25 Aug	26 Aug-10 Oct	11 Oct-30 Nov	1-25 Dec	
	Kc values	0.35	0.75	1.05	0.9	0.75
	ETo (mm)	209	219	214	117.5	**759.5**
	ETc (mm)	73.2	164.3	224.7	105.8	**567.9**

5.5.1 Irrigation water requirement

5.5.1.1 Difference between Crop and Irrigation Water Requirements

It is important to make a distinction between crop water requirement (CWR) and irrigation requirement (IWR). CWR refers to the water used by crops for cell construction and transpiration but IWR is the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirement. If irrigation is the sole source of water supply for the plant, then the irrigation requirement will be at least equal to the crop water requirement, and is generally greater to allow for inefficiencies in the irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the soil, underground seepage, etc.), then the irrigation requirement can be considerably less than the crop water requirement.

The Net Irrigation Requirement (NIR) does not include losses that occur in the process of applying the water. NIR plus losses constitute the Gross Irrigation Requirement (GIR). It is important to realize that the estimation of crop water requirements is the first stage in the estimation of irrigation requirements of a given cropping program. Hence the calculation of crop water requirements and irrigation requirements must not be viewed as two unrelated procedures.

5.5.1.2 Importance of Estimating Irrigation Requirements

Estimating the crop water and irrigation requirements for a proposed cropping pattern is an essential part of the planning and design of an irrigation system. The irrigation water requirement (IWR) is one of the principal parameters for the planning, design and operation of irrigation and water resources systems. Detailed knowledge of the IWR quantity and its temporal and spatial variability is essential for assessing the adequacy of water resources, for evaluating the need of storage reservoirs and for the determining the capacity of irrigation systems. It is a parameter of prime importance in formulating the policy for optimal allocation of water resources as well as in decision-making in the day-to-day operation and management of irrigation systems.

Incorrect estimation of the IWR may lead to serious failures in the system performance and to the waste of valuable water resources. It may result in inadequate control of the soil moisture regime in the root zone. It may also cause water-logging, salinity or leaching of nutrients from the soil. It may lead to the inappropriate capacities of the irrigation network or of storage reservoirs and to low water-use efficiency and to a reduction in the irrigated area. Overestimating IWR at peak demand may also result in increased development costs.

5.5.2 Net and Gross irrigation water requirement

The net irrigation requirement is derived from the field balance equation:

$NIR = ETc - (Pe + Ge + Wb) + LR$

Where:

NIR = Net irrigation requirement (mm)
ETc = Crop evapotranspiration (mm)
Pe = Effective dependable rainfall (mm)
Ge = Groundwater contribution from water table (mm)
Wb = Water stored in the soil at the beginning of each period (mm)
LR = Leaching requirement

5.5.2.1 Effective dependable rainfall

a) Dependable rainfall

Crop water requirements can be partially or fully covered by rainfall. However, while the rainfall contribution may be substantial in some years, it may be limited in other years. In planning irrigation projects, the use of mean values of rainfall should be avoided if more than 10 years of annual rainfall data are available. In such cases, by using these data a probability analysis can be carried out so that a dependable level of rainfall is selected.

The dependable rainfall is the rain that can be accounted for with a certain statistical probability, determined from a range of historical rainfall records. It can be, for example, the depth of rainfall that can be expected 3 out of 4 years (75% probability of excess) or, better still, 4 out of 5 years (80% probability of excess). A rough indication of rainfall probability can be obtained by grouping the rainfall data and then dividing the number of times that monthly rainfall falls within a group by the number of monthly records

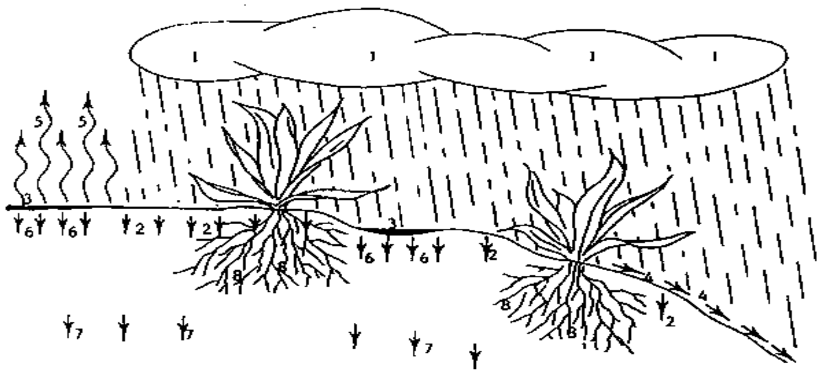
Not all dependable rainfall is effective and some may be lost through surface runoff, deep percolation or evaporation. Only a part of the rainfall can be effectively used by the crop, depending on its root zone depth and the soil storage capacity.

b) Effective rainfall

When rainwater (1) falls on the soil surface, some of it infiltrates into the soil (2); some of it stagnates on the surface (3) while some flows over the surface as runoff (4). When the rain stops, some of the water stagnating on the surface (3) evaporates to the atmosphere (5), while the rest infiltrates into the soil (6). From all the water that infiltrates into the soil (2) and (6), some percolates below the root zone (7) while the rest remains stored in the root zone (8). Therefore, effective rainfall (8) is total rainfall (1) minus runoff (4) minus evaporation (5) minus deep percolation (7). Only the water retained in the root zone (8) can be used by the plants, and represents what is called effective part of the rainwater.

The effective rainfall is used to define this fraction of the total amount of rainfall for meeting the water need of the plant. Many factors influence the amount of effective rainfall: climate, soil texture and structure, depth of root-zone, topography, initial soil moisture conditions, irrigation method There are factors, which the farmers cannot influence (climate and soil texture) and those, which the farmers can influence (soil structure).

Fig. 35: Effective Rainfall (8) = (1) - (4) - (5) - (7)



Dependable and Effective Rainfall

There are different methods of for estimating dependable rainfall. Different methods exist to estimate the effective rainfall. One of the most commonly used methods is the USDA Soil Conservation Service Method. FAO recommends the following formula to estimate effective dependable rainfall.

$Pe = 0.8P-24$ for $P > 70$ mm/month
Pe = dependable effective rainfall
P = monthly mean rainfall
$Pe = 0.6P-10$ for $P < 70$ mm/month

5.5.2.2 Groundwater contribution

The contribution of the groundwater table (Ge) to the ETc varies with the depth of the water table below the root zone, the soil type and the water content in the root zone. Very detailed experiments will be required to determine the groundwater contribution under field conditions. As a rule, under most smallholder conditions high water tables are rare and as a result groundwater contribution to crop water requirements is normally ignored.

5.5.2.3 Water stored in the soil

At times, and for certain crops, planting takes place right after the rainy season. Some water (Wb) could be left in the soil from the previous irrigation, which can be used for the next crop. This amount can be deducted when determining the seasonal irrigation requirements.
However, it is important to note that water stored in the root zone is not 100% effective due to losses through evaporation and deep percolation. The effectiveness ranges from 40-90%. In most situations encountered in the planning of smallholder irrigation schemes, the project sites are located in dry areas with very low rainfall. Hence, for planning purposes, the contribution of water stored in the soil is considered negligible in such schemes.

5.5.2.4 Leaching requirement

The salinity in the root zone is directly related to the water quality, irrigation methods and practices, soil conditions and rainfall. A high salt content in the root zone is normally controlled by leaching. An excess amount of water is applied during the irrigation, where necessary, for the purposes of leaching. This excess amount of water for leaching purposes is called the Leaching Requirement (LR). Estimate the net irrigation water requirements for the above example:

Calculation: For Onion during initial and development stages

$Pe = 0.8 \times 110-24 = 64$ mm/month for September

$Pe = 0.6 \times 21.3-10 = 2.78$ mm/month for October

$Pe = 0.6 \times 15.6-10 = -0.64$ mm<0 for October

For initial stage

$NIR = CWR-(Pe + Ge + Wb) + LR = 73.2 - ((64/30 \times 15 + 2.78/30 \times 5) + 0 + 0) + 0 = 16.0$ mm

For development stage

$NIR = CWR-(Pe + Ge + Wb) + LR = 166.1 - (2.78/30 \times 25 + 0 + 0) + 0 = 162.8$ mm

5.5.2.5 Gross irrigation water requirement

The gross irrigation requirements account for losses of water incurred during conveyance and application to the field. This is expressed in terms of efficiencies when calculating project gross irrigation requirements from net irrigation requirements as shown below:

Gross irrigation water depth (GIR) = $\frac{NIR}{E}$, Where, E = Irrigation efficiency

There are three basic irrigation efficiency concepts. These are:

Conveyance efficiency (Ec) = $\frac{\text{Water received at inlet to block of fields}}{\text{Water released from the headwork}}$

Distribution efficiencies (Ed) = $\frac{\text{Water received at field inlet}}{\text{Water received at inlet to block of fields}}$

Application efficiency (Ea) = $\frac{\text{Water stored in the root zone}}{\text{Water received at field inlet}}$

Project efficiency (E) = Ec x Ed x Ea

Table 15. Typical Surface Irrigation Efficiencies

Description	**%**
Conveyance efficiency (Ec)	65 - 90
Field canal efficiency (Eb)	70 – 90
Distribution efficiency (Ed = Ec.Eb)	30 – 65
Application efficiency (Ea)	40 – 50
Project efficiency (E)	30 – 40

Calculate gross depth of water applied for the above example. Assume/select application efficiency of 50%.

Table 16. Net Irrigation Requirements of onion and pepper

Growth stages	**Onion**				**Pepper**			
	ETc (mm)	**Pe (mm)**	**NIR (mm)**	**GIR (mm)**	**ETc (mm)**	**Pe (mm)**	**NIR (mm)**	**GIR (mm)**
Initial stage	48.5	32.5	16.0	32.1	73.2	87.7	0.0	0.0
Dev't stage	166.1	2.3	163.8	327.6	164.3	64.9	99.3	198.6
Mid-season	95.8	0	95.8	191.5	224.7	1.9	222.8	445.7
Late season	55.9	0	55.9	111.9	105.8	3.9	101.8	203.7
Total	**366.3**	**34.8**	**331.5**	**663.1**	**567.9**	**158.4**	**424.0**	**848.0**

5.6 Estimation of IWR for multiple crops

The following steps should be used to estimate irrigation water requirements (IWRs) for multiple cropping programmes.

1. Select the crops to be planted on a particular season taking into account farmers' preferences, climate, soil property, diseases, harvesting time and marketing as well as labour requirements.
2. Determine proportion of area to be covered by each crop
3. Determine planting dates for each crop and draw a chart showing the length of growing periods (LGPs) of each crop including area proportions (Ap)
4. Determine the four growth periods of each crop
5. Estimate ETo and effective rainfall (Pe) for the months in the planting season (mm)
6. Select Kc values for each crop
7. Estimate ETc for each crop by multiplying ETo by Kc (mm)
    a) Calculate weighted Kc of all the crops by multiplying Kcs and Ap and then multiply weighted Kc by ETo
    b) Multiply ETo by Kcs of each crop but do not add the ETcs of all crops
8. Estimate NIR (mm) by subtracting the Pe from ETcs for the corresponding periods (months)
9. Determine the GIR by applying appropriate irrigation efficiency
10. Convert the GIR (mm) into flow rate (l/s)
11. Compare the estimated flows with available supply
12. Revise the cropping pattern, cropping calendar or area proportions if available water supply is less than the irrigation water requirement.

Table 17. Irrigation Water Requirements for Multiple Crops

Project:			Woreda:						Region:				
Meteorological Station:			Altitude:					Lat:		Long:			
Crop	Description	Area ratio		Crop Coefficients (Kcs)									
No.	Crop	pi (%)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Total
a) Crop Coefficients (kci)													
A	Crop-1												
B	Crop-2												
C	Crop-3												
F	Weighted mean kc = ∑(pi/100 x kci)												
G	No. of crop days in the month												
b) Irrigation Water Requirement													
1	ETo, mm												
2	ETc, mm= (f) x (1)												
3	Pre-irrigation (mm)												
4	CWR, mm = (2)+(3)												
5	Average rainfall, P (mm)												
6	Effective rainfall, Pe (mm)												
7	NIR =(4)-(6)												
8	GIR = NIR/E (mm)												
9	(L/s/ha) = (8)/(days x hrs/day x 3600)												
c)	Available Water (L/s)												
10	Area to be irrigated (ha (c)/ (9)												
	with 24 hrs irrigation/day												
	with t-hrs irrigation/day												

NB: The area to be irrigated is the lowest figure in the last two rows

Area to be irrigated (ha) = A_{24} x t hrs/24 hrs. (A_{24} is area to be irrigated in 24 hrs)

MODULE 6: IRRIGATION SCHEDULING

The need for increased food and fiber production in many parts of the world has resulted in an increase in irrigated areas regardless of water resource availability. For many irrigation projects, water becomes a limiting factor for development. Proper water management would maximize the water use efficiency of the irrigated crops. In some cases, drainage water or other low quality water might be used to irrigate salt tolerant crops. Scheduling irrigation under limited water resources and saline conditions requires a different approach from those known for unconstrained conditions. In addition, scheduling irrigation under variable rainfall requires weather forecasting and a flexible management system to cope with rainfall uncertainty.

6.1 General requirements for irrigation scheduling

Irrigation scheduling is defined as the process of determining **when** to irrigate and **how much** water to apply. It is concerned with the farmers' decision process concerning time to irrigate and the quantity of water to apply in order to maximize profit. For maximum flexibility, the irrigator should have control of the irrigation interval, water application flow rate and duration. Through proper irrigation scheduling, it should be possible to apply only the water which the crop needs in addition to unavoidable seepage and runoff losses and leaching requirements. This requires knowledge on crop water requirements and yield responses to water, the constraints specific to each irrigation method and irrigation equipment, the limitations relative to the water supply system and the financial and economic implications of the irrigation practice. Thus, the consideration of all these aspects makes irrigation scheduling a very complex decision making process, one which only very few farmers can understand and, therefore, adopt. Farmers need:

-How often (when) 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

The maximum amount of water which can be given should be determined and may be influenced by crop type and root depth, soil texture, climate and the irrigation method.

Irrigation scheduling requires knowledge of:- the soil, the soil-water status, the crops, the status of crop stress, and the potential yield reduction if the crop remains in a stressed condition

The Influence of water shortages on yields can be well understood by asking questions

- Which crops are sensitive to water shortages? Generally, crops grown for their fresh leaves or fruits are more sensitive to water shortage than crops grown for their seeds or dry fruit.
- Which growth stages are sensitive to water shortages?

Studying and testing water applications and frequencies are justified for many reasons.

- Economic reasons:- Watering is often expensive (water is scarce or operations are labour-intensive or pumping and transport are costly).
- Social Reasons:- If water is scarce, it must be shared among those who need it, wastage by some can be detrimental to others.
- Ecological reasons:- Over-irrigation does not increase productivity but leads to the depletion of water resources, particularly underground reserves.

- Agricultural reasons:- Excess water is sometimes harmful to the plants

Irrigation scheduling is one of the factors that influence the agronomic and economic viability of farms. It is important for both water savings and improved crop yields.

Irrigation schedules are expressed in terms of frequency, rate and duration of how water is diverted or delivered to a farm unit. The irrigation water is applied to the field according to predetermined schedules based upon the monitoring of the soil water status and the crop water requirements. The adoption of appropriate irrigation scheduling practices could lead to increased yields and greater profit for farmers, significant water savings, reduced environmental impact of irrigation and improved sustainability of irrigated agriculture.

6.1.1 Soil-water relationship

Soil is one of the three parameters that need to be considered when preparing an irrigation schedule. This chapter will look more in detail into the soil data necessary for irrigation scheduling and how to obtain them as well as into the soil-water-plant relationship.

The soil acts as a reservoir of water in the soil. This reservoir is filled through irrigation and rainfall and emptied by the plant (transpiration), evaporation from the soil surface and deep percolation beyond the root zone. Each soil type has its own storage capacity determined by its texture. The storage capacity is relatively small in sandy soils as compared to that 0f clays.

