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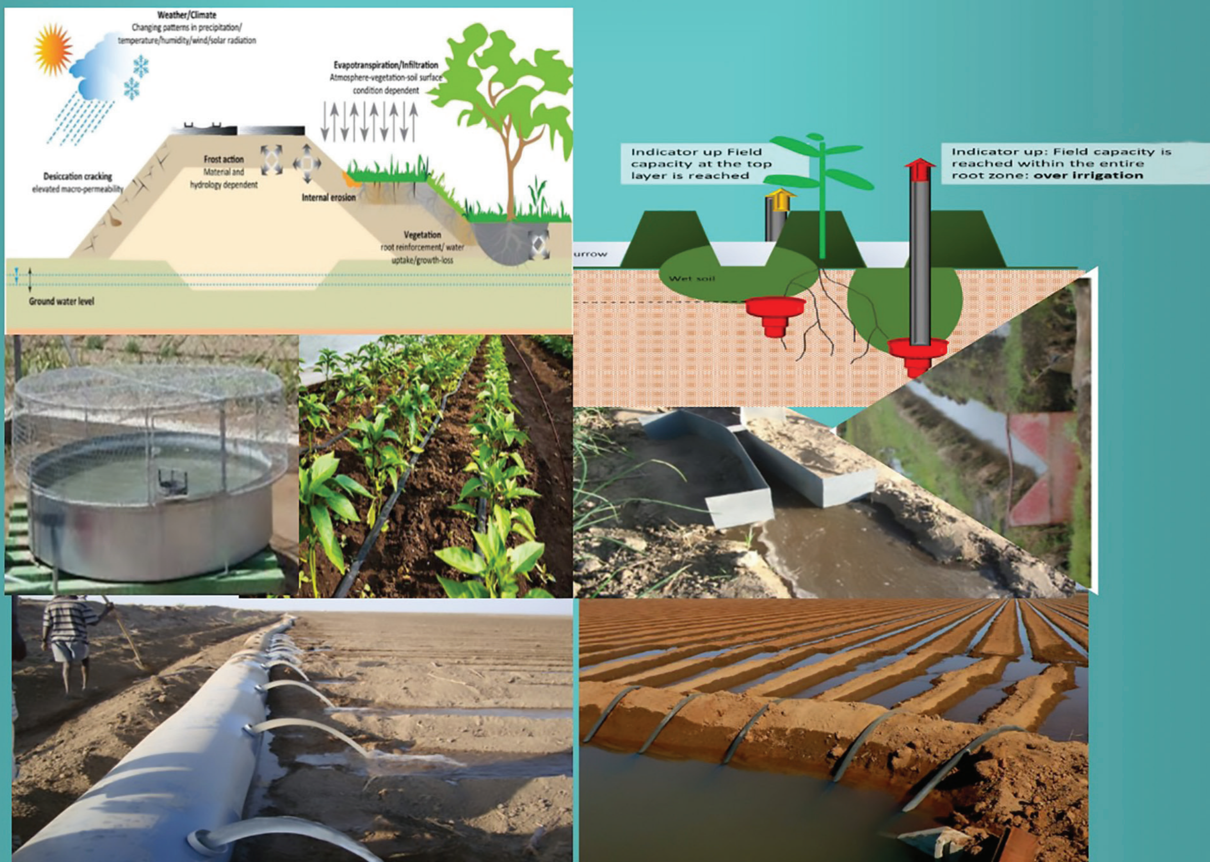
MINISTRY OF AGRICULTURE

National ON-FARM WATER MANAGEMENT TRAINING MANUAL



August 2019
Addis Ababa, Ethiopia

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July 2019
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About this Edition: This on farm water management training manual is the first edition containing 5 parts designed to meet the technical need of Ethiopian Irrigation expertise working at farm level irrigated agriculture development and irrigated crop production system.

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PREFACE

Irrigated agriculture plays a very important role in food security and livelihood improvements of Ethiopia. Irrigated Agriculture can also be transformed if only if irrigation is intensely invested and managed. Conversely with an increasing competition for the limited amount of irrigation water, it requires an efficient and productive use and provide much closer control than ever before. The importance of irrigated crops is becoming extremely vital to the Ethiopian agriculture, particularly for producing high value, market-oriented crop and livestock products. Improved management of on farm irrigation water requirement needs a preliminary sprouted information and techniques in the planning, design, evaluation, operation and management of irrigation systems.

This manual is to provide best-bet technologies and approaches to on farm irrigation water management system for woreda experts and kebele agriculture development agents directly working with farmers and attributed to meet the technical need of Ethiopian irrigation expertise working at farm level irrigated agriculture development and irrigated crop production system. The manual contains five units. In the first unit, the main emphasis is given to soil plant water relation and soil moisture measurements, crop and irrigation water requirements. In the second unit the training manual included irrigation water requirements, scheduling and methods, on third unit it deals about irrigation water measurements, fourth unit also deals with on farm water management improving practices and the last unit also shows the miss use of irrigation water problems and its management system.

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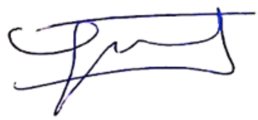
Irrigation is considered as a means of modernizing the country's agricultural economy and an important investment for improving rural income through increased agricultural production and productivity. It is also central for reducing the ever-increasing pressure on land by increasing the productivity of a unit of land as well as by bringing new land under cultivation of irrigation system, particularly in the lowlands where population density is relatively low and uncultivated land is abundantly available. Furthermore, irrigation plays an important role in combating the effects of recurrent droughts and sustains production if and only if we use it efficiently and effectively for the available resources.

Ministry of Agriculture (MoA) Small Scale Irrigation Development Directorate, based on the national strategic directions is striving to achieve its commitments in which modernizing irrigated agriculture is on top of its highest priorities to sustain the rapid, broad based and equitable economic growth and development of the country. To date, major efforts have been made to realize Agricultural Transformation Agenda of the country that can transform smallholder irrigation agriculture from subsistence oriented, low input-low output agriculture to a high performing and well integrated all-inclusive and sustainable economic growth.

This training manual prepared for improving our irrigated agricultural system expert skill which comprises five units that have been as one of the key outputs of this training module systematically arranged in association with on-farm water management system. In the process of developing this manual different partner institutions in the four regions were involved. In this regard, we highly recognize the technical inputs delivered from the four regions, specifically from bureau of agriculture from Amhara, Tigray and SNNPR and Oromia. We would like to extend our appreciation and thanks to all contributors and editors for their support in developing and editing of this highly valuable training manual.

Finally, I acknowledge with sincere regards and thanks, goes to the Small scale and micro irrigation support (SMIS) project for its technical and financial support in developing this training manual through organizing write shop for team of experts and review and validation workshop for federal and regional partner institutions.



Elias Awol
Director, Small Scale Irrigation Development Directorate
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INTRODUCTION

Water is a vital component of agricultural production. It is essential to maximize both yield and quality. Water has to be applied in the right amounts at the right time in order to achieve the right crop production. At the same time, the application of water should avoid waste of a valuable resource and be in sympathy with the environment as a whole. Understanding, measuring and assessing how water flows around the farm, and recognizing how farming practices affect flows, will help farmers to manage water efficiently and reduce pollution risks.

Irrigation is one means by which agricultural production can be increased to meet the growing food demands of the fast growing population of Ethiopia. Increasing food demand can be met through irrigation by increasing cropping intensity by growing two or three crops per year since expansion of the area under cultivation is a limited option. The problems of crop failures, due to dry spells and droughts are common events in the rural settings of Ethiopia and hence Agricultural production can be stabilized and increased by providing adequate supply of water through irrigation and retaining of rainwater in to the soil horizon at an effective root zone level.

Hence, understanding on-farm water management ‘’a system approach towards controlling water on a farm in a manner that provides for the beneficial management of water for satisfying the irrigation and drainage needs of a crop under the constraints imposed by the prevailing physical social, environmental, and production systems” is vital for irrigation agriculturalists.

In an environment of limiting water resources, irrigation efficiencies of existing surface irrigation systems can be increased by reducing conveyance losses through maintenance and rehabilitation of canals, appropriate irrigation scheduling and management decisions. Previously, there are so many types of manuals were produced without considering both measuring devices of

This document on irrigation water management in agriculture at farm level aims to address the key aspects of water and irrigation management at an environmental, economic and social level. Emphasis is given to correct management of water, both in terms of quantity and quality.

SCOPE OF THE MODULE

Basically, the module focuses on soil-water-plant relationships and measurements, irrigation water demand estimation, irrigation scheduling, Irrigation application methods, irrigation water quality management, irrigation drainage management techniques and indicative technologies in agricultural Lands as prevention and reclamation measures. The material discusses the entire possible theoretical basis on a concept and tries to put how it can be estimated considering the field conditions and some basic information available from literature or laboratory results. It also includes the procedures of computing the required parameters and supports it by a simple computing techniques. The module also tries to show the yield response of water through scheduling. It finally explains how computer program packages can be used in an irrigation system to schedule a system. In addition to irrigation water applications system it also deals with the skill of how irrigation can be measured and managed very well. Finally, on the last but not the least the module also try to show the effect of misuse of irrigation water management and how it can be managed without affecting the environment adversely. Generally the module comprises five chapters which are logically arranged one after the other.

UNIT 1

SOIL-WATER-PLANT RELATIONSHIPS AND SOIL MOISTURE MEASUREMENTS

1.1. FUNDAMENTAL CONCEPT

Effective and efficient irrigation begins with a basic understanding of the relationships among soil, water, plants and the atmosphere. Figure-1 illustrates the on-farm hydrologic cycle for irrigated lands. Water can be supplied to the soil through precipitation, irrigation, or from groundwater (e.g., rising water table due to drainage management). Plants take up water that is stored in the soil (soil water), and use this for growth (e.g., nutrient uptake, photosynthesis) and cooling. Transpiration is the most important component of the on-farm hydrologic cycle, with the greatest share of transpiration devoted to cooling. Water is also lost via evaporation from leaf surfaces and the soil. The combination of transpiration and evaporation is evapotranspiration (ET). ET is influenced by several factors, including plant temperature, air temperature, solar radiation, and wind speed, relative humidity, and soil water availability. The amount of water the plant needs, its consumptive use, is equal to the quantity of water lost through ET (USEPA, 2003).