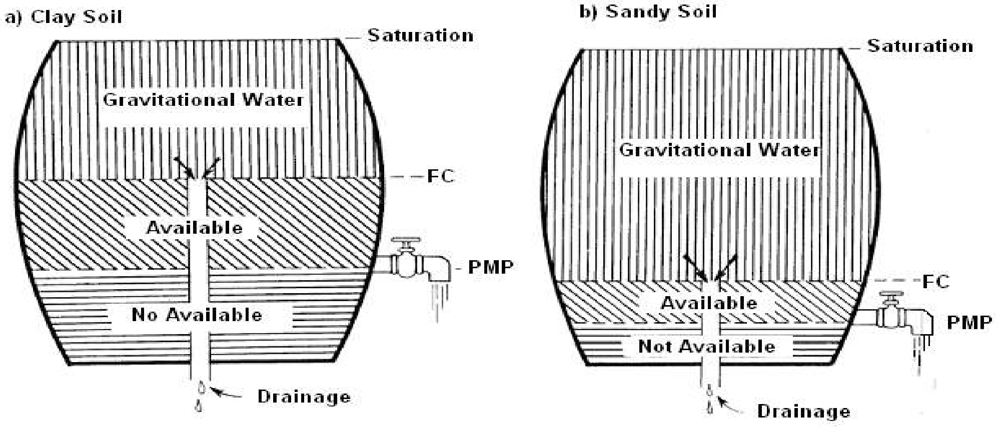
Important soil characteristics in irrigated agriculture include:

(1) The water-holding or storage capacity of the soil;
(2) The permeability of the soil to the flow of water and air;
(3) The physical features of the soil such as organic matter content, depth, texture and structure; and
(4) The soil's chemical properties such as the concentration of soluble salts, nutrients and trace elements.

The amount of water available in different soil types may be compared to the amount that can be drawn from a tap on the side of a barrel filled with water. Fine-textured soils generally hold more water than coarse--textured soils. Medium-textured soils actually have more water available for plant use than some clay soils, since water in clays can be held at a greater tension that reduces its availability to plants.

Fig. 36 below makes a comparison between a heavy clay soil and a light sandy soil. After saturation, excess water is drained through the forces of gravity. The rate of drainage is slower in heavier soil. This is called gravitational water. This leaves the water below the line marked field capacity (FC). As can be seen in the diagram, the amount of water that is “available” in the clay soil is greater than in the sandy soil.

Fig. 36: Comparison of Water Stored in Heavy and Light Soils



The soil moisture content can also be expressed in percent of volume. In the example above, 1m^3 of soil (e.g. with a depth of 1 m, and a surface area of 1 m^2) contains 0.150 m^3 of water (e.g. with a depth of 150 mm = 0.150m and a surface area of 1 m^2). This results in soil moisture content in volume percent of:

$$\frac{0.150\ \text{m}^3}{1\ \text{m}^2} \times 100 = 15\%$$

Fig 37. Soil moisture content

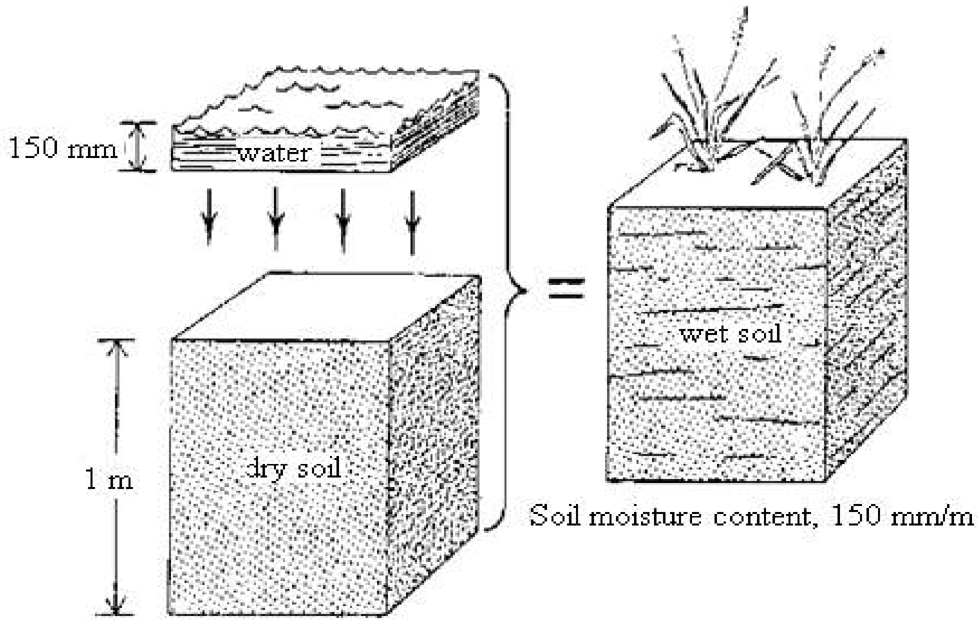


Table 18. Typical Values for the Available Water for Different Soil Textures

		Available Water (AW)	
Soil Type	**Soil Texture**	**mm/m**	**%**
Heavy	Clay	120-200	12-20
↑	Silty clay	130-190	13-19
	Silty clay loam	130-180	13-18
Medium	Silty loam	130-190	13-19
	Loam	130-180	13-18
↓	Sandy loam	110-150	11-15
	Loamy sand	60-120	6-12
Light	Sand	50-110	5-11

Source: Field Guide on Irrigated Agriculture for Field Assistants, IPTRID (FAO), Report No.1, April 2001

The TAW or Sa for plant use in the root zone is commonly defined as the range of soil moisture held at a negative apparent pressure of 0.1 to 0.33 bar (a soil moisture level called 'field capacity') and 15 bars (called the 'permanent wilting point'). It varies from 25 cm/m for silty loams to as low as 6 cm/m for sandy soils. Typical values for the TAW per one-meter depth of soil are given in Table 14 above. Sa is estimated from

Sa = (FC-WP) x 1000
d = p x Sa x D

Where, d = Depth of net irrigation application (mm)
p = Management allowable depletion level -crop dependent (decimal)
D = Depth of root zone in mm
FC = Field capacity (decimal)
PWP = Permanent wilting point (decimal)

6.1.1.1 Permissible deficit or depletion of soil available water

The fraction of moisture in the soil, which is in the range of 20-70 percent of the total available moisture (Sa) and is easily absorbed by the plants (without any stress that results in yield reduction) is called readily available moisture. It is a product of Sa multiplied by p, which represents the maximum permissible depletion of available water (moisture). The p value differs according to the kind of plant, the root depth, the climatic conditions and the irrigation techniques. Tables 19 and 20 of FAO Irrigation and Drainage Paper No. 33 provides p values, which vary from 0.25 in shallow rooted sensitive crops to 0.70 in deep-rooted tolerant crops.

Field observations have shown that the lower the soil moisture depletion (p), the better the crop development and yield. Hence, the recommended p values are:

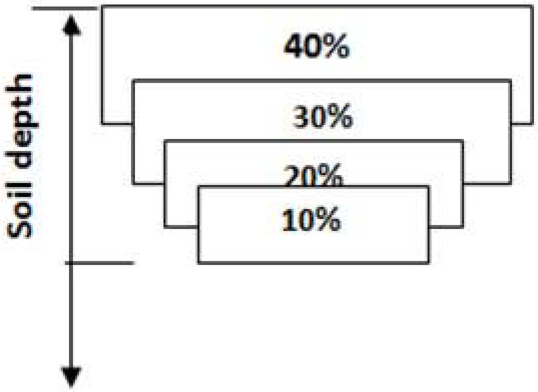
- 0.20-0.30 for shallow rooted seasonal crops
- 0.40-0.60 for deep-rooted field crops and mature trees

6.1.1.2 Effective root depth and water extraction pattern

This is the soil depth from which the plants take nearly 80 percent of their water needs, mostly from the upper part where the root system is denser (see Fig. 38 below). The rooting depths depend on the plant physiology, the type of soil, and the water availability (kind of irrigation).

In general, vegetables (beans, tomatoes, potatoes, onions, peanuts, cucumbers, etc.) are shallow rooted, about 50-60 cm; fruit trees, cotton and some other plants have medium root depths, 80-120 cm. Alfalfa, sorghum, and maize have deeper roots. Rooting depths vary with growth stage up to development stage.

Fig. 38. Water extraction patterns in the root-zone



6.1.2 Plant susceptibility to soil drying

Cultivated species are usually subdivided into varieties with different characteristics. These characteristics (for example, the length of the leaf stock, the colour of the leaves and the shape of the flowers) may be of little importance as regards to water requirements, but they may be significant as regards the way in which the plants use this water. That is susceptibility to drought, earliness or lateness of the life cycle, root system or root resistance to waterlogged soil.

Table 19 below gives four groups of cultivated plants: - setting out, for each one, the harmful effects of drought periods at a given stages of the life cycle.

Table 19: Critical Periods for Cultivated Species Susceptible to Drought

Phases of the Life Cycle	**Sorghum**	**Bean**	**Potato**	**Headed cabbage**
Imbibitions	■	■	-----------	▨
Germination & emergence	■	▨	-----------	
Establishment & rooting			▨	
Leaf formation		▨	▨	▨
Formation of the head	--------------	------------	-----------	▨
Tillering		------------	-----------	-----------------
Shooting	▨	------------	-----------	-----------------
Tuberization	-------------	------------	■	-----------------
Flowering	■	■		
Fertilization & fruit set	■	■		
Fruit enlargement	▧	■		
Fruit maturation	▨	▨		
Withering of leaves				
Withering of stems				

Swelling of the tubers	-------------		▩	
Dormancy of vegetative organs	-------------	-------------		-----------------
Bud break	-------------	------------	▨	-----------------
	↓	↓	↓	↓
Similar Species	maize, millet, sunflower, rice, wheat	peppers, tomato, night-shade, , peas, groundnut, cotton, soya	yam, sweat, potato, ginger	onion, shallot, lettuce, spinach, tobacco

Key	Plant susceptibility to dry soils
	Minor risk affecting less than 10% of the harvest
▨	Risk affecting more than 10% of the harvest
▩	Risk of losing more than 50% of the harvest
■	Risk of losing the entire harvest
-----------	The plant described does not have these phases

Source: Hugue Dprieze- Philippe De Leener: Land and Life, Ways of Water, Runoff, I&D (1992)

To ensure satisfactory crop yields, the periods in which water is effectively available in the soil must coincide with those during which the cultivated plants need water.

6.2 Determination of irrigation scheduling

Common approaches of irrigation scheduling include:

1. Irrigating on fixed intervals or following a simple calendar, i.e., when a water turn occurs or according to a predetermined schedule;
2. Irrigating when one's neighbor irrigates ;
3. Observation of visual plant stress indicators (change of colour, curling of leaves and wilting);
4. Measuring (or estimating) soil water by use of instruments or sampling techniques such as feel (feeling the soil), gravimetric, electrical resistance (gypsum) blocks, tensiometers or neutron probes;
5. By following a soil water budget based on weather data and/or pan evaporation; and
6. Some combination of the above.

Item 1 and 3 are commonly applied in Ethiopia. Item 5 (soil water budget) is not readily adopted due to the technical and time requirements that include measuring or obtaining quality weather data, soil information, crop information, and soil moisture monitoring and making necessary calculations due to capacity limitation for updating schedules. However, procedures used in item 5 can be applied on a one-time basis by trained technicians to produce irrigation calendars suggested in item 1 that can be applied for long-term usage.

6.2.1 Plant observation

The type of soil and climatic conditions have a significant effect on the main practical aspects of irrigation, which are the determination of how much water should be applied and when it should be applied to a given crop. In addition to the basic factors relevant to the preparation of irrigation schedules examined below, other important elements should also be considered, such as crop tolerance and sensitivity to water deficit at various growth stages, and optimum water use.

There are two methods for estimating water applications and frequencies: a) pragmatic and b) simplified calculation of the water balance. The two methods are based on the same principle- making sure that the volume of soil occupied roots contains a stock at least half its useful capacity.

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 is water-stressed its 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).

6.2.2 Soil observation

Soil moisture status can be determined based on observation and feel of soils. Table 20 below provides general indication of soil moisture status of different soil textures.

Table 20: Soil Feel method

Depletion of available soil moisture in % of FC	Feel or appearance of soil and moisture deficiency of water per meter of soil (mm)			
	Coarse texture	Moderately coarse texture	Medium texture	Fine and very fine texture
0	Upon squeezing no free water appears on soil but wet outline of ball is left on hand 0.0	Upon squeezing no free water appears on soil but wet outline of ball is left on hand 0.0	Upon squeezing no free water appears on soil but wet outline of ball is left on hand 0.0	Upon squeezing no free water appears on soil but wet outline of ball is left on hand 0.0
0-25	Tends to stick together slightly, sometimes form a week ball under pressure (0 – 17)	Forms weak ball, breaks easily, will not stick (0 – 34)	Forms a ball, is very pliable, slicks readily if relatively high in clay. (0 – 42)	Easily ribbons out between thumb and forefinger (50-100)
25-50	Appears to be dry, will not form a ball under pressure (17-42)	Tends to ball under pressure but seldom held together (34-67)	Forms a ball somewhat plastic, will slick slightly with pressure (42 – 83)	Forms a ball, ribbons out b/n forefinger &thumbs (50- 100)
50-75	Appear to be dry, will not form a ball with pressure (42- 67)	Appear to be dry, will not form a ball (67 -100)	Somewhat crumbly, holds together form pressure (83-125)	Somewhat pliable, will ball under pressure (100- 158)
75-100 (PWP)	Dry, loose single grained flows through fingers (67-83)	Dry, loose flows through fingers (100-125)	Powdery dry sometimes slightly crusted but easily broken down (125-167)	Hard baked cracked, sometimes has loose crumbs on surface (158 – 208)

6.2.3 Irrigation scheduling based on CWR calculation

The following parameters will be required to determine irrigation scheduling.

- Cropping program
- Daily water requirements of the different crops (ETc) at the different stages of their growth
- Root zone depth at the different growth stages of each crop (RZD)
- Total available soil moisture (Sa)
- Allowable soil moisture depletion level (P)
- On-site rainfall data

The cropping programme provides the different crops, their rotation and the time of planting and harvesting. The RZD of each crop at the different stages of growth can be derived preferably from local information or, in their absence, from Tables presented. The Sa is usually determined through laboratory analysis during the soil surveys. As explained earlier, the level of P depends on the crop and its stage of growth as well as on the soil type and irrigation system. A rain gauge would also be required on site to record the daily rainfall received. Irrigation frequency and duration have to be calculated for each crop of the existing cropping pattern and a sound irrigation schedule has to be put together in order to irrigate all crops at the time and for the duration they require the water.

Once the irrigation schedule is known, simplifications can be introduced in order to make the schedule practical and 'user-friendly' for the farmers. For example irrigation intervals and irrigation duration can be made uniform over a period of 14 days or a month. This is particularly important in smallholder irrigation schemes where a number of farmers are involved, living at some distance away from the scheme. If they know the irrigation schedules for the rest of the month, they are in a better position to organize their work, household tasks and family life accordingly. The rainfall can be taken into consideration at the time the irrigation schedule is applied. By using a rain gauge and by recording the amount of rainfall on a daily basis, this amount can be weighed against part of, or one or more irrigation applications. Therefore, the irrigation cycle is interrupted and a number of days are skipped, depending on the amount of rainfall, the daily water requirements and the moisture to be replenished in the root zone depth of the soil.

6.2.3.1 Irrigation Interval

Irrigation frequency is defined as the frequency of applying water to a particular crop at a certain stage of growth and is expressed in days. In equation form it reads:

$$II = \frac{Sa \times P \times RZD}{ETc}$$

Where:

II = Irrigation interval (days)
Sa = Total available soil moisture (= FC – PWP) (mm/m)
P = Allowable depletion (decimal)
RZD = Effective root zone depth (m)
ETc = Crop evapo-transpiration or crop water requirement (CWR) (mm/day)

Example

Consider onion whose average crop water requirement is 4.6 mm/day during its mid season stage. The total available moisture of the soil is 100 mm/m, the root zone depth is 0.5 m and the allowable depletion level is 35%. How often should irrigation be applied?

$$II = \frac{Sa \times P \times RZD}{ETc} = \frac{160 \times 0.35 \times 0.6}{4.6} = 7.3 = 7 \text{ days}$$

6.2.3.2 Irrigation scheduling- simple calculation method

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 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 steps that are explained in detail below:

Step 1: Estimate the net and gross irrigation depth in mm.
Step 2: Calculate the irrigation water need (NIR) 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.

Example 2

Step 1: Estimate the net and gross irrigation depth (d_n) 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. Net irrigation depth is assumed to depend only on the root depth of the crop and the soil type. Hence, estimate the root depth for a crop under consideration based on soil type as root penetration depends on soil type. Considering root depth of 0.6 m and depletion level of 35%, the net depth of irrigation is

dn= 0.35 x 160 x 0.6 = 33.6 mm

Step 2: Calculate the irrigation water need (NIR) in - over the total growing season

Consider the irrigation water need of onion as estimated above which is 332 mm for the total growing season. This means that over the total growing season a net water layer of 332 mm has to be brought onto the field.

Month	Initial	Development	Mid season	Late season	Total
NIR (mm)	16.0	163.8	95.8	55.9	**331.5**

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).

No of applications = 331.5/33.6 = 9.86 ≅10

Step 4: Calculate the irrigation interval II)

Thus a total of 7 applications are required. The total growing season for onion is 3.5 months (Sept-Dec) or 3.5 x 30 = 105 days. Hence, irrigation interval is

105/10 = 10.5≅ 10 days.