Although water uptake by plants is under physiological control, it is often described as a purely physical process, as a consequence of gradients in water potential in the soil–plant–atmosphere continuum (SPAC). The SPAC is the pathway for water moving from soil through plants to the atmosphere. A plant grows in soil and opens to atmosphere. About 99% of all the water that enters the roots leaves the plant’s leaves via the stomata without taking part in metabolism (Ali, 2010).

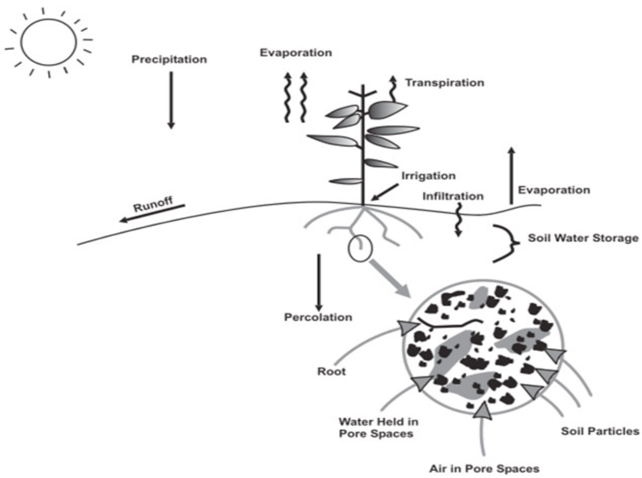


Figure 1.1: On-farm hydrologic cycle for irrigated farm

1.2. THE IMPORTANCE OF SOIL TO WATER USE

Soil type is the main factor in determining how much water reaches the root zone of a plant. Sandy soils have high infiltration rates and drain quickly. This allows air to move back into pore spaces. Clay soils, however, usually have low infiltration rates, so water that does flow in is held tightly and is hard to draw out. Loamy soils are somewhere between clay and sandy soils. Soil water holding capacity can be greatly increased by improving the amount of soil carbon and soil organic matter.

Soil management is linked to water use as soil properties influence the movement and storage of water. Soil texture and soil structure, strongly influence the way water behaves in a soil. Moreover, these properties affect the movement of water into the soil, drainage and water storage in the soil profile. The reason that texture and structure have such a strong influence on water storage and availability is the size of soil particles and pores, and their arrangement. The soil texture determines the capacity of the soil of holding water. A soil with large particles and large pore spaces (e.g. sand) hold the least amount of water. On the other hand, soil rich in clay has small particles and can store a large amount of water. However, not all of it is available to plants as small pores hold onto water very tightly. Compacted soil has small, disconnected pore space which reduces the amount of water that is available to plants.

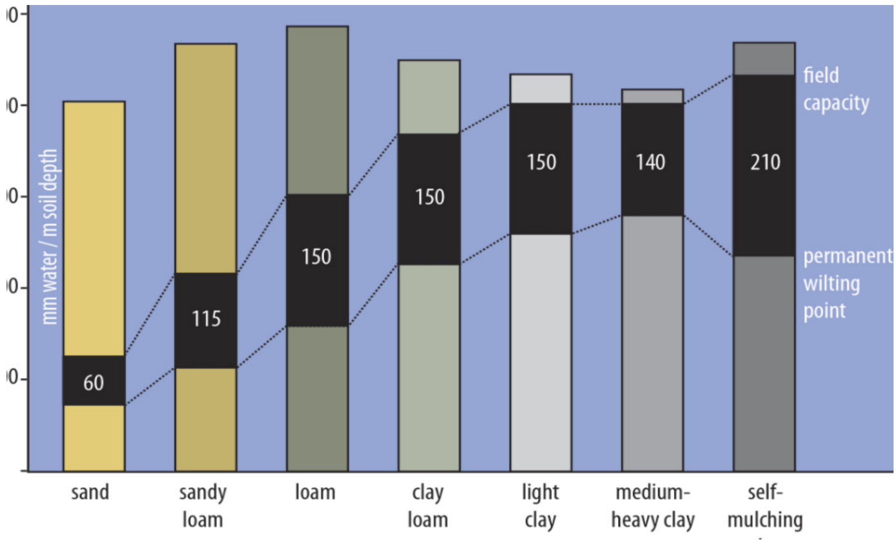


Figure 1.2: Available water in different soil types

1.2.1. WHAT IS SOIL TEXTURE?

Soil texture is the amount of sand, silt and clay in the soil. It has a strong influence on water storage and availability because of the variation in the particle size distribution and the surface area. Smaller particles fit together more tightly than larger particles and therefore the pores for air and water are also smaller. Small pores retain water against gravitational forces, drainage and also against plant use, while the larger pores found in sand allow water to drain.