To be on the safe side, the interval is always rounded off to the lower whole figure.

In this example, the irrigation schedule for onion is as follows:

dn = 33.6 mm
GIR = 84 mm (irrigation efficiency of 40%)
II = 10 days

Example 3

Determine the irrigation schedule for the same crop based on

- the total growing period as estimated above
- the months of peak irrigation water need
- a combination of the two

Option 1: Irrigation schedule for onion based on total water requirement

Table 21. The comparison of irrigation water required and applied

Description	**Initial**	**Development**	**Mid season**	**Late season**	**Total**
NIR (mm)	16.0	163.8	95.8	59.9	331.5
dn (mm)	67.2	168	67.2	49.4	351.8
dn-NIR (mm)	51.2	4.2	-28.6	11.3	**38.1**

There is water shortage during mid and late season. The mid season is critical because it is at this stage that flowering and fruit setting occurs

Option 2: Irrigation schedule for onion based on months of peak water requirement

As can be seen above, peak irrigation water need is during development stage. In this example the irrigation schedule will be based on this stage.

Step 1: Estimate the net and gross depths in mm of the irrigation applications.

The depths of irrigation are calculated in the same way as above.

Step 2: Calculate the irrigation water need over the stage of peak irrigation water need

The peak irrigation water need = 95.8 mm.

Step 3: Calculate the number of irrigation applications during this period

The number of applications is 95.8/33.6 = 2.9, rounded 3 applications.

Step 4: Calculate the irrigation interval in days

3 applications are given during 20 days; Irrigation interval = 20/3 = 6 days.

Table 22. The comparison of irrigation water required and applied

Description	Initial	Development	Mid season	Late season	Total
NIR (mm)	16.0	163.8	95.8	59.9	331.5
dn (mm)	235.2	571.2	95.8	168.0	**1070.2**
dn-NIR (mm)	219.2	407.4	0.0	112.1	**738.7**

Excess water is supplied in all growth stages excluding the mid season stage.

Option 3: Irrigation schedule for Onion combining the two previous schedules

It is possible to combine the two schedules obtained in Option 1 and Option 2. For the non-peak period, Option 1 schedule is used. For the peak period, Option 2 is used. The result is shown below.

Table 23. The comparison of irrigation water required and applied

Description	Initial	Development	Mid season	Late season	Total
NIR (mm)	16.0	163.8	95.8	59.9	331.5
dn (mm)	67.2	168	95.8	49.4	**380.4**
dn-NIR (mm)	51.2	4.2	0.0	11.3	**66.7**

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.

6.2.3.3 Adjusting the irrigation schedule to actual rainfall

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.

An example is given below for a situation with of pepper water need of 4.8 mm/day during mid stage and a net irrigation depth of 33.6 mm. As soon as the accumulated deficit exceeds 33.6 mm, irrigation water is supplied. Note that the "deficit" can never be positive; maximum zero. In this example, irrigation takes place on day 6, etc. with net irrigation depth of 45 mm in each occasion.

Table 24**.** Example of Irrigation Scheduling

No	NIR (mm/day)	Rain (mm)	Da (mm)	Calculation	Accumulated deficit (mm)
1.			33.6		
2.	4.8	-	-		-4.8
3.	4.8	-	-	(-4.8-4.8)	-9.6
4.	4.8	-	-	(-9.6-4.8)	-14.4
5.	4.8	-	-	(-14.4-4.8)	-19.2
6.	4.8	-	-	(-19.2-4.8)	-24.0
7.	4.8	-	-	(-24-4.8)	-28.8
8.	4.8	-	-	(-28.8-4.8)	-33.6
9.	4.8	-	33.6	(33.6-4.8)	28.8
10.	4.8	12	-	(12+28.8-4.8)	36.0
11.	4.8	-	-	(36-4.8)	

6.3 Relationship between irrigation scheduling and irrigation methods

- In surface irrigation systems supplied through collective irrigation networks, the first step for irrigation scheduling is the delivery on a volume basis, in such a way that farmers can control irrigation discharge rates and duration. A step further is the adoption of arranged delivery systems that allow farmers to control the frequency of irrigation.
- Modifications in the delivery system should go together with improvements of the on-farm system in such a way that farmers control both the discharge rates applied to basins, furrows or borders and the supply time. This requires simple equipment to control inflow rates and, thus, the applied depths.
- It could be advisable that simple irrigation scheduling calendars and/or simplified forms
- of exploring irrigation scheduling simulation models be developed and installed to support information for farmers and system managers.
- The tools referred to above should constitute simple technological packages that could help transfer management responsibilities to farmers at sector or distribution level (turnover).
- When modernization of on-farm surface irrigation systems is already developed, the improved use of surface irrigation equipments and automation devices could be achieved if management decisions concerning the system state variables (inflow rate, advance time, infiltration characteristics) can be coupled with irrigation scheduling decisions.
- For modernized on-farm surface irrigation systems, it could be suitable to progressively adopt simulation models and/or soil moisture monitoring to support irrigation scheduling decisions and, in the case of collective supply systems, to provide enough demand lag time for the arranged deliveries.
- In the case of more advanced surface irrigation systems when real time or feedback control is utilized, it is advisable to couple the corresponding surface irrigation models with real-time scheduling methods.

Sprinkler irrigation systems

- In sprinkler irrigation systems, unlike in surface irrigation, farmers are in control of discharge rates and duration of irrigation. However, in most cases, farmers do not know the discharge rates being applied, namely when variations in pressure head induce variations in flow rates. The use of simple discharge measuring devices upstream of the system could be the first step for farmers to appropriately define the application depths.

- For set systems and travelling gun systems, several irrigation scheduling methods could be applied based on the estimation of soil moisture deficit (SMD): simulation models using soil, crop and meteorological information, monitoring of soil moisture or soil water potential; or a combination of both. The use of simple irrigation scheduling calendars could be of interest for scheduling a large number of small farms.
- For lateral moving systems applying very frequent irrigations and small application depths, specific approaches combining irrigation, fertigation, chemigation and energy management are suitable.

Trickle irrigation systems

- In the case of very frequent irrigations, the scheduling is dictated by the replacement of the water consumed and includes fertigation and chemigation scheduling. Specific approaches and models could be applied.
- In the case of less frequent irrigations, several scheduling methods can be utilized such as simulation models including videotel systems, soil water potential monitoring, or crop water stress indicators.
- The effectiveness of scheduling requires that farmers know both the flow rate they are utilizing as well as the full characteristics of the system and equipment they are using.

Irrigation performances and irrigation scheduling

- In surface irrigation, the irrigation scheduling variables are intimately related to the performances. The distribution uniformity depends on the applied depth through the couple inflow rate and time for cut-off. Beside these variables, the application efficiency also depends on the timeliness of irrigation. Consequently, research and development for improving on-farm surface irrigation or the irrigation scheduling in gravity systems have to take a multidisciplinary approach.
- For sprinkler irrigation, uniformities mostly depend on the quality of design and of the equipment selected. Application efficiencies are influenced both by the uniformity and by the depth and timeliness of irrigations. Therefore, increased attention has to be paid to the design of sprinkler systems and to relations between design and operation, including scheduling.
- The performance of trickle irrigation systems essentially depends on the quality of design and equipment and consequent rules for operation. Irrigation scheduling should be carefully oriented to maximize profit and combine water applications with fertigation/chemigation.
- Field evaluations of on-farm irrigation systems under operation should be extensively performed, aiming at improving both systems operation and irrigation scheduling.
- The control of quality of systems design and equipment is relevant for improving the performances of on-farm irrigation systems.
- Multidisciplinary research, combining agronomy and irrigation engineering disciplines should look for new improvements in coupling irrigation methods and irrigation scheduling.

Environmental and economic aspects

- It is recognized that improved irrigation scheduling, and irrigation management in general, contribute to controlling the environmental impacts of irrigation. However, research and appropriate methodologies are required to expand the analysis and assessment of the environmental benefits of irrigation scheduling.
- Similarly, research and appropriate methodologies for evaluating the economic impacts of irrigation scheduling are also required.
- Policy-makers and decision-makers need evidence of benefits of irrigation scheduling. Thus, the expansion of related environmental and economic impact assessment could help the adoption and funding of irrigation scheduling programmes and services.

6.4 Conversion of irrigation depth to flow rates

What is flow rate?

The flow-rate 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 (m^3) and the time in seconds (s) or hours (h). The flow-rate is also called discharge-rate. The water running out of a tap fills a one liter bottle in one second. Thus the flow rate (Q) is one litre per second (1 l/s).

Volume (V) =Area x Depth (m^3 or liters) (Equation 6)

Example 1: 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:

$$Q = \frac{\text{Volume of water}}{\text{Time}} = \frac{200\,\text{l}}{20\,\text{s}} = 10\,\text{l/s}$$

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 meter per second" (m^3/s) is more conveniently used.

Example 2: A river discharges 100 m^3 of water to the sea every 2 seconds. What is the flow-rate of this river expressed in m^3/s?

$$Q = \frac{\text{Volume of water}}{\text{Time}} = \frac{100\,\text{m}^3}{2\,\text{s}} = 50\,\text{m}^3/\text{s}$$

In the previous sections, 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. 8.64 mm/day

$$Q = \frac{10{,}000\ \text{m}^2/\text{ha} * 8.64\ \text{mm/day}}{24\ \text{hrs/day x } 3600\ \text{seconds/hr x } 1000} = 1.0\ \text{liter/sec/hectare (qu)}$$

In other words, an irrigation application of 8.64 mm per day corresponds to a continuous water flow of one liter per second per hectare. Further details of the conversion are given in the Scheme Irrigation.

Flow rates can be estimated for other irrigation hours per day and NIR other than 8.64 mm.

$q = \frac{NIR}{8.64} q_u$ for NIR different from 8.64 mm

$q = \frac{24}{t} q_u$ for irrigation duration (hrs/day) different from 24 hrs

$q = \frac{24NIR}{8.64t} q_u$ for NIR different from 8.64 mm and irrigation duration (hrs/day) different from 24 hrs

Example: Determine the continuous water flow when the gross irrigation depth is 33.6 mm and the interval is 7 days

Answer: 33.6 mm every 7 days is 33.6/7 = 4.8 mm/day; 4.8 mm/day

$$q_o = \frac{NIR}{8.64} q_u \quad = \frac{4.8}{8.64} 1 =$$ 0.56 liter/sec/hectare for onion

$$qp = \frac{NIR}{8.64} q_u \quad = \frac{4.5}{8.64} 1 =$$ 0.5 liter/sec/hectare for pepper

For 16 hours of irrigation per day,

$$q_o = \frac{24NIR}{8.64t} q_u \; = \; \frac{24x4.8}{8.64x16} 1$$ = 0.83 liter/sec/hectare for onion

$$q_o = \frac{24NIR}{8.64t} q_u \; = \; \frac{24x4.5}{8.64x16} 1$$ = 0.75 liter/sec/hectare for pepper

6.5 Variations in scheme irrigation scheduling

The three basic components of a scheme schedule are:

- The delivery flow rate to the various canals within the system
- The delivery frequency or timing of the deliveries
- The duration of the deliveries

The schedule selected is a function of delivery system flexibility and farm irrigation requirements. The more flexible on-demand irrigation delivery systems may allow the farmer to specify flow rate, irrigation frequency and/or duration. The more rigid ones, such as rotational systems, may have severe restraints on any of the components. Characteristics of some scheduling variations are described below.

6.5.1 Rigid schedules

This schedule is usually predetermined by the scheme bylaws, scheme policy, or other means. The schedule is often determined before the start of the irrigation season-based on historical crop water requirements, or simply by allocating expected water supplies proportionally to land ownership or other criteria. Some kind of rotational schedule is usually implied. Capital costs are the least with this type of schedule, as canals and structures are designed for continuous supply at peak demand periods.

6.5.2 Rotational schedules

6.5.2.1 Fixed rotation

This schedule implies a fixed flow rate, fixed irrigation frequency and fixed duration. It is a type of fixed interval and fixed amount schedule. Intervals are, for example, weekly, bi-weekly or monthly. The irrigation interval and amount are often determined by the peak use period on a scheme. The average allowable depletion (P) at peak use periods, along with application and distribution efficiencies, determines the amount of water delivery. This type of schedule is easy to administer from a schematic point of view. Very little communication, planning, or monitoring is required as compared to other systems. Canals are easy to design and operate for the fixed flow rate and durations. However, except at peak, the supply does not equal demand and efficiencies are low early and late in the season. The excessive water applied early and late in the season may result in nutrient leaching, water-logging, and salinity problems. Since cropping patterns, soils, and even climatic conditions may vary widely in a scheme, fixed rotation schedules are seldom adequate, even during peak demand periods.

6.5.2.2 Varied frequency rotation

In this variable interval-fixed amount scheduling method, flow rate and irrigation duration remain constant but the irrigation frequency is modified. This type of schedule represents a significant improvement over the fixed rotation type. The interval is generally varied in accordance with the changing water use of the crops in the scheme. For example, irrigations may be scheduled to occur when a fixed average deficit has built up in the scheme area. Mono-crop and perennial-crop schemes are ideally suited for this type of schedule, provided that soils and climatic conditions in the scheme are similar. The method is suited to deep-rooted crops and soils with high water-holding capacities. Some advantages of this system are that irrigation systems (especially surface systems) are easily designed and operated for a fixed or constant depth of water application. High Efficiencies are possible in early and late season (in contrast to the previous method).

6.5.2.3 Varied rate rotation

In this type of fixed interval-variable amount scheduling method, irrigation frequency and duration are fixed and the flow rate is varied to approximate seasonal demands. Mono-crop or perennial-crop areas with deep uniform soils are best suited for this schedule. As with the varied frequency system, this method may result in greater efficiencies than with fixed rotations, as over-applications early and late in the season are minimized. However, small stream sizes are often difficult to manage in farm and scheme canals. Flow control structures must be capable of adjustment to the required rates. As surface irrigation systems are most efficiently operated for fixed application depths, this may also present a problem for farm-level management. The farmer must generally become a better water manager to deal with the efficient application of variable rate and amounts. Again, communication from the irrigation management committee down to farm-level must be adequate.

6.5.2.4 Run-of-the-river supply

For most of the run-of-the-river projects, it appears impossible to match water demand with water supply. Even in the improbable case of the assumed cropping patterns being adhered to, it remains difficult to translate the water requirements for each individual plot with its own specific crop and specific planting dates into a realistic demand curve. Nevertheless, assuming that this might be achieved, the demand curve will never satisfactorily match the erratic flows in the river. Under these circumstances, the only way to utilize the available water as optimally as possible is to divide the water proportionally to the irrigable areas. The assumption is that the group of farmers in a tertiary unit will use this erratic flow best, because they have field-level knowledge.

MODULE 7: METHODS OF IRRIGATION

Proper irrigation water management aims at optimum and efficient use of water for best possible crop production keeping water losses to the minimum. Water is applied to the soil surface by a number of various irrigation methods. These irrigation methods are adopted to irrigate crops with the main objective to store water uniformly in the effective root zone soil with the maximum quantity required and ensured water losses to the minimum and sustain crop production with the desired quality of produce.

There are many factors to consider before selecting a particular irrigation system. These include water resources, topography, soils, climate, type of crops to be grown, availability and cost of capital and labour, type and appropriateness of a particular irrigation technology to farmers and its associated energy requirements, water use efficiencies, as well as socio-economic, health and environmental aspects. It is not wise to use a single criterion for selection purposes. However, there are instances when one criterion can weigh heavily in favour of a particular irrigation system.

7.1 Classification of irrigation methods

The principal methods being used for applying irrigation water to irrigated crops are broadly grouped under: (1) Surface irrigation (wild flooding, border, basin or ring, check basin and furrow); (2) Sprinkler irrigation (resembling artificial rain); (3) Drip irrigation (or trickle irrigation or sometimes called it localized irrigation).

In general, each irrigation method has certain advantages and disadvantages and is adopted based on certain principles. Some methods may be adapted to a fairly wide range of conditions. In some areas, different methods can be profitably adopted and in others, only one specific method is applicable. However, the choice of the most appropriate method to be used should be based on a set of criteria that serve to minimize water losses and increase efficient water management and resulted in increased crop yields. Details of each irrigation method are discussed hereunder.

7.2 Surface irrigation methods

Surface irrigation refers to direct irrigation water to irrigating fields by gravity allowing water to flow over the soil surface from a supply channel at the upper reach of the field. It is the dominant and widely practiced method of irrigation, which accounts for about 95% of irrigation systems worldwide and has been used for thousands of years to irrigate a wide range of crops on different soil types. This method, particularly in Ethiopia is considered as the most dominant irrigation method being used among the subsistence farmers and even in state owned irrigated commercial farms. The two basic requirements that need prime importance to obtain high efficiency in surface irrigation methods are properly constructed water distribution systems to provide adequate control of water to the fields and proper land preparation to permit uniform distribution of water over the irrigated field. Surface irrigation is suited both for small and large farms.