Ideally, a soil will contain a range of pore sizes, larger pores which drain readily so as to prevent water logging following soil saturation and smaller pores which store water for plant use. Not all water held in very small pores is available to plants because water can be retained strongly. The amount of water that can be absorbed by the soil increases as the surface area of the particles in the soil increases. Fine clay has about 10,000 times as much surface area as the same weight of medium-sized sand. Soil with high organic matter can also retain water very well. Soil texture is the single most important physical property of the soil. Knowing the soil texture alone will provide information about:

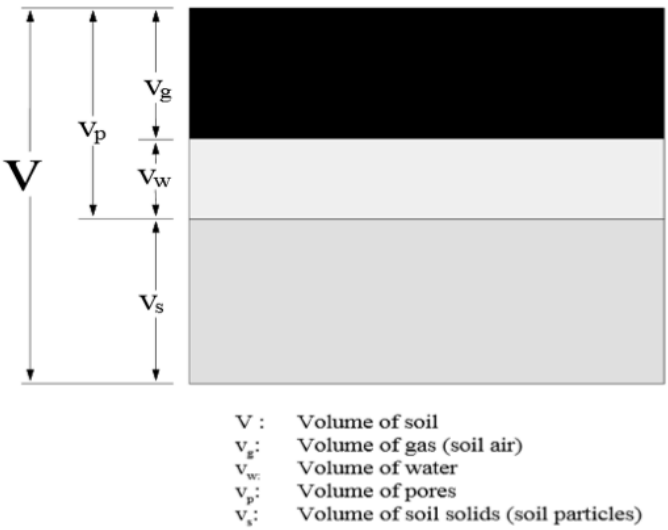
- Water flow potential
- Water holding capacity
- Fertility potential
- Suitability for many urban uses like bearing capacity
- Critical for understanding soil behavior and management

1.2.2. WHAT IS SOIL STRUCTURE?

Soil structure is the arrangement of the solid components of soil and the spaces in between. Ideally, soil should have pores for the flow of water and gases, and pores that contain water and dissolved nutrients for plant growth.

1.2.3. OTHER IMPORTANT SOIL PROPERTIES

Several other important soil properties are defined below. These properties can be visualized with the help of the schematic diagram shown below. This diagram shows the soil as a three-phase system. For convenience the phases are separated.



Porosity(ϕ) $= \dfrac{\text{Volume of Pores}}{\text{Volume of Soil}} = \dfrac{Vp}{V}$

Porosity lies in the range 0.3 - 0.6 (30 - 60%). Coarse-textured soils tend to be less porous than fine-textured soils.

Bulk Density(ρb) $= \dfrac{\text{Mass of soil particles}}{\text{Volume of Soil}} = \dfrac{Ms}{V}$

In sandy soils the bulk density can be as high as 1.6 gm/cm^3, whereas in aggregated loams and in clay soils, it can be as low as 1.1 gm/cm^3. The density of the alumino-silicate particles in the soil is 2.6 gm/cm^3.

Porosity $= 1 - \dfrac{\text{Bulk Density}}{2.6}$

Thus if a soil has a porosity of 0.5, the bulk density will be 1.3 gm/cm^3

$$\textbf{Soil Water Content}(\Theta) = \frac{\textit{Volume of water}}{\textit{Volume of Soil}} = \frac{Vw}{V}$$

In sandy soils, the value of soil water content at saturation varies from 40 - 50 %. In medium-textured soils it is about 50%, while it may be up to 60% in clayey soils. In swelling clay soils, the volume of water at saturation may be much more than the porosity of the dry soil.

Infiltration: A function of soil is to absorb water at the land surface, and store it for use by plants or slowly release it to groundwater through gravitational flow. The infiltration capacity is the maximum amount of water that can enter a soil in a specific time. It is influenced by the soil type, structure, and moisture content at the start of the rain. Soil compaction can reduce the infiltration rate. Soil compaction occurs when soil particles are pressed together, reducing pore space. Heavily compacted soils contain few large pores and have a reduced rate of both water infiltration and drainage from the compacted layer. This occurs because large pores are the most effective in moving water through the soil when it is saturated.

Capillarity: Capillary rise is the process where groundwater is sucked upward by the soil through very small pores that are called capillaries. The movement of the water depends on soil texture; in clay soils the upward movement of water is slow but covers a long distance. In sandy soils, the upward movement of the water is quick but covers only a short distance.

1.2.4. SOIL SAMPLING

Soil sampling is commonly used to determine the amount of soil moisture. The wetness of the soil can be described as the gravimetric soil water content, the volumetric soil water content and the soil water potential (also known as soil water suction).

a) Gravimetric soil water content: is the quantity of water in the soil on a weight basis. It is expressed on gr of water per gr of dry soil).

Gravimetric soil moisture (W%) = <u>wt. (wet soil) – wt. (oven dry soil)</u> x 100% wt.
(Oven dry soil)

b) Volumetric soil water content: is the quantity of water on a volumetric fraction of soil. It is measured by calculating the quantity of water per unit of soil and multiply it by the soil bulk density. It is expressed in cc of water per cc of soil.

Volumetric soil moisture (%) = gravimetric soil moisture x bulk density

C) **Soil water potential or soil water suction:** is the pressure needed to extract water from the soil. This measure is used because some soils hold water more tightly than others, and all soils hold water more tightly as they dry. It represents the energy plants must exert to draw water from the soil. Soil water suction can be measured by porous media (e.g. gypsum blocks), devices that detect when water moves down through the soil to them. The soil water potential is expressed in kilopascals (kPa).