Surface irrigation methods are often selected because they are considered to be simple methods and well suited to the economic conditions of subsistence farmers with little or no basic knowledge of irrigation. It is, thus, hardly surprising that the efficiency of surface irrigation is in the hands of farmers who have no control over farm discharges and the timing of applications are poor. In contrast to its management, the design of surface irrigation layouts for basins, borders, and furrows and their construction is relatively simple and no special materials are required.

The maintenance of the system too is less problematic and can be done locally by the farmers themselves. However, the surface method as compared to other irrigation systems, results in the highest water losses, mainly due to surface runoff and deep percolation. In this case, the crop being irrigated does not utilize much of the water supplied. Other losses often occur as a result of water transmission through open channels, due to seepage and evaporation. Therefore, the method should only be used where there is a reliable water source available, and where irrigation abstractions do not adversely affect the environment and downstream users.

Various crops in Ethiopia are irrigated mostly by surface irrigation methods. In general, there are five commonly used surface irrigation methods; namely, wild flood irrigation, basins or ring, check basins, border irrigation, and furrow irrigation.

Advantages of surface irrigation methods are: (i) The land surface is either completely or partially wetted while irrigating the crops; (ii) surface irrigation methods are widely being practiced in areas where lands are subdivided into Small plots and farmers are relatively poor, like in the Ethiopian condition; (iii) variable sizes of streams can be used; (iv) cost of water application is quite low and sufficiently skilled personnel are not required. In the contrary, limitations of surface irrigation methods are: (i) considerable land is wasted for the construction of channels and bunds, (ii) cost of construction of reservoirs, water courses, field channels and bunds are quite high, (iii) lining of channels and water courses to minimize seepage involves considerable cost, (iv) require frequent maintenance and interference of channels and bunds with other farm activities.

7.2.1 Basin irrigation method

Check basin irrigation method consists of dividing the field into several relatively level plots called checks surrounded by low soil bunds. Small checks are level, while bigger ones are slightly sloping along the length. Water is conveyed to checks by a system of supply channel, laterals and field channels.

Check basin irrigation is the simplest and most widely used of all surface irrigation methods because of its simplicity. It is, therefore, most suited to flat lands with soil types having moderate to slow infiltration rates, but can be used on sloping land, provided that the soil is deep enough to allow leveling without exposing the subsurface soil. Small ridges or dikes of earth 30 to 50 cm high are constructed around the area to form the check basin. The size of basins depends on the slope, the soil type and the available water flow to the basins. In this regard, the size of the basins are small when the slope of the land is steep, in sandy soils, with small stream size and low depth of application is required and if field preparation is done by hand.

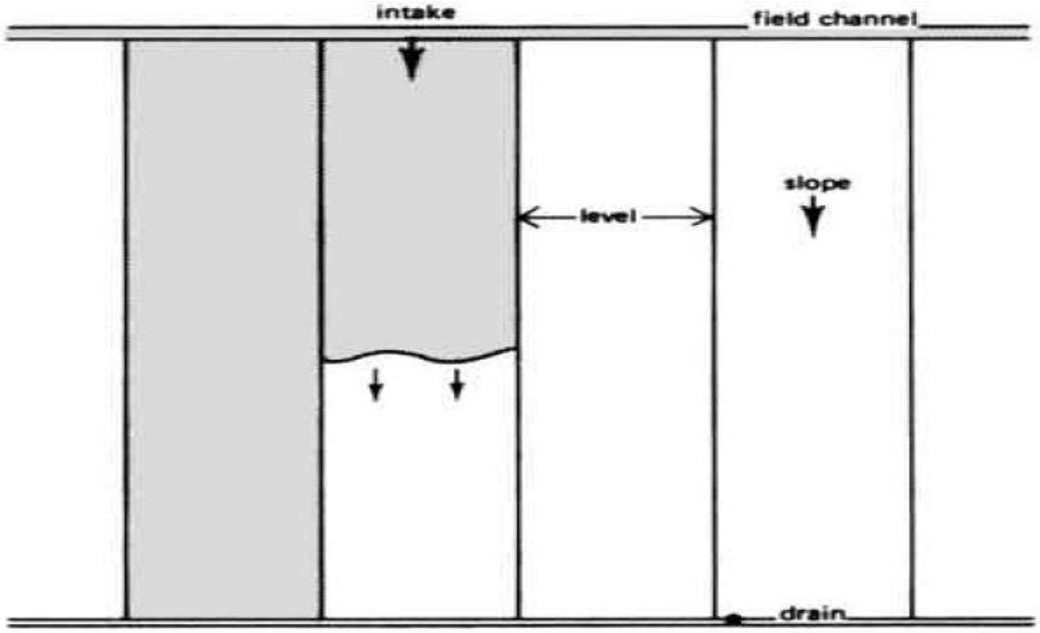
This type of irrigation is, generally used with crops that can withstand contact with water for long periods (such as rice, closely spaced grain crops and deep- rooted fodder crops such as alfalfa, vegetables). However, the method is especially suited to grain and fodder crops in heavy soils where water is required to stand for a comparatively a long time to ensure adequate infiltration. It may be adapted to very permeable soils with small checks that must be covered with a large stream for a short time to avoid deep percolation losses at the upstream side. In addition, the method is most suited for leaching of salts from the soil profile, particularly from the active root zone, where the salt damage is critical.

Advantages of the method are: variable sizes of streams can effectively be used; it can be adopted for a wide range of soils; water application efficiency is high as compared with wild flooding; no loss of water by run- off; rain and irrigation water can be used for wetting the active root zone soil; water logging conditions can easily be created, which is favourable for rice cultivation and leaching down of salts can easily be done. The principal limitations of the method are: Interference of the ridges with other farm activities, considerable land is wasted, which occupied by ridges and lateral field channels, impedes surface drainage, since the land is flat and ridged, precise land grading and leveling are necessary, labour requirements for land preparation and application of irrigation water are much higher, high initial capital investment as compared with other surface methods and the method is not suitable for irrigated crops sensitive to wet soil conditions.

7.2.2 Border strip irrigation

Border irrigation is a sub- system of controlled flood irrigation in which the land is divided into parallel border strips demarcated from one another by earth ridges. Water is successively delivered into each strip from a head or field ditch at its upper end. The method is designed in such a way that a sheet of water advances down the border and covers all the plots uniformly. As indicated above a field is divided by borders into a series of strips 3 to 30 m wide and generally from 60 to 300 m long. The size of the border is governed by the stream size, land slope, soil type and water intake rate of soil.

Fig.39. Layout of a border strip irrigation system

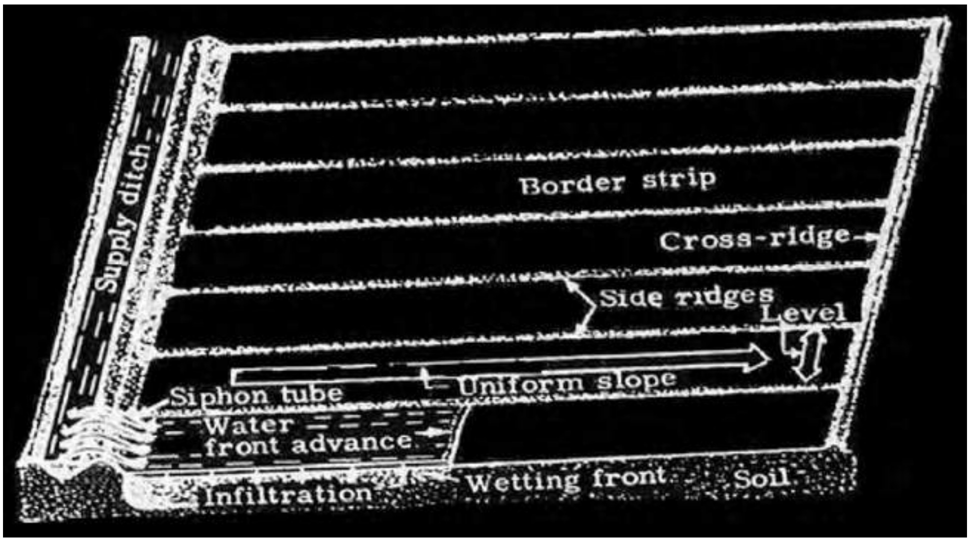


The width of a border strip depends on the size of stream and the degree of land leveling practicable. When the size of the stream is small, the width of strip is reduced. The length of a border strip in sandy and sandy loam soil various from 60 to 120 m in order to reduce losses through deep percolation, in medium loam soils 100 to 180 m and in clay loam or clay soils from 150 to 300 m. In terms of slope, the optimum is in between 0.2 to 0.4 percent, although much steeper slopes are possible with great care to control erosion by applying only small volumes of water.

The land is leveled between side ridges to make the irrigation water run in a narrow sheet from the upper to the lower end of the field. When irrigation starts, the infiltration rate is high at the upper end of the border, but as the soil becomes saturated, the leading edge of the water continues to move downhill. Its rate of forward movement depends on soil type, slope, and quantity of water released. To provide enough water at the lower end of the field without over watering the upper end, a high ridge is constructed at the lower end to hold back a pool of water to irrigate the lower end after the supply is cut- off. The levees or ridges forming the borders to the strips should be 20 to 25 cm high on average. When irrigating, each strip is flooded at the upper end and when the irrigation water has progressed to about 80 percent of the length of the border, it is recommended to cut- off the irrigation water and let the residue pound to irrigate the lower end.

The border method may be adopted in soils of variable texture. It is, however, suited to soils having moderately low to moderately high water intake rates. This type of irrigation is best suited for close growing crops, such as small grains /wheat and barley/, maize, potato, some vegetables /beet, radish/, alfalfa, and grasses. The border method of irrigation has some advantages and limitations. The main advantages are: less land is wasted for making ridges and channels, efficiency of water application is relatively high as compared to wild flooding, variable stream size can be used and labour requirement is quite low. The limitations are: Precise land leveling is essential; initial cost of land preparation and land grading is high; the method is unsuitable for uneven and undulating land with shallow soils and required more skilled labour.

Fig. 40. Border Irrigation; (Source: A.M. Michael, Irrigation theory and practice. First edition, 1978, New Delhi)



7.2.3 Basin and Ring irrigation

Fruit crops in orchards are irrigated by constructing basins or rings around trees. Basins are usually used for small trees, while rings are used in bigger tree, which are widely spaced. Both methods involve only practical wetting of the soil surface. A considerable amount of water is saved and the irrigation efficiency is found to be high. A young tree may initially be irrigated by the basin method (fig. 8) and then later when it grows bigger it can be irrigated using the ring method (fig. 9). A basin is usually made for one tree sapling, but it may include more than one tree sapling when they are not spaced very wide. Basins may be square, circular or rectangular. When a basin encompasses more than one tree sapling, it takes a rectangular shape. Basins are made longer and wider as saplings grow in size. The soil inside the basin is flat with the base areas of trees kept little raised so that the stem of the tree don't come in direct contact with the water, only part of the land is flooded. Water supplied through laterals and each basin is connected to a lateral with a short and narrow furrow. A lateral or field channel passes between two rows of trees alternatively supplying water to individual basins on both sides.

Advantages: (1) a considerable amount of irrigation water is saved; (2) it involves only partial flooding of the soil surface; (3) water losses through deep percolation and evaporation greatly reduced; (4) variable sizes of streams can easily be controlled; (5) water application efficiency is very high and (6) the labour requirement for making basins are low.

Disadvantages: (1) the method is only suited to orchards or fruit trees; (2) basins and channels somewhat restrict the movement of animals and farm implements. Ring method consists of irrigating of fruit trees in orchards by constructing circular trenches around trees. Ring trenches are smaller in both depth and width around small trees and are larger around bigger trees. Rings are prepared considering the canopy development of a fruit tree consideration.

Fig. 41. Layout of check basin irrigation system

7.2.4 Furrow irrigation

Furrow irrigation refers to irrigating land by constructing furrows between two rows of crops or alternately after every two rows of crops, particularly for narrow spaced row crops such as onions, cabbage and pepper. In contrast to basin and border irrigations, it involves only wetting part of the surface of the soil and water in the furrow moves laterally by capillaries to the un-watered areas below the ridge and also downward to wet the root zone soil. This reduces evaporation losses, improves aeration of the root zone, less puddling of the soil surface and permits earlier cultivation after irrigation. Besides, furrow prevents an accumulation of salts near the plant bases, in areas where salts are a problem. Furrow irrigation is, perhaps, the most widely used method for row crops. It is usually practiced on gently sloping land up to 3% in arid climates but restricted to 0.3% in humid areas because of the risk of erosion during intensive rainfall. From a farming point of view furrows should be as long as possible as this reduces the cost of irrigation and drainage and easy for mechanization. The furrow method is well suited both to small and large farms.

In deciding the most practical and efficient length of furrow to be used a number of factors need to be considered, such as the type of soil- coarse texture or clay soil, the size of the irrigation stream, the slope of the land, and the irrigation depth or duration of the water application. In general, furrow lengths range from 60 m to 300 m or more depending on the determining factors mentioned above but the field size and shape of fragmented fields of the subsistence farmers put practical limits on furrow length as well. These factors are in fact interrelated with the texture of the soil determining the infiltration rate and the slope determining the speed at which the stream of water flows down the furrow. In principle, furrow lengths are shorter in coarse soils and longer in heavier soils. In this regard, furrow length is as short as 10- 20 m long in vegetable gardens, while for large mechanized irrigation scheme, where growing deep-rooted crops such as cotton may be up to 500m. Efficient furrow irrigation always involves run-off and surface drainage system is required down at the end of the furrow perpendicular to it, where excess water drains out from the field. The recommended maximum furrow lengths for different soil types and slopes are given in Table 25.

Table 25. Recommended furrow lengths for different slopes, soil types and net depth of water application, mm

Furrow Slope, %	Maximum flow of water per second	Furrow length (m)							
		Soil types and available soil moisture in mm/m depth of soil							
		Clays			Loam		Sands		
		50	75	150	100	150	50	75	100
0.05	3.0	120	300	400	270	400	60	90	150
0.10	3.0	180	340	440	340	440	90	120	190
0.20	2.5	220	370	470	370	470	120	190	250
0.30	2.0	280	400	500	400	500	150	220	280
0.50	1.2	280	400	500	370	470	120	190	250
1.00	0.6	250	280	400	300	370	90	150	190
1.50	0.5	220	250	340	280	340	80	120	190
2.00	0.3	180	220	270	250	300	60	90	150

Source: Irrigation Agronomy Manual, Revised version, former MoA /ADD, March 1990, Addis Ababa

It can be understood from the table that furrow lengths are decreased with increasing or decreasing of the slopes. When the slope is increased run- off will increase parallel, particularly on heavy clay soils with low infiltration rate and when the slope is decreased the flow of water will be slow and percolation may be a problem significantly on coarse textured soils with high infiltration rate. Moreover, as the slope increases, the movement of water into the ridges will be decreased, resulting in water loss at the end of the furrow. In addition, higher velocities of water in the furrow lead to risks of soil erosion. Thus, in deciding a furrow system as with all other surface methods, careful consideration of the aforementioned factors is a must. In order to control or at least minimize erosion, particularly in areas where there is heavy rainfall a particular hazard of irrigation schemes located in highland areas, furrow must have a limited slope and the following guidelines are recommended (see table 26 below).

Table 26. Slope of furrow related to soil type

Soil type	Maximum recommended slope, %
Sand	0.25
Sandy loam	0.40
Fine sandy loam	0.50
Clay	2.50

With furrow irrigation, the water is applied to small channels, known as furrows that are between the rows of plants. Water is admitted to the head of each furrow, and the rate of flow is adjusted so that the furrow flows full without overtopping. As the water reaches the end of the furrow, the required amount of water has infiltrated into the soil to satisfy the irrigation requirements. The rate of flow into the furrow depends primarily on the intake rate of the soil and the length of the furrow. Infiltration rates for various soil textures and suitable furrow flow rates per 100 m length of furrow are given in Table 27 below

Table 27. Soil Infiltration rates and suitable furrow inflows per 100 m of furrow length/furrow spacing 1 m/

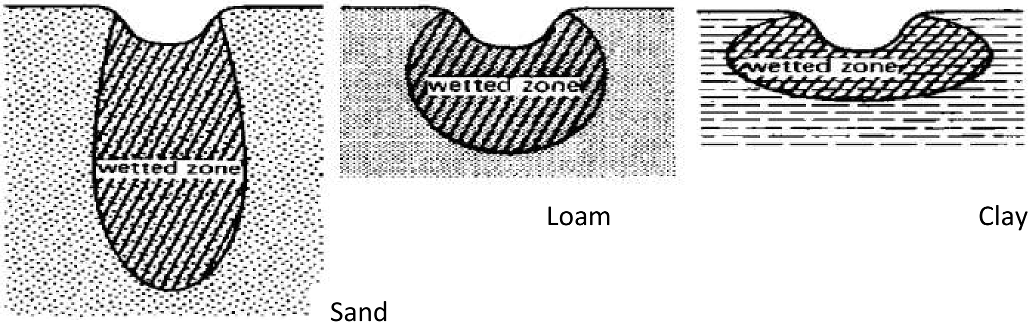
Soil	Infiltration rate, mm/h	Furrow inflow l/sec/100 m length
Clay	1- 5	0.03- 0.15
Clay loam	5- 10	0.15- 0.30
Silt loam	10- 20	0.30- 0.50
Sandy loam	20- 30	0.50- 0.80
Sand	30- 100	0.80- 2.70

Source: Stern, P.H. 1985. Small- scale Irrigation.