1.2.5. SOIL MOISTURE LEVELS

Readily Available Water (RAW): In simple terms, the Readily Available Water (RAW) is the water that a plant can easily extract from the soil. RAW is the soil moisture held between field capacity and a nominated refill point for unrestricted growth. In this range of soil moisture, the plants have good condition to grow and are neither waterlogged nor water-stressed.

Refill point: As water is removed by plants and by evaporation from the soil surface it becomes more and more difficult for plants to extract water as it clings more tightly to soil particles and in small pore spaces. When water extraction becomes difficult for plants and more water is required to maintain growth rates, the soil is said to be at the 'refill point'. If the soil dries to the permanent wilting point, the plant can no longer remove any water from it. The drier the soil, as shown by high tensiometer values, the more water needs to be added to bring the soil back to field capacity. Refill point for horticultural crops lies between a tension of -20 and -60 kPa.

Permanent wilting point: It is defined as the soil water content below which plants cannot extract any water from the soil. Water is then held in very small pores or chemically bound to the soil particles. Permanent wilting point corresponds to a suction of 15 bars. In irrigation and drainage, the main objective is to maintain the soil water content between field capacity and permanent wilting point.

Gravitational water: As water infiltrates the soil, it fills the pore spaces between the soil particles. Gravitational water is the status when pores are completely saturated and therefore water percolates down through the soil profile and below the root zone. Gravitational water may take a few hours to drain away in sandy soils, or days or even weeks in clay soils.

In a *saturated* soil all the pore space is occupied by water. Under field conditions full saturation is hardly ever achieved, as there is almost always some air trapped in the soil. The approximate saturation achieved in practice is referred to as Field saturation. As the soil drains, air occupies the biggest pores in the soil. As more and more water is removed from the soil, smaller and smaller pores are drained.

Field capacity: It is defined as the soil water content when the gravity filled pores are drained. This occurs one day after field saturation in a sandy soil and three days after field saturation in a clay soil. Field capacity is also defined as the water content when the suction on the soil is 1/3 bar. Below field capacity, for all intents and purposes, no more gravity drainage occurs. Water is removed from the soil by evaporation at the soil surface or through uptake by plants.

Field capacity is the condition of equilibrium when the gravity forces are equal to the evaporation forces. Evaporation at the soil surface pulls water upward through capillary forces, while capillary forces also hold water around the soil particles. In this condition, water stops moving downward and is held by surface tension in the soil.

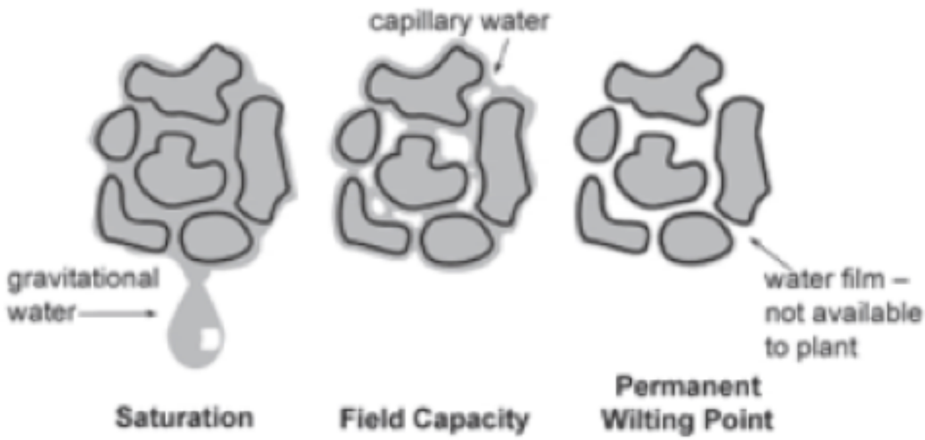


Figure 1.3: Soil saturation, field capacity and permeant wilting point

Deep percolation: The drainage of soil water downward by gravity below the maximum effective depth of the root zone toward storage in subsurface strata.

Irrigators need to know the amount of water available to the plant. This varies according to the soil texture and the plant's effective root zone.

Figure 1.4: Different levels of soil moisture affect plant growth

1.3. WATER MOVEMENT IN THE SOIL

When water is applied to soils it moves via such pathways as infiltration, runoff, and evaporation (Figure 1). The ultimate fate and transport of applied water is determined by various forces, including gravity and capillary force. Gravity pulls water downward freely in soils with large pores, causing it to move through the root zone quickly if not taken up by the crop. As the water passes through the soil, the pores are filled again with air, preventing crop damage that could arise due to excess water. In soils with smaller pores, water moves via capillary forces. This “capillary water” moves more slowly than gravitational water, and tends to move from wetter areas to drier areas. The lateral distribution of capillary water makes it more important to the irrigated crop since it provides greater wetting of the soil. In saturated conditions, gravity is the primary force causing downward water movement, while capillary action is the primary force in unsaturated soil. Soil-water potential is the sum of matric, solute, gravitational, and pressure potential, detailed discussions of which are beyond the scope of this document. In simple terms, however, water in the soil moves toward decreasing potential energy, or commonly from higher water content to lower water content (USEPA, 2003).