In order to determine the correct flow rate per furrow requires testing in the field. A simple advance and recession test can be done. To do this, the irrigation agronomist marks off three points along the furrow - a point near the beginning, the midway point, and a meter from the end of the furrow. The water is directed into the furrow at the desired operating flow rate, and the times when the water passes the three markers are noted. At the end of the irrigation, the irrigation agronomist, using the same points along the furrow, notes the time that it takes the water to infiltrate and regress from the end of the furrow to the beginning. With these two sets of data, the irrigation agronomist plots the advance and recession curves for the flow rate in the furrow (on x-y axis graph: x-axis is representing the length of furrow and corresponding marks; y-axis is the time) on the same graph paper. If the two curves are more or less parallel to each other, this indicates that the flow and time for the length of furrow, under being tested gave a good water distribution. If this is not the case, the flow rate and/or time of irrigation should be changed. This test should be done for each alteration until the desired results are achieved.

Furrow irrigation adapts better than any other method to crops that are grown in rows with more than 30 cm spacing, such as vegetables, maize, groundnut, sugarcane, cotton, and potatoes. Fruit crops are also irrigated by furrow method. Crop types, farm equipment to be used and planting distances between plants are the factors that determine furrow size and shape. Furrows are usually v-shaped in cross section, 25- 30 cm wide at the top, and 15- 20 cm deep, shallower in lighter soils and deeper in heavier soils. wider, U-shaped furrows with a greater wetted area are sometimes used on soils with slower water intake rates. Usually, the spacing between furrows is narrower in sandy soils and wider in heavy soils. This is to ensure that water spreads laterally into the soil below ridges and downwards in the effective rooting depth uniformly. Furrow spacing in sandy soils is in a range of 60 to 80 cm, whereas in clay soils 75 to 150 cm and in loam soils 60 to 90 cm. Shallow rooted and transplanted crops using seedlings require small width and shallow depth, while deep rooted crops have wide and deep furrow depth. There are 3 different types of furrow methods: straight level furrow, straight graded furrow and contour furrow.

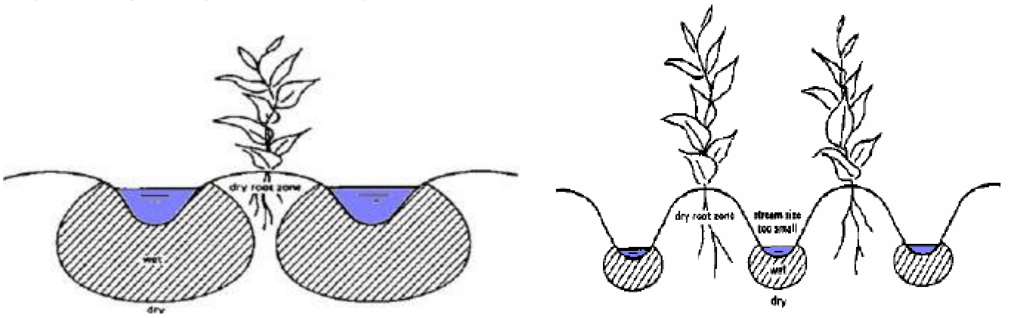
Fig.42. Different wetting patterns in furrows, depending on the soil type



Loam Clay

Sand

Fig. 43. Spacing and wetting of furrows



a) Too wide furrow spacing **b) Too small flow**

Advantages of furrow irrigation are great savings of water as compared to other surface methods, variable size of streams can be used, and the water application efficiency is high as compared to other surface methods. In addition a wide range of soils can be irrigated using the method, only part of the land is wetted and losses of water by evaporation, run- off and deep percolation are reduced. Sometimes in high rainfall areas furrows can be used as drainage channels and salts are accumulated at the upper parts of ridges, not significantly affecting the growing crop on the middle of the ridges. Principal limitations of the furrow method are that land requires precise grading to a uniform slope, labour requirement is high for grading and making furrows, skilled labour is necessary to control water in furrows and the method is not suitable for light irrigation.

Fig. 44. Furrow Irrigation

7.3 Sprinkler irrigation

Sprinkler irrigation refers to the application of irrigation water under pressure in which water is sprinkled in the form of a spray or artificial rain. This is achieved by distributing the water under pressure through a system of overhead perforated pipelines to various types of sprinkler heads or nozzles fitted to riser pipes attached to a system of pipes laid on the ground and spraying the water from above onto the crop and land. Nozzles of fixed type or rotating under pressure of water are set at suitable intervals in the distribution pipes. Sprinkler systems can be fixed in place, portable, semi-portable, or mobile. Sprinkler nozzle types and numbers are selected depending on designed application rates and wetting patterns.

Sprinkler irrigation is used on approximately 5% of irrigated land throughout the world. It will never seriously replace surface irrigation but it has advantages over surface irrigation:

- Systems for good water management practices are built into the technology, thus, providing the flexibility and simplicity required for successful operation;
- Independent of the variable soil and topographic conditions, uneven land and steep slopes that cannot be irrigated by surface irrigation can be watered without leveling the land;
- Uniform distribution of water in the field can be achieved with high water use efficiency, except in windy condition that distort the even distribution of water and result in uneven distribution;
- Small streams of irrigation can be used efficiently;
- Accurate measurement of the water applied;
- High mobility of the whole irrigation system from one field to another;
- Less interference with subsequent farming operations;
- Least waste of lands for laying out the system, thus, labour cost is reduced;
- Fertilizers, pesticides and herbicides can easily be applied with the irrigation water;
- Controlled water application rate is possible with careful selection of the system;
- Operating procedures are simple and less skilled operators can operate the system;
- Automation is possible with the system in comparison with that of the surface methods and
- High yields of good quality fruits and vegetables are obtained under this system.

There are, however, certain disadvantages associated with the method and the principal limitations are: High capital investment for initial installation of the system; operating cost of sprinkler is high /due to cost of energy/; technical personnel for its operation and maintenance are required; clean water is required in order to avoid clogging of nozzles; sensitivity of the system to windy conditions that distort the uniform distribution of water; water losses by evaporation from soil surface and plant canopy, if wetted and water losses in adjacent border areas wetted by the sprinklers. There is also a risk of the induction of leaf diseases, (because of this fact sprinklers are not suitable for crops sensitive to diseases), and the chance of salt accumulation on wet foliage. Sprinklers also require much more sophisticated design skills and on- farm support in terms of maintenance and supply of spare parts.

Evaporation losses from sprinklers depend on the relative humidity, the temperature, the wind velocity and fineness of drops that in turn depend on the water pressure and nozzle size. In spite of the fact that more water may be lost through evaporation from the air and plant leaves, still sprinkler irrigation can have greater efficiency than surface irrigation methods. In sandy soils, especially, it allows more even distribution than furrow or basin irrigation. In clayey soils with slow infiltration rates, the rate of water application for sprinkler irrigation may have to be very slow to avoid surface runoff and soil erosion. Application rates of sprinkler systems needs to match with infiltration rates and the slope of the irrigated fields. High application rates can result in surface runoff or in ponding and deep percolation losses. The low application rates can be inefficient to meet crop water needs, due to excessive evaporation. Therefore, proper sprinkler system design is essential to achieve high efficiencies with minimal runoff or deep percolation.

There are many types of sprinkler system available to suit a wide variety of operating conditions such as permanent, semi- permanent, solid set, semi- portable and portable but the most common one is the portable system using pipes (aluminum or plastic) for supplying water with small rotary impact sprinklers. The efficiency of sprinkler irrigation depends as much on the farmer as on the system. For design purposes a figure of 75% is generally used. Sprinkler irrigation is better suited to large farms rather than the small farms.

7.3.1 Adaptability of sprinkler system

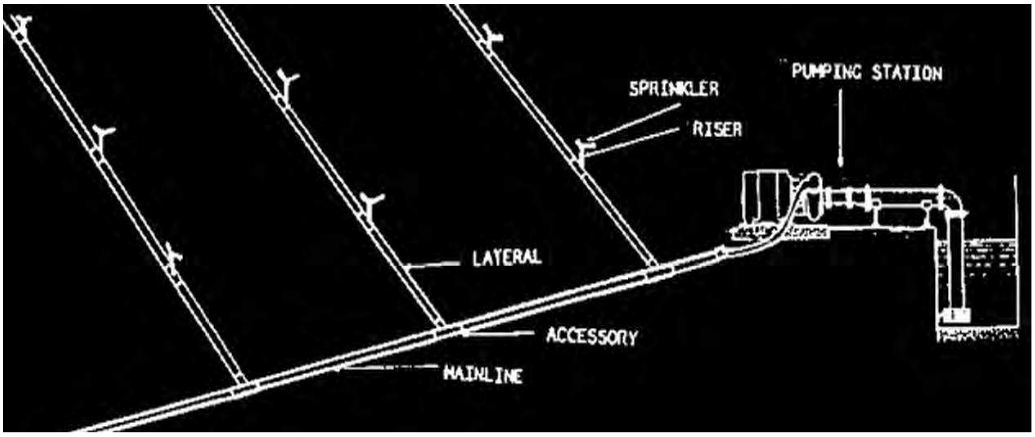
The sprinkler method may be used for many crops and on all types of soils on lands of widely different topography and slopes. However, it finds its best use in the irrigation of: (1) sandy soils and soils with high infiltration rates, (2) shallow soils that do not allow proper land leveling, which critically required for surface irrigation methods can be irrigated using sprinkler system, (3) areas with steep slopes having erosion hazards, (3) high value crops (4) areas where water is scarce and costly.

Sprinkler irrigation is not suitable for rice and crops susceptible to diseases that can be caused by wet conditions. It is not also suitable in soils with significantly low infiltration rates such as in heavy clay soils, which increased losses of water through run- off that, do not have sufficient time to infiltrate. The sprinkler system should be designed to apply sufficient water to meet the crop demands at peak periods of consumptive use when the system is used for full irrigation, particularly in areas with water scarcity. In humid areas, it can be used for supplemental irrigation during periods of drought. Sprinkler irrigation is also used for protecting crops from frost.

7.3.2 Principal components of sprinkler system

The pumping station is located at the water source, and the pump lifts the water and makes it available under pressure to the system. The pump is required to overcome elevation differences between the water source and the field, counteracts frictional losses within the system, and provides adequate pressure at the nozzle for good water distribution. A gravity flow system uses the potential energy in an elevation drop to create pressure for its operation. The components of sprinkler system are: (1)the main line that delivers water from the water source to the field. It may be either permanent or movable; (2)the lateral pipe that delivers the water from the main line to different sections of the field.

Fig. 45. Typical Sprinkler Irrigation System components (Source: FAO, Irrigation and Drainage Paper. Rome, 1984)



The lateral line is usually movable. (3) The riser delivers the water from the lateral line to the sprinkler. The length of the riser depends on the crop, although a minimum value of 30 cm is recommended to assure a good distribution pattern. (4) The sprinkler is the unit that sprays the pressurized water through an orifice and rotates to distribute water on to the field. (5) Accessories are parts of the system that connect all other units together to form a watertight system and these are important parts of an efficient system and should be installed whenever possible.

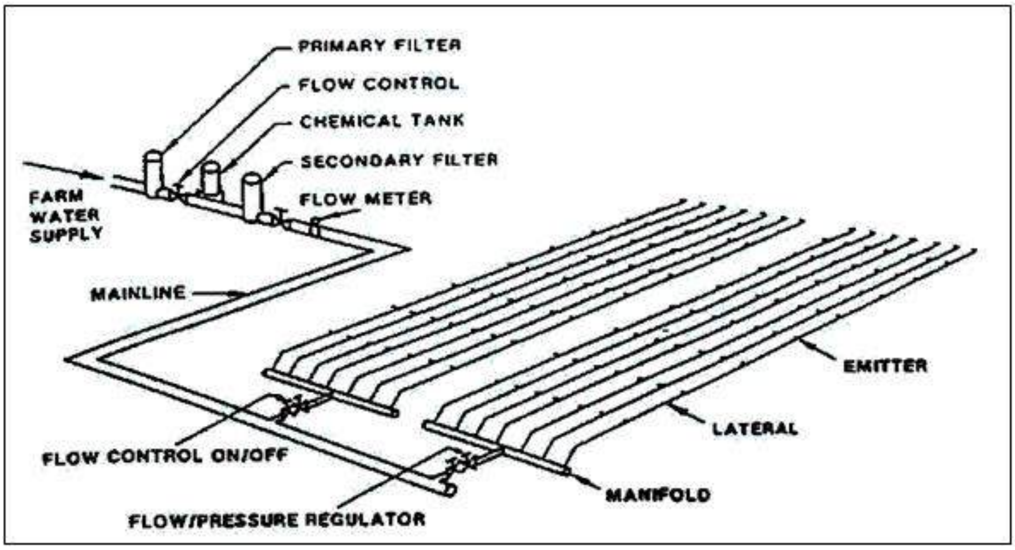
7.4 Drip Irrigation

Drip irrigation, sometimes called trickle irrigation, refers to the application of water into the soil at slow rates, drop by drop, with frequent but precise quantities through small-sized openings called emitters located at, or just above ground level (up to 300 mm and above) directly to the soil surface to irrigate a limited area around each plant. The system suits areas of high temperatures and limited water resources or those that have high water costs. Drip irrigation is suitable for most soil types and most types of topography. This system allows for the accurate application of water with minimal loss that might occur, due to evaporation, poor distribution and seepage, or over- watering. Drip irrigation as compared with other methods of irrigation is the recent technology developed through intensive research and new development over the past 30 years and the least used system on a worldwide scale and involves less than 0.1% of irrigated land in the world. Drip irrigation technologies were developed in Israel, Denmark and USA.

It is the most advanced irrigation method with the highest application efficiency of 90 to 95%. The water is delivered continuously in drops at the same point and moves into the soil and wets the root zone vertically by gravity and laterally by capillary action forming a wetted area like an onion shape. The planted area is only partially wetted. Drip irrigation improves the growth rates of high value crops by delivering moisture directly to their root zones. This saves water because only the important parts of the plants are irrigated. Weed growth is reduced since only the plant is irrigated, and working between the plants is easier because of the dry soil. This technology can be used in hilly terrain, and is not labor- intensive as it can be automated. The technology can be adapted to use energy-saving components.

Complete drip irrigation systems basically consists of a head control unit, main and sub-main pipelines, hydrants, manifolds and lateral lines with drippers or drip emitters /see Fig. 46 below/ at a certain intervals. The components of a drip irrigation system are: (1) Control station (head control unit): Its features and equipment depend on the system's requirements. Usually, it consists of the shut-off, air and check (non-return) valves, a filtering unit, a fertilizer injector and other smaller accessories. (2) Main and sub- main pipelines: The main and sub- main pipelines are usually buried, especially when made of rigid Pvc. (3) Hydrants: Fitted on the mains or the sub- mains and equipped with 2-3- in shut-off valves, they are capable of delivering all or part of the piped water flow to the manifold feeder lines. They are placed in valve boxes for protection. (4) Manifold (feeder) pipelines: These are usually 50, 63 or 75 mm. where made of HDPE, they are attached to the hydrants through compression- type, quick release, PP connector fittings and remain on the surface. (5) Dripper laterals: These are always made of 12- 20 mm soft black IDPE, PN 3.0-4.0 bars. They are fitted to the manifolds with small PP connector fittings at fixed positions and laid along the plant rows. They are equipped with closely spaced dripper emitters.

Fig. 46. Basic components of a drip irrigation system Source: FAO, Irrigation and Drainage Paper. Rome, 1984)



The drip irrigation method is a proven technology suitable for cultivation of edible (grapes, fruits, and vegetables) and ornamental plants with high commercial values. This system may be used not only to increase soil moisture but to apply fertilizers and micronutrients as well. Crops that can be irrigated using drip irrigation systems include; sugarcane, groundnuts, coconuts, cotton, coffee, grapes, potatoes, and widely spaced fruit crops /papaya, banana, guava and citrus/, closely spaced vegetable crops, and flowers.