It is important to realize that large pores in the soil can conduct more water more rapidly than fine pores. In addition, removing water from large pores is easier and requires less energy than removing water from smaller pores.

- Factors that affect water movement through soil include texture, structure, organic matter and bulk density. Any condition that affects soil pore size and shape will affect water movement.

  Examples include compaction, tillage, decayed root channels and worm holes.
- The rate and direction of water moving through soil is also affected by soil layers of

different material. Abrupt changes in pore size from one layer to the next affect water movement. *When fine soil overlies coarse soil, downward water movement will temporally stop at the fine coarse interface until the fine layer above the interface is nearly saturation.*

- When a coarse soil is above a fine soil, the rapid water movement in the coarse soil is greater than through the clay and water will build up above the fine layer as the water front comes in contact with fine layer. This can result in a buildup of a perched water table if water continues to enter the coarse layer.

Pore size is one of the most important fundamental properties affecting how water moves through soil. Larger pores as in sand conduct water more rapidly than smaller pores in clay.

- The two forces that allow water to move through soil are gravitational forces and capillary forces. Capillary forces are greater in small pores than in large pores.
- Gravitational and capillary forces act simultaneously in soils. Capillary action involves two types of attractions, adhesion and cohesion. Adhesion is attraction of water molecules to solid surfaces; cohesion is the attraction of water molecules to each other. Gravity pulls water downward when the water is not held by capillary action. Thus gravity influences water in saturated soils.
- Sandy soils contain larger pores than clay soils, but do not contain as much total pore space.
- Sandy soils do not contain as much water per unit volume of soil as clay soils.

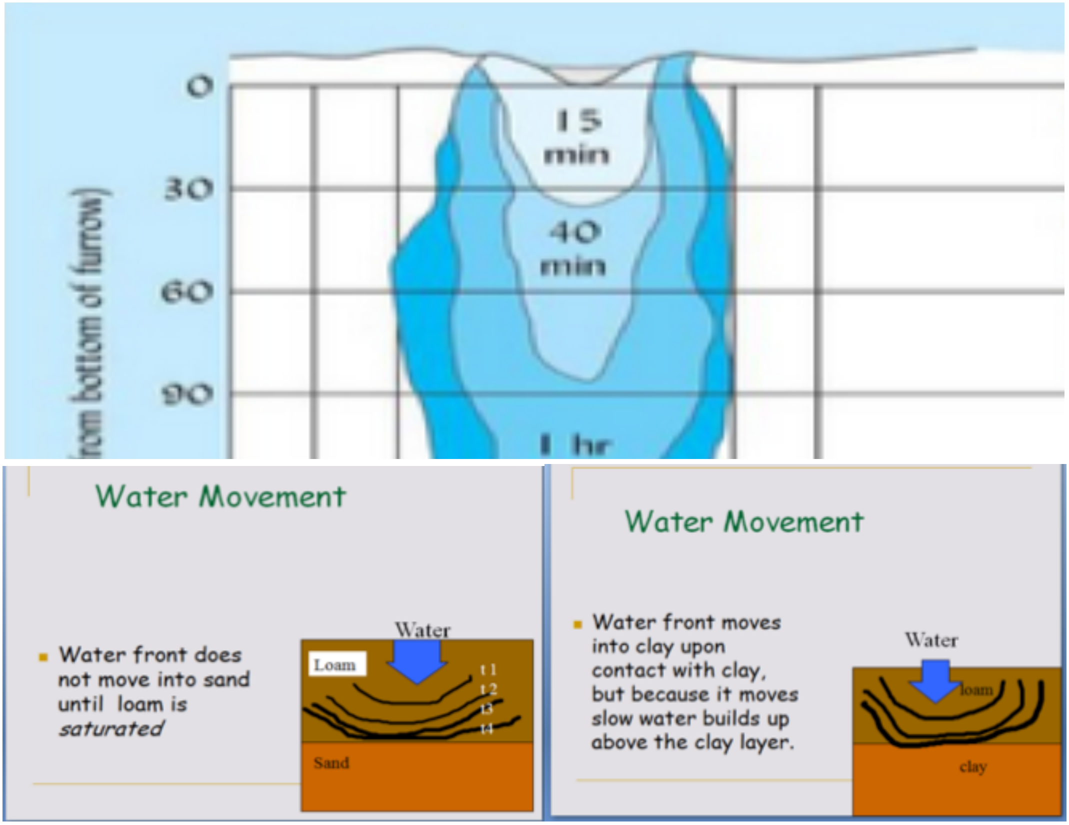


Figure 1.5 Water movement in the soil horizon

1.4. ROLE OF WATER IN PLANT LIFE

Water is essential for plant growth. Plants extract mineral laden water from the soil. For effective irrigation and drainage, it is important that the processes governing soil water storage and soil water movement be understood. During the day the plant is under heavy energy load (net radiation, Rn). While a small fraction of this energy is used in photosynthesis, most of it must be dissipated. If this energy is still absorbed by the canopy to its fullest extent, then leaves can reach a killing temperature of 40° to 50°C or more. This energy load is dissipated via three physical channels:

1. The "albedo" which is determined by the total reflectivity of the leaf as affected by its optical characters and its architecture;
2. "sensible heat" which is the radiation emitted from the canopy as heat; and

3. The "latent energy" which is dissipated by plant transpiration.

The role of water in plant is therefore,

1. Component of protoplasm
2. Substrate for plant metabolism
3. Solvents for plant absorption and transportation
4. Keeping plant in shape (extension)
5. Balance plant temperature

Plant growth depends upon a renewable supply of soil water, which is governed by the movement of water in the soil, the soil-water holding capacity, the amount of soil water that is readily available to plants, and the rate at which soil water can be replenished. Efficient irrigation provides plants with this renewable supply of soil water with a minimum of wasted time, energy, and water. Knowledge and understanding of the factors that affect water movement in the soil, storage of water in the soil, and the availability of water to plants are essential to achieving maximum irrigation efficiencies.

1.5. STORAGE AND AVAILABILITY OF SOIL WATER

The amount of water that soil can hold, its water holding capacity, is a key factor in irrigation planning and management since the soil provides the reservoir of water that the plant draws upon for growth. Water is stored in the soil as a film around each soil particle, and in the pore spaces between soil particles. The magnified area in Figure 1 illustrates how soil water and air are held in the pore spaces of soils. All soil water is not equally available for extraction and use by plants. The ability of plants to take water from the soil depends upon a number of factors, including soil texture, soil structure, and the layering of soils.

Soil texture and structure affect the size, shape, and quantity of pores in the soil, and therefore the space available to hold air or water. For example, the available water capacity of coarse sand ranges from 0.1 to 0.4 inches of water per foot of soil depth (in/ft), while silt holds 1.9–2.2 in/ft, and clay holds 1.7–1.9 in/ft. In fine-textured soils and soils affected by salinity, sodicity, or other chemicals, a considerable volume of soil water may not be available for plant use due to greater soil water tension.

Field capacity is the amount of water a soil holds after "free" water has drained because of gravity. "Free" water, which is conceptually similar to "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. Available water capacity is the difference between the amount of water held at field capacity and the amount held at the permanent wilting point.

1.5.1. SOIL MOISTURE MEASUREMENT

Very often, vegetation and crops depend at any time more on the moisture available at root level than on precipitation occurrence. Water budgeting for irrigation planning, as well as actual scheduling of irrigation action, requires local soil moisture information. Soil moisture determinations measure either the soil-water content or the soil-water potential. Soil-water content is an expression of the mass or volume of water in the soil, while the soil-water potential is an expression of the soil-water energy status. The relation between content and potential is not universal, but depends on characteristics of the local soil, such as soil density and soil texture. Soil water content on the basis of mass is expressed in the gravimetric soil moisture content, θg, defined by:

$$\vartheta g = M\ water/M\ soil$$

Where M water is the mass of the water in the soil sample and M soil is the mass of dry soil that is contained in the sample. Because in precipitation, evapotranspiration and solute transport variables are commonly expressed in terms of flux, volumetric expressions for water content are often more useful. The volumetric soil moisture content of a soil sample, θv, is expressed defined as:

$$\vartheta v= Vwater /Vsample$$

Where Vwater is the volume of water in the soil sample, and V sample is the total volume of (dry soil + air + water) in the sample. Again, the ratio is usually expressed in per cent. The relationship between gravimetric and volumetric moisture contents is:

$$\vartheta v= \vartheta g(\rho b/\rho w)$$

Where ρb is the dry soil bulk density and $\rho w$is the soil-water density. Because this method is based on direct measurements, it is the standard with which all other methods are compared. Unfortunately, gravimetric sampling is destructive, making repeat measurements on the same soil sample impossible. Because of the difficulties of accurately measuring dry soil and water volumes, volumetric water contents are not usually determined directly.

The soil water potential describes the energy status of the soil water and is an important parameter for water transport analysis, water storage estimates, and for soil-plant-water relationships. A difference in water potential between two soil locations indicates a tendency for water flow, from high to low potential. When the soil is drying, the water potential becomes more negative and the work that must be done to extract water from the soil increases. This makes water uptake by plants more difficult, so the water potential in the plant drops, resulting in plant stress and, eventually, severe wilting. Formally, the water potential is a measure of the ability of soil water to perform work or, in the case of negative potential, the work required to remove the water from the soil. Water contents are typically written as percentages. However, in solving the mass balance or continuity equations for water it must be remembered that the components of water content parameters are not dimensionless. Gravimetric water content is the weight of soil water contained in a unit weight of soil (kg water/kg dry soil). Likewise, volumetric water content can be expressed as is a volume ratio fraction (m3water/m3 soils). The basic unit for expressing water potential is energy (in Joule, kg m^2 s^{-2}) per unit mass, J kg-1. Alternatively, energy per unit volume (J m-3) is equivalent to pressure, expressed in Pascal (Pa = kg m-1 s -2). Units encountered in older literature are: bar (= 100 kPa), atmosphere (= 101.32 kPa), or pounds per square inch (= 6.895 kPa). A third class of units are those of pressure head in (centi-) metres of water or mercury, energy per unit weight.