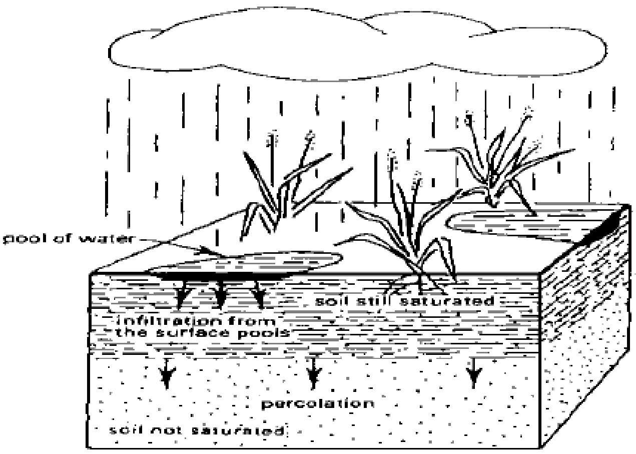
Advantages of drip irrigation: (1) More uniform distribution of water and can be obtained higher crop yields; (2) More efficient use of available water or water savings /90- 95% efficiency/, minimal evaporation losses and deep percolation is entirely avoided; (3) Reduced cost for fertilizer and other chemical application, particularly nutrients can easily be applied with the irrigation water/fertigation/; (4) low labor operating requirements, reduced cultivation, control, and labor cost for leveling; (5) low energy requirement as compared with sprinkler system; (6) Utilization of saline water resources, as a result reduced salinity hazard and possibility of using poor quality without causing significant hazard to the crop; (7) Possibility of using marginal lands with soils such as porous and shallow depth; (8) Physical soil conditions are maintained; (9) It is well suited to small and varied plots on small farms, (10) weeds and pest problems are at minimum; (11) well-adopted in sloping lands and irregular topography without causing erosion; (12) lesser amount of tillage operations and a possibility of uninterrupted operation; (13) Not susceptible to wind and more flexible.

However, drip irrigation system has also its limitations: Initial cost is high, particularly for installation of the conventional drip system; it requires more skilled labour in design, management and maintenance. The clogging of emitters and lateral blockage from sand and silt, chemical precipitation from groundwater and algae from surface water are the most serious problems. There are also issues with restricted root zone and the plant may be susceptible to water logging due to poor plant anchorage. Salt accumulation in the root zone may required leaching periodically. The is a risk of xposed to mechanical damage; a lack of influence on the micro- climate and poor germination may result.

7.5 Drainage

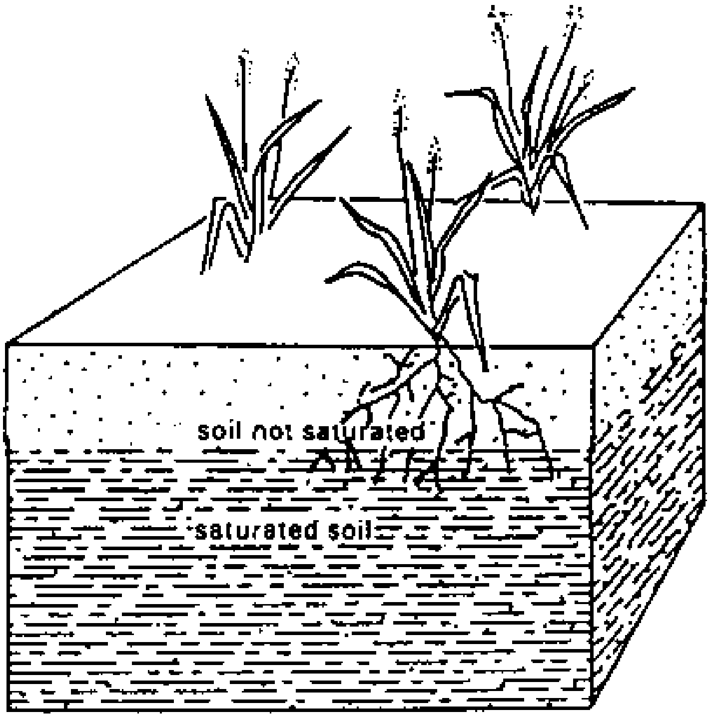
During rain or irrigation, the fields become wet. The water infiltrates into the soil and is stored in its pores. When all the pores are filled with water, the soil is said to be saturated and no more water can be absorbed; when rain or irrigation continues, pools may form on the soil surface (Fig. 47).

Fig. 47. During heavy rainfall the upper soil layers become saturated and pools may form. Water percolates to deeper layers and infiltrates from the pools.



Part of the water present in the saturated upper soil layers flows downward into deeper layers and is replaced by water infiltrating from the surface pools. When there is no more water left on the soil surface, the downward flow continues for a while and air re-enters in the pores of the soil. This soil is not saturated anymore. However, saturation may have lasted too long for the plants' health. Plant roots require air as well as water and most plants cannot withstand saturated soil for long periods (rice is an exception). Besides damage to the crop, a very wet soil makes the use of machinery difficult, if not impossible. The water flowing from the saturated soil downward to deeper layers, feeds the groundwater reservoir. As a result, the groundwater level (often called groundwater table or simply water table) rises. Following heavy rainfall or continuous over-irrigation, the groundwater table may even reach and saturate part of the root-zone (see Fig. 48 below). Again, if this situation lasts too long, the plants may suffer. Measures to control the rise of the water table are thus necessary.

Fig.48. After heavy rainfall the groundwater table may rise and reach the root-zone



7.5.1 Need for drainage

The removal of excess water either from the ground surface or from the root-zone, is called drainage. Excess water may be caused by rainfall or by using too much irrigation water, but may also have other origins such as canal seepage or floods.

In very dry areas there is often an accumulation of salts in the soil. Most crops do not grow well on salty soil. Salts can be washed out by percolating irrigation water through the root-zone of the crops. To achieve sufficient percolation, farmers will apply more water to the field than the crops need. But the salty percolation water will cause the water table to rise. Drainage to control the water table, therefore, also serves to control the salinity of the soil. Drainage can be either natural or artificial. Many areas have some natural drainage; this means that excess water flows from the farmers' fields to swamps or to lakes and rivers.

Natural drainage, however, is often inadequate and artificial or man-made drainage is required.

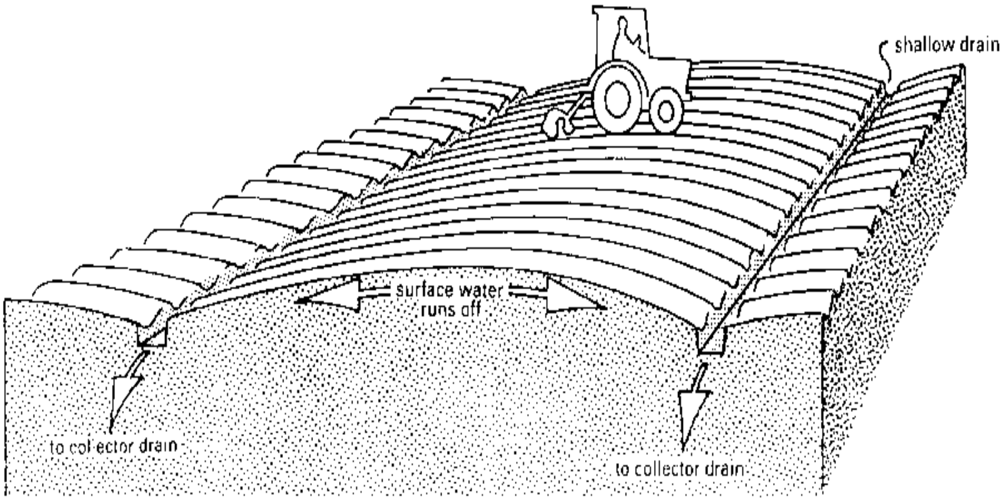
7.5.2 Types of drainage

There are two types of artificial drainage: surface drainage and subsurface drainage.

7.5.2.1 Surface drainage

Surface drainage is the removal of excess water from the surface of the land. This is normally accomplished by shallow ditches, also called open drains. The shallow ditches discharge into larger and deeper collector drains. In order to facilitate the flow of excess water toward the drains, the field is given an artificial slope by means of land grading (see Fig. 49 below).

Fig. 49. The field is given an artificial slope to facilitate drainage



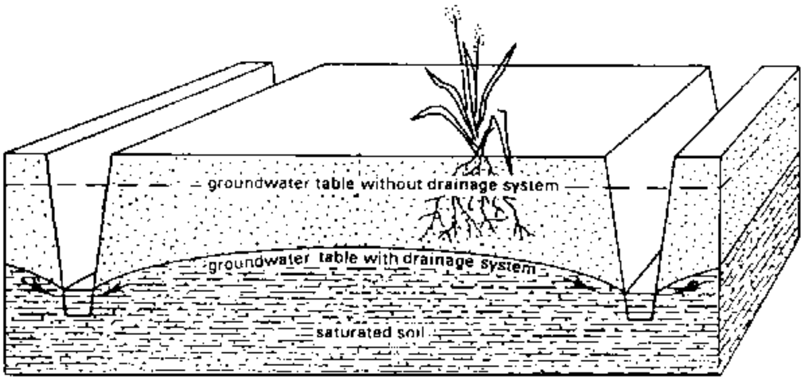
7.5.2.2 Subsurface drainage

Subsurface drainage is the removal of water from the root-zone. It is accomplished by deep open drains or buried pipe drains.

i. Deep open drains

The excess water from the root-zone flows into the open drains (see Fig. 50). The disadvantage of this type of subsurface drainage is that it makes the use of machinery difficult.

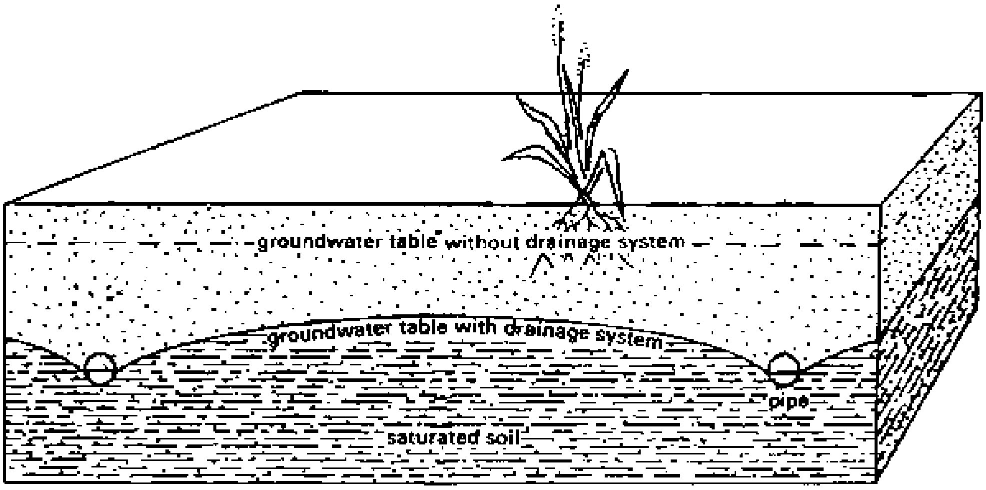
Fig. 50. Control of the groundwater table by means of deep open drains



ii. Pipe drains

Pipe drains are buried pipes with openings through which the soil water can enter. The pipes convey the water to a collector drain (see Fig. 51 below).

Fig. 51. Control of the groundwater table by means of buried pipes



Drain pipes are made of clay, concrete or plastic. They are usually placed in trenches by machines. In clay and concrete pipes (usually 30 cm long and 5 - 10 cm in diameter) drainage water enters the pipes through the joints (see Fig. 51, top). Flexible plastic drains are much longer (up to 200 m) and the water enters through perforations distributed over the entire length of the pipe (see Fig. 52, bottom).

Fig. 52. Clay pipes (top) and flexible plastic pipe (bottom)

iii. Deep open drains versus pipe drains

Open drains use land that otherwise could be used for crops. They restrict the use of machines. They also require a large number of bridges and culverts for road crossings and access to the fields. Open drains require frequent maintenance (weed control, repairs, etc.). In contrast to open drains, buried pipes cause no loss of cultivable land and maintenance requirements are very limited. The installation costs, however, of pipe drains may be higher due to the materials, the equipment and the skilled manpower involved.

MODULE 8: CROPPING PLAN

8.1 Crop selection

Cropping intensity and production potential are in general higher for crops under irrigation than for crops under dry land farming. This calls for a balanced cropping program, a sound rotation and strict plant protection measures. When designing an irrigation scheme or carrying out irrigation planning, the preparation of cropping programs is the first step in calculating crop water requirements. Based on this, the capacity of the irrigation system and the area to be covered by the system can be determined, taking into consideration the water availability.

Besides water availability, other important factors to consider in crop selection are prevailing climatic conditions and soils, the farmer preference and marketing potentials. These affect the choice of crops and crop varieties and the planting time. Labour requirements and availability, market distances and needs, transport costs and reliability, and measures to combat pests and diseases must also all be considered as they determine the scale and frequency of production. These factors are often site-specific, which must be taken into cognizance when a farmer produces different crop varieties.

a) Physical factors

- Climatic factors (temperature, rainfall, frost)
- Length of Growing Period (LGP)
- Land quality
    - Topography particularly slope of the land as it affects drainage and influences soil and water management practices
    - Soil depth and fertility
- Water resource (quantity and quality)
    - Socioeconomics
    - Preference of beneficiaries
    - Market availability
    - Experience of users

8.2 Cropping pattern

Once the crops are selected, one can determine the seasonal cropping pattern and prepare cropping calendar for each crop. A typical cropping pattern and plan is shown in Table 1 below. This diagram helps in establishing which crop will occupy what part of the available area during each season, also taking into consideration the crop rotation requirements.

While the time needed for land preparation and for harvest should not be included when calculating the crop water requirements, it is useful to indicate on the cropping plan the time needed for so doing. Planting or transplanting dates, the length of the period that the crop will be in the ground, the time and conditions needed for harvest as well as for land preparation for the next crop are all important. Repeating this for the next season gives a clear picture of the yearly cropping pattern.

Table 28. Typical Example of Cropping Calendar and Pattern

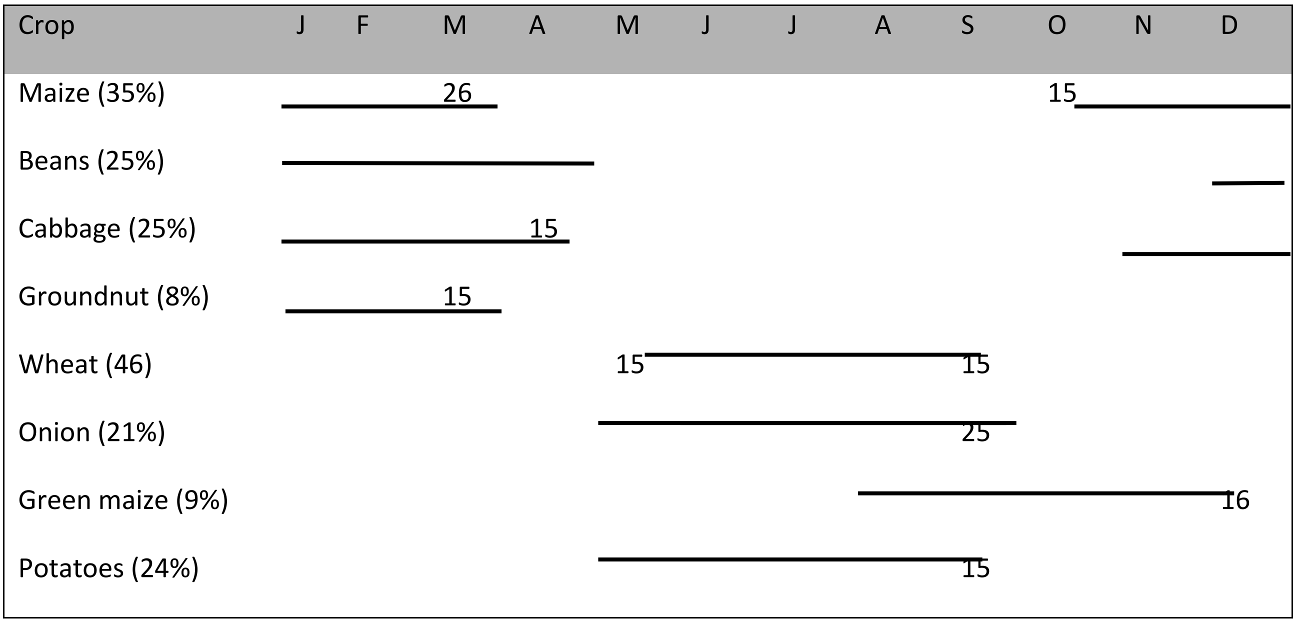


Table 29. Actual Cropping Pattern in Sewir Irrigation Scheme in North Shoa Zone, 2008

Crop	J	F	M	A	M	J	J	A	S	O	N	D
Sorghum									36.5			
Maize											15.4	
Teff				32.7					17.3			
Onion				57.7							28.8	
Pepper										2.0		
Masho				9.6								
Total	**57.7**	**57.7**	**90.4**	**100**	**42.3**	**42.3**	**54.0**	**71.2**	**100**	**100**	**100**	**100**

MODULE 9: SALT AFFECTED SOILS

A soil may be rich in salts because the parent rock from which it was formed contains salts. Sea water is another source of salts in low-lying areas along the coast. A very common source of salts in irrigated soils is the irrigation water itself. Most irrigation waters contain some salts. After irrigation, the water added to the soil is used by the crop or evaporates directly from the moist soil. The salt, however, is left behind in the soil. If not removed, it accumulates in the soil; this process is called salinization. Very salty soils are sometimes recognizable by a white layer of dry salt on the soil surface.

Salty groundwater may also contribute to salinization. When the water table rises (e.g. following irrigation in the absence of proper drainage), the salty groundwater may reach the upper soil layers and, thus, supply salts to the root zone. Soils that contain a harmful amount of salt are often referred to as salty or saline soils. Soil, or water, that has a high content of salt is said to have a high salinity.

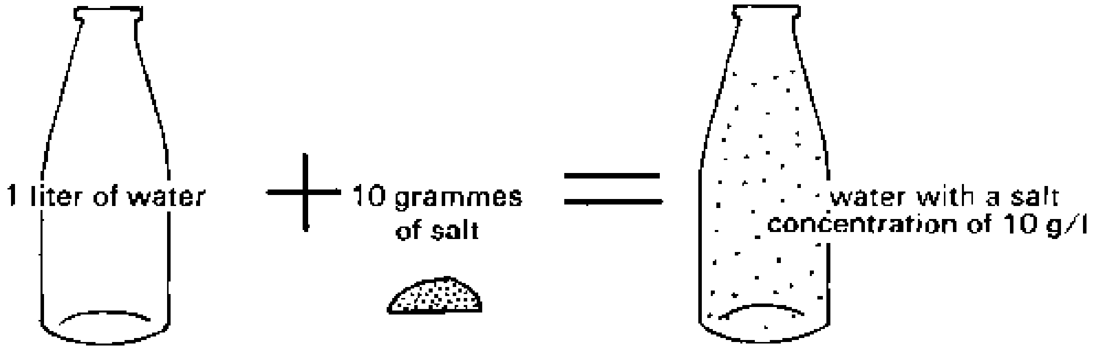
Basically, highland soils are acidic and salinity or sodicity might not be prevalent. The problem is much worse in irrigated lowland areas like the Awash basin. However, there may not be a risk of salinity as long as the salt concentration of the irrigation water is low.

9.1 Water salinity

Water salinity is the amount of salt contained in the water. It is also called the "salt concentration" and may be expressed in grams of salt per litre of water (grams/litre or g/l) (see Fig. 53), or in milligrams per litre (which is the same as parts per million, p.p.m).

However, the salinity of both water and soil is easily measured by means of an electrical device. It is then expressed in terms of electrical conductivity: millimhos/cm or micromhos/cm. A salt concentration of 1 gram per litre is about 1.5 milli mhos/cm. Thus a concentration of 3 grams per litre will be about the same as 4.5 millimhos/cm.

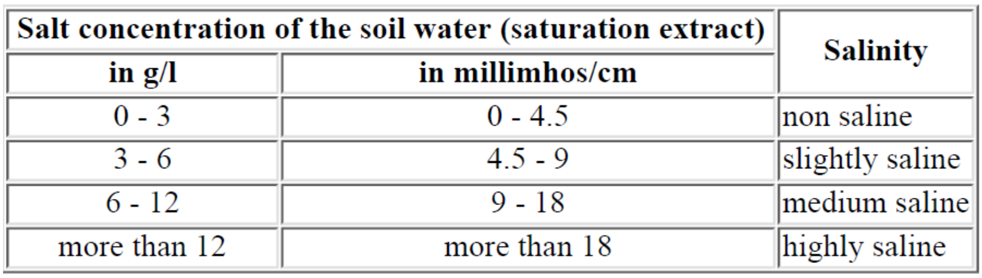
Fig. 53. A salt concentration of 10 g/l



9.2 Soil salinity

The salt concentration in the water extracted from a saturated soil (called saturation extract) defines the salinity of this soil. If this water contains less than 3 grams of salt per litre, the soil is said to be non saline (see Table 29 below). If the salt concentration of the saturation extract contains more than 12 g/l, the soil is said to be highly saline.

Table 29. Levels of salinity depending on the salt concentration

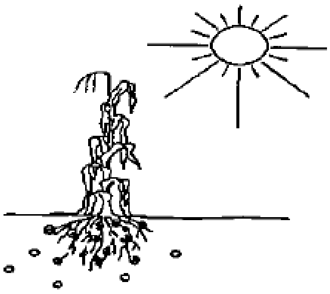


Salt concentration of the soil water (saturation extract)		Salinity
in g/l	in millimhos/cm	
0 - 3	0 - 4.5	non saline
3 - 6	4.5 - 9	slightly saline
6 - 12	9 - 18	medium saline
more than 12	more than 18	highly saline

9.3 Problem of salinity/ sodicity in Ethiopia

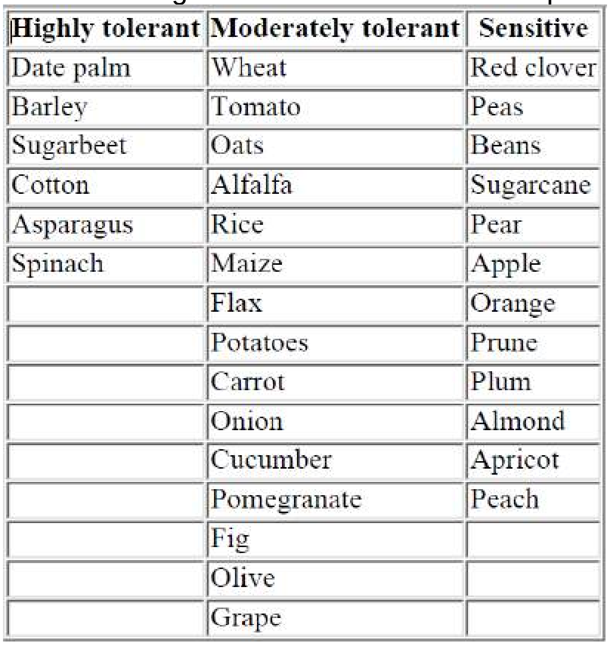
Most crops do not grow well on soils that contain salts. One reason is that salt causes a reduction in the rate and amount of water that the plant roots can take up from the soil (see Fig. 54 below). Also, some salts are toxic to plants when present in high concentration.

Fig. 54. A high salt concentration in the soil is harmful for the plants as the water uptake is reduced



Some plants are more tolerant to a high salt concentration than others. Some examples are given in the following table (see Table 30 below).

Table 30. Degree of tolerance of different plants



Highly tolerant	Moderately tolerant	Sensitive
Date palm	Wheat	Red clover
Barley	Tomato	Peas
Sugarbeet	Oats	Beans
Cotton	Alfalfa	Sugarcane
Asparagus	Rice	Pear
Spinach	Maize	Apple
	Flax	Orange
	Potatoes	Prune
	Carrot	Plum
	Onion	Almond
	Cucumber	Apricot
	Pomegranate	Peach
	Fig	
	Olive	
	Grape	

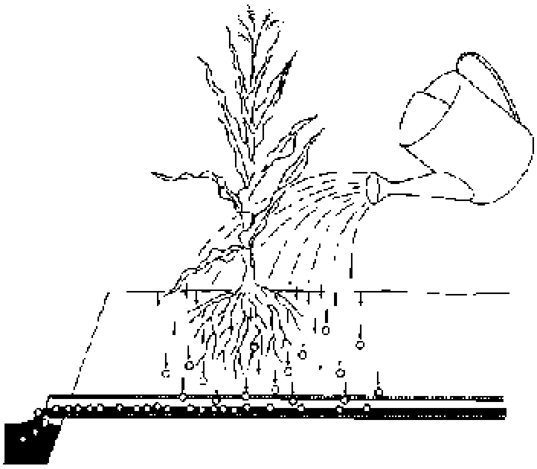
The highly tolerant crops can withstand a salt concentration of the saturation extract up to 10 g/l. The moderately tolerant crops can withstand salt concentration up to 5 g/l. The limit of the sensitive group is about 2.5 g/l.

Salty soils usually contain several types of salt. One of these is sodium salt. Where the concentration of sodium salts is high relative to other types of salt, a sodic soil may develop. Sodic soils are characterized by a poor soil structure: they have a low infiltration rate; they are poorly aerated and difficult to cultivate. Thus, sodic soils adversely affect the plants' growth.

9.4 Management of salt affected soils

Numerous areas in the world are naturally saline or sodic or have become saline due to improper irrigation practices. Crop growth on many of these is poor. However, their productivity can be improved by a number of measures.
Improvement of a saline soil implies the reduction of the salt concentration of the soil to a level that is not harmful to the crops. To that end, more water is applied to the field than is required for crop growth. This additional water infiltrates into the soil and percolates through the root zone. During percolation, it takes up part of the salts in the soil and takes these along to deeper soil layers. In fact, the water washes the salts out of the root zone. This washing process is called leaching (see Fig. 55 below).

Fig.55. Leaching of salts

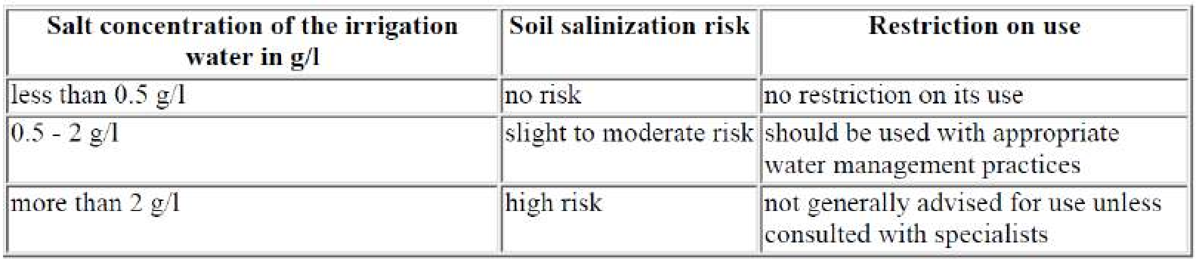


The additional water required for leaching must be removed from the root-zone by means of a subsurface drainage system. If not removed, it could cause a rise of the groundwater table which would bring the salts back into the root zone. Thus, improvement of saline soils includes, essentially, leaching and sub-surface drainage.

Improvement of sodic soils also implies the reduction of the amount of sodium present in the soil. This is done in two stages. Firstly, chemicals (such as gypsum), which are rich in calcium, are mixed with the soil; the calcium replaces the sodium. Then, the replaced sodium is leached from the root zone by irrigation water as explained above. Soils will become salty if salts are allowed to accumulate. Proper irrigation management and adequate drainage are not only important measures for the improvement of salty soils, they are also essential for the prevention of salinization.

The suitability of water for irrigation depends on the amount and the type of salt the irrigation water contains. The higher the salt concentration of the irrigation water the greater the risk of salinization. The following Table gives an idea of the risk of salinization

Table 31. Risk of salinization



Salt concentration of the irrigation water in g/l	Soil salinization risk	Restriction on use
less than 0.5 g/l	no risk	no restriction on its use
0.5 - 2 g/l	slight to moderate risk	should be used with appropriate water management practices
more than 2 g/l	high risk	not generally advised for use unless consulted with specialists

The type of salt in the irrigation water will influence the risk of developing sodicity: the higher the concentration of sodium present in the irrigation water (particularly compared to other soils), the higher the risk.

Irrigation systems are never fully efficient. Some water is always lost in canals and on the farmers' fields. Part of this seeps into the soil. While this will help leach salt out of the root zone, it will also contribute to a rise of the water table; a high water table is risky because it may cause the salts to return to the root zone. Therefore, both the water losses and the water table must be strictly controlled. This requires careful management of the irrigation system and a good subsurface drainage system.

MODULE 10:OPERATION AND MAINTENANCE OF IRRIGATION SYSTEMS

10.1 Operation of irrigation systems

10.1.1 Water delivery to the canals

There are three methods for delivery of water to canals: continuous delivery, rotational delivery and delivery on demand.

a)Continuous Water Delivery:- Each field canal receives its calculated share of the total water supply as an uninterrupted flow. The share is based on the irrigated area covered by each canal. Water is always available whether it may be used or not. This method is easy and convenient to the operator or water committee, but has a disadvantage in its tendency to waste water. The method is rarely used in small irrigation schemes.

b)Rotational Water Delivery:- Water is moved from one field canal or group of field canals to the next. Each user receives a fixed volume/discharge of water at defined intervals of time. This is a quite common method of water delivery.

c)Water Delivery on Demand:- The required quantity of water is delivered to the field when requested by the user. This on-demand method requires complex irrigation infrastructure and organization, especially for small farmer-operated schemes where the number of users is large and plot holding are small.

10.1.2 Water delivery to the fields

The water delivered in an open canal can be supplied onto the fields in different ways.

i) Bank Breaching:- Bank breaching involves opening a cut in the banks of a field canal to discharge water onto the field. Although this method is commonly a practice, it is not recommended because the canal banks become weak due to frequent destruction and refill. It also becomes difficult to control the flow properly.

ii) Permanent outlet structures:- Small structures, installed in the bank or a field canal are used to release water from the field canal onto the fields. The structure can be made of timber with wooden stop-logs or concrete with steel gates. The method is especially used for borders and basin irrigation and it usually gives good water control to the fields. The disadvantage is that the structures are fixed, thereby reducing the flexibility of water distribution.

iii)Siphons and Spiles:- The siphon is primed by putting its one end in the water and then filled with water (through suction by hand) to take out air. It is then laid over the canal bank while a hand placed over the end of the pipe prevents air re-entering the pipe. Spiles are short lengths of pipes made from rigid plastic, concrete, steel, bamboo or other materials and buried in the canal banks. Since spiles are permanently installed, they have the same advantage as permanent outlet structures. A plug is used to close the spiel on the inlet side. The discharge through the siphon and spile depends on their diameters and the difference between the water level in the canal and the water level on the adjacent field (or the center of the pipes outlet) as shown in figures 56 and 57 below. The water level in the canal should always be above the level of the siphon and spile inlets and outlets.

Fig.56. Free Flow Spile

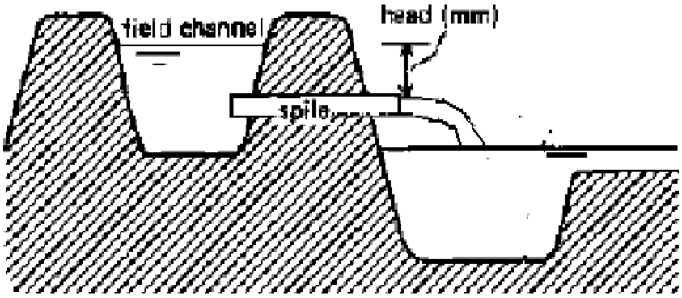
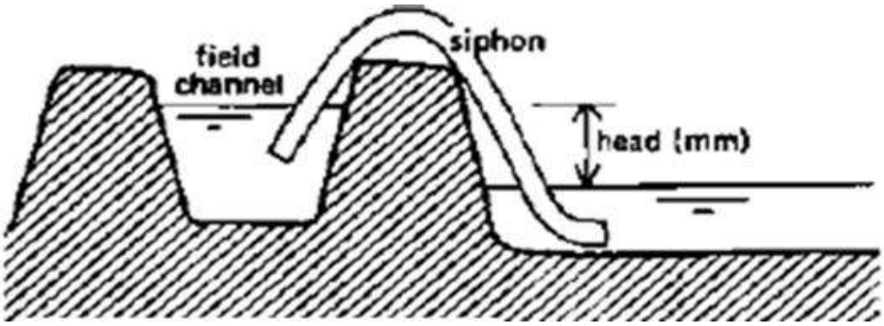


Fig.57. Submerged siphone



10.1.3 Advice to farmers on proper water management

In many irrigation schemes, the farmers involved do not have experience in irrigation. They need agronomic advice as well as training in water management. With regards to water management, the farmers should be assisted in determining parameters like contact time, advance and recession and the number of siphons to use in each furrow, border strip or basin. Similarly, they should be trained in operating structures such as division boxes.

10.2 Maintenance of irrigation systems

10.2.1 Aims and results of poor maintenance

Maintenance means regular repairs to ensure system operation continue satisfactorily. Principal aims of the regular good maintenance are:

- Repair damages or prevent deterioration of canals and structures which would otherwise require expensive rehabilitation
- Allow the system to operate satisfactorily supplying all parts of the command
- Solve problems before they become major works

Lack of proper maintenance results in serious consequences such as the following:

- The system cannot be operated well.
- Agricultural production fails
- Investment is lost
- The farmers are left with a system which is of limited use

A system in poor repair condition causes

- Poor water supply
- Disputes
- Continuing loss of income of farmers
- Opposition from the farmers
- Increasing problems including environmental issues
- Farmers do not pay fees and the condition of the system will even be more worse

10.2.2 Causes of canal system failure

i) Collapsing canal banks due to

- Fast running water results in
  - Collapse of embankments and serious canal deterioration
  - Reduced flow and frequent disruption of water supply that brings
  - Frequent maintenance
- Unstable embankment due to poor materials
- Leaking lining in elevated embankments
- Borrowing animals (digging holes on embankments)
- Cattle crossing the canal etc

ii) Erosion of canal bottom and sides due to steep slopes

iii) Overtopping of canal due to

- Too small canal size
- Too low canal bunds
- Obstruction in the canal caused by vegetation growth and stones or other materials in the canal

10.2.3 Water losses and leakages

Causes of water losses include:

- Holes in the embankments due to improper compaction or organic materials in the bund
- Holes dug by crabs and other animals
- Overtopping due to low embankment
- Leaking through cracks of lined canal reach
- Seepage through porous canal reach
- Illegal off-takes
- Leakage in intakes/turnouts

a) Damages and Inadequate Structures

Damages and inadequate structures can be caused by, but not limited to, the following

- Poor design
- Location of structure, which is not good (poor setting)
- Low height in relation to canal banks
- Inadequate protection of embankment (causes erosion)
- Insufficient maintenance
- Poor quality of construction (cracking or piping)

b) **Inadequate Water Distribution**

Inadequate water distributions can also be caused by due to one or more of the following

- Inadequate or non-functional structures
  - Abolishment and collapse of structures
  - Farmers' indifference to adhering to better management practices
- Lack of guidelines and criteria for water distribution
  - No adherence to agreed cropping pattern
  - Uncertainty of water supply
  - Indifference of farmers
- Non functional or non-existence of water users associations
  - Non-cooperation and indifference of farmers operation and maintenance
  - Excessive and arbitrary off-take in water by individuals
  - Shortage of water in the middle and tail end and low cropping intensity

10.2.4 Types of maintenance

i) Routine maintenance

Small-scale work done routinely throughout the year

Minor earthworks

- Filling holes in canal banks
- Removal of trash and silt from in structures
- Greasing of gate operating mechanisms

ii) Major maintenance

Large repairs should be planned for period when irrigation system is routinely shutdown

- Re-sectioning of canals
- De-silting
- Removing of weeds from canals
- Grass-cutting and vegetation removal from banks
- Gate repair and painting
- Repair of failed parts of structures
- Channel protection works
- Earthworks
- Cleaning out cross-drainage culverts

iii) Emergency maintenance: Urgent or temporary repairs to maintain water delivery

- Construction of temporary canal sections
- Strengthening of structures
- Repair of landslides and canal breaches

10.2.5 Inspection, prioritization and responsible bodies for maintenance

a) Priorities of maintenance helps

- Secure/maintain good water control
- Prevent water loss
- Ensure good water flow throughout the canal length

- Prevent major problems developing in future
- Much maintenance should be aimed at:
  - Stopping development of problems
  - Ensuring that the system remains fit for its purpose

b) Priority setting in-terms of seriousness of the problems

- First priority should be to component parts which serve large area
- Head regulators and main water control structures also are important
- Canal embankments and other canal structures located in upper canal reaches should also be checked
- Desilting and removal of vegetation at the head of the canal may receive priority as flow of water down the canal may be restricted.

c) Inspection of Irrigation System

- Major inspection should be carried out at the end of the irrigation season
- The system should be inspected regularly during the time of operation
- Potential problems should be checked at intervals
- Minor repairs should be carried out before major work is required
- Inspection should start at the top of the canal
-

Canals: What are the things to inspect?

- Any areas of seepage
- Any low points in the banks, which could be overtopped
- Erosion of canal banks by heavy rainfall
- Check that any previous repairs to the banks are sound
- Cracking, damaged joints and weeds in lining
- Uphill drainage water entering the canal, bringing earth and silt, risk of overtopping and damaging the canal banks
- Reasonable access along the canal banks
- Water planting and floating weeds

Things to inspect related to structures

- Moving parts of gated structures- lubrication of spindle, bearings/sliding parts, leaking rubber seals
- Erosion damage to downstream protection
- Erosion of earth canal section downstream of structures
- Seepage from in-line canal culverts
- Blockage of cross-drainage culverts
- Damage to in-line siphons and drop structures
- Cracking of masonry and concrete structures

10.2.6 Measures to reduce maintenance

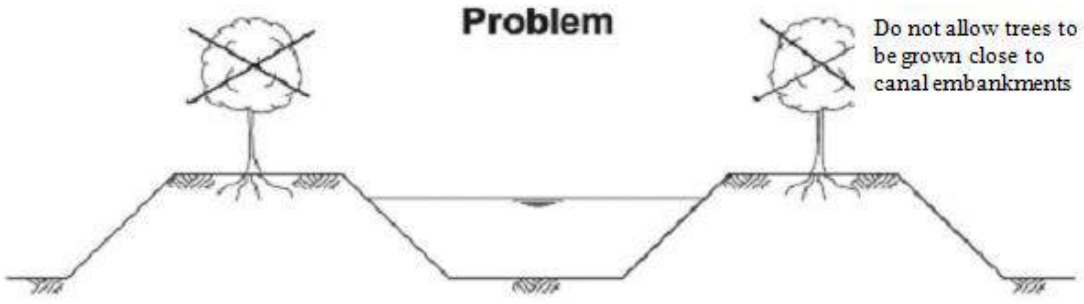
- A main canal drawing supply from river should not be operated at the peak of the flood and just afterwards for silt reduction
- Do not operate the canals too full-freeboard
- Prevent cattle from crossing and entering the canal
- Ensure that the outside slopes of canal banks are not cut back and cropped by farmers
- Avoid farmers’ arguments about the location of canal outlets by relocating them appropriately,
- Ensure that big trees and bushes do not grow on the canal banks

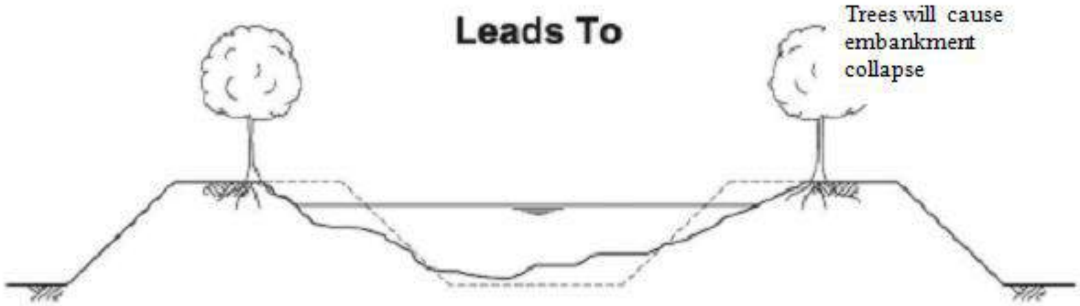
10.2.7 Planning maintenance work involves the following series of steps

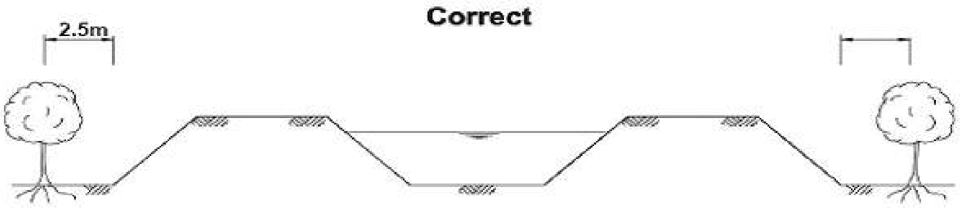
1. Identify potential problems as part of routine maintenance
2. Make regular inspections and note new problems
3. Make annual/seasonal inspections-review of problems already registered, any new issues entered
   - Details of problems
   - Identify works to be carried out
   - Prioritize works
   - Decide on work to be carried out
4. Survey and design (if required)
5. Estimating budgeting
   - Cost of maintenance works
   - Revision of scope of works (if required)
   - Overall budget
   - Calculation of required fees
6. General Assembly
   - Approval budget and fees
   - Agreement on how work should be implemented
7. Assign responsible bodies for maintenance
   - Routine maintenance- by farmers
   - Major maintenance – by farmers and Woreda offices (requires proper inspection and planning)
   - Emergency maintenance - by farmers and woreda offices

Fig. 58. Causes of Earth Canal failure and Results

a) Trees Growing on Canal Banks



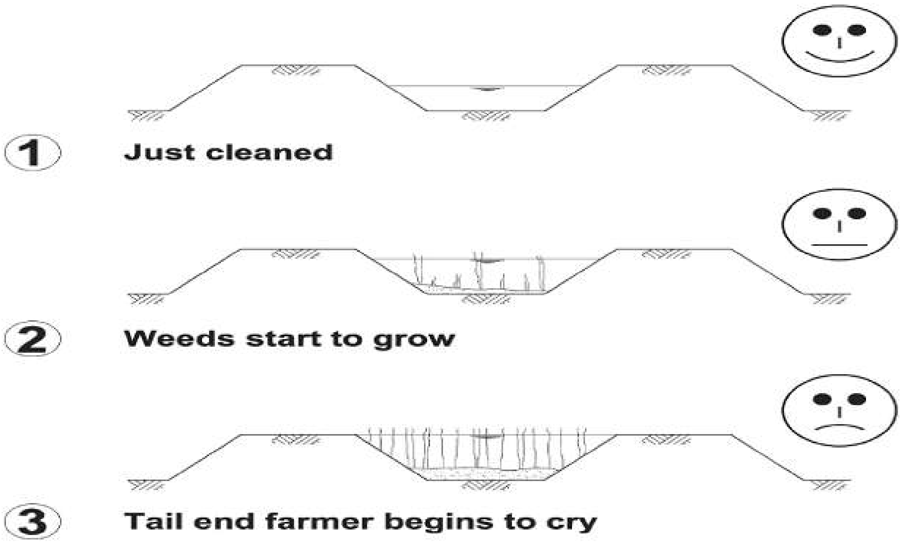




Trees growing outside banks

The correct positioning of trees will not cause damage

b) Farmers Encroaching on Canal Banks

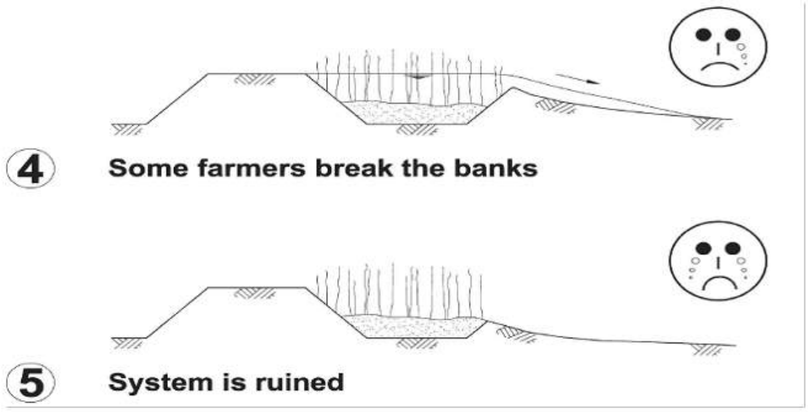


① Just cleaned

② Weeds start to grow

③ Tail end farmer begins to cry

c) **Effect of no maintenance**



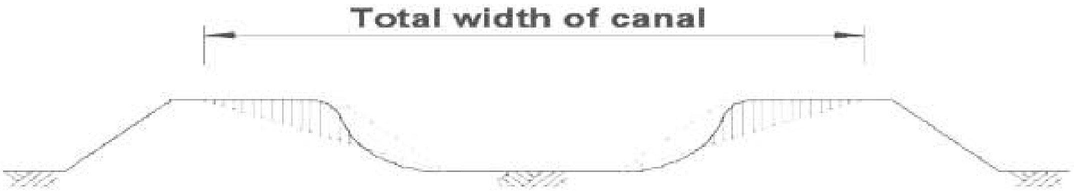
④ Some farmers break the banks

⑤ System is ruined

c) **Maintenance of Canal Banks**

(a) Problem : Erosion of side slopes

All canals will eventually take a U-shaped form. This cannot be prevented but maintenance is necessary to prevent slides.



(b)

A possibility is to change the steepness of the side slopes. Flatter side slopes will prevent erosion but require a larger total width of canal.

10.3 Water Users' Group

The issues discussed here focus on: the role of water users' associations; how to prepare a service agreement; and the need for adjustments and improvements of agreements. To begin with operating and maintaining an irrigation scheme almost always requires joint action by the water users with communities taking part in development. In traditional irrigation schemes, farmers would get together to build a diversion weir across a river or dig an access canal, because these were things they could not accomplish on their own. Without the capacity for organization and decision making among the users, it was simply not possible to complete a scheme. This capacity helped users to develop an organization capable of operating and maintaining the scheme.

In a modern scheme where most of the preparation and construction is done by a government agency, the water users have much less experience in organizing themselves. Yet the fact that in such schemes the water is usually delivered to a group of farmers requires a water users' association (WUA) that is capable of assuming responsibility for water distribution among farmers. In many cases, the WUAs are also responsible for maintenance and for collecting irrigation fees from its users. WUAs could also play an important role in negotiating with the scheme operators on the service agreement.

The service agreement is between two parties: the farmers (or their WUAs) and the scheme operators. These two parties can have different objectives. This means that when the service agreement is being drawn up, the two parties have to negotiate with one another. This manual does not provide guidelines for conducting such negotiations. It is believed that farmers and scheme operators need to develop their own methods and skills, so that these are well suited to their culture and customs.
In small-scale schemes, the negotiations could probably be conducted in a series of meetings attended by all the farmers and all the scheme operators. But since it is not always possible for every farmer to attend every meeting, the farmers' group must agree on the

number of farmers who need to be present to make the decisions of the meeting binding for the whole group.

Another important issue is the participation of women in these discussions. In many irrigation schemes, women are very active in irrigated agriculture; this means that they also need to be involved in drawing up the service agreement. Even in small schemes, different farmers can have different interests, for many different reasons. To mention a few:
A) A farmer may be rich or poor: A rich farmer can more easily obtain inputs such as credit, seeds, and fertilizers, so that even on the same area of land he/she can benefit more from the irrigation scheme than a poor farmer can.
B) The farm may be large or small: On a large farm, it is usually easier for the farmer to store irrigation water and to use it whenever it is convenient.
C) The farm may be at the head-end of the scheme or at the tail-end of it: Head-enders usually finds ways of obtaining more water from the scheme than tail-enders.
A rich farmer with a large farm located at the head-end of the scheme is likely to propose another type of service agreement than a poor farmer with a small piece of land at the tail-end of the scheme. In the negotiation process between the farmers and scheme operators, the voices of the richer, larger and head-end farmers are likely to be louder than those of the poorer, smaller and tail-end farmers. A service agreement based only on the loud voices may well result in a situation where the less privileged farmers will not benefit enough from the scheme to be able and/or willing to contribute to its operation and maintenance.

On the other hand, if a service agreement is over-protective of the less privileged and less productive farmers, it may be difficult to obtain the contributions that the farmers need to make for the continued operation of the scheme. Hence, there is a need for adjustment and improvement of the service agreement.

The service agreement is the result of negotiations between parties whose objectives may differ. One cannot expect that the first service agreement will be perfect. Experience during the first irrigation season will show:
A) Whether the irrigation services could be provided according to the agreement, or whether this did not always happen.
B) Whether the scheme operators took appropriate corrective action.
C) Whether the farmers made their contributions in return for the services.

Even with positive experience on the above items, the following questions still need to be asked:
A) Whether the irrigation services provided according to the agreement were adequate for crop production, or whether they could be improved.
B) Whether the farmers' contributions were adequate to cover the costs of operating and maintaining the scheme.
These types of questions need to be asked after every irrigation season and, if necessary, the service agreement should be adapted accordingly. This means that the organizational arrangements made to produce the service agreement need to remain in place permanently, to ensure that the scheme is capable of adjustment and improvement.

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