1.5.2. METHODS OF MEASUREMENT

Methods and instruments available to evaluate soil water status may be classified in three ways. Fundamentally, we distinguish between determination of water content and determination of water potential. Second, a so-called direct method requires availability of a sizeable amount of representative terrain, from which large numbers of soil samples can be taken for destructive evaluation in the laboratory. Indirect methods use an instrument placed in the soil to measure some soil property related to soil moisture. Third, we can range methods according to operational applicability, taking into account the regular labor involved, the degree of dependence on laboratory availability, and the complexity of the operation and the reliability of the result. Moreover, the preliminary costs of acquiring instrumentation must be compared with the subsequent costs of local routine observation and data processing.

For determination of soil water content there are four operational alternatives. First there is classical gravimetric moisture determination, which is a simple direct method. Secondly, there is lysimetric, a non-destructive variant of gravimetric measurement. A container filled with soil is weighed either occasionally or continuously to indicate changes in total mass in the container, which may in part or totally be due to changes in soil moisture. Thirdly, water content may be determined indirectly by various radiological techniques, such as neutron scattering and gamma absorption. Fourthly, water content can be derived from dielectric properties of soil, for example by using time-domain reflectometry. Soil water potential measurement can be performed by several indirect methods; in particular tensiometers, resistance blocks, and soil psychrometers. None of these instruments are effective at this time over the full range of possible water potential values.

i. Gravimetric method

Soil samples of about 50 g are removed from the field with the best available tools (shovels, spiral hand augers, bucket augers, perhaps power-driven coring tubes), disturbing the sample soil structure as little as possible. Immediately after taking the soil sample, it should be placed in a leak-proof, seamless, pre-weighed and identified container. As the samples will be placed in an oven, the container should be able to withstand high temperatures without melting or losing significant mass. The most common soil containers are aluminium cans, but non-metallic containers should be used if the samples are to be dried in microwave ovens in the laboratory. If soil samples are to be transported for a considerable distance, tape should be used to seal the container to avoid moisture loss by evaporation. The samples and container are weighed in the laboratory both before and after drying, the difference being the mass of water originally in the sample. The drying procedure consists in placing the open container in an electrically heated oven at 105°C until the mass stabilizes at a constant value. Drying times required usually vary between 16 and 24 hours. Note that drying at 105°±5°C is part of the usually accepted definition of 'soil-water content', originating from the aim to measure only the content of "free" water which is not bound to the soil matrix.

If the soil samples contain considerable amounts of organic matter, excessive oxidation may occur at 105°C and some organic matter will be lost from the sample. Although the specific temperature at which excessive oxidation occurs is difficult to specify, lowering the oven temperature from 105 to 70°C seems to be sufficient to avoid significant loss of organic matter, but this can lead to determination of too-low water content values. Oven temperatures and drying times should be checked and reported.

Gravimetric soil -water contents of air-dry (25°C) mineral soil are often less than 2 per cent, but as the soil approaches saturation, the water content may increase to values between 25 and 60 per cent, depending on soil type. Volumetric soil -water content, θv may range from less than 10 per cent for air-dry soil to between 40 and 50 per cent for mineral soils approaching saturation. Soil θv determination requires measurement of soil density, for example by coating a soil clod with paraffin and weighing it in air and water, or some other method. Water contents for stony or gravely soils can be grossly misleading. When rocks occupy an appreciable volume of the soil, they modify direct measurement of soil mass, without making a similar contribution to the soil porosity. For example, gravimetric water content may be 10 per cent for a soil sample having a bulk density of 2 000 kg m-3; however, the water content of the same sample based on finer soil material (stones and gravel excluded) would be 20 per cent, if the bulk density of fine soil material was 1 620 kg m-3. Although the gravimetric water content for the finer soil fraction, θg, fines, is the value usually used for spatial and temporal comparison, there may also be a need to determine the volumetric water content for a gravely soils. The latter value may be important in calculating the volume of water in a root zone. The relationship between the gravimetric water content of the fine soil material and the bulk volumetric water content is given by:

ϑv, stony= ϑg,fines (ρb/ρv) (1 + M stones/M fines)

Where θ stony is the bulk volumetric water content of soil containing stones or gravel, and M stones and M fines are the masses of the stone and fine soil fractions.

ii. Soil water content: indirect methods

The capacity of soil to retain water is a function of soil texture and structure. In removing a soil sample, the soil being evaluated will be disturbed, so its water-holding capacity is altered. Indirect methods of measuring soil water are helpful as they allow information to be collected at the same location for many observations without disturbing the soil water system. Moreover, most indirect methods determine the volumetric soil water content without any need for soil density determination.

1) Radiological methods

Two different radiological methods are available for measuring soil-water content. One is the widely used neutron scatter method, which is based on the interaction of high-energy (fast) neutrons and the nuclei of hydrogen atoms in the soil. The other method measures the attenuation of gamma rays as they pass through soil. Both methods use portable equipment for multiple measurements at permanent observation sites and require careful calibration, preferably with the soil in which the equipment is to be used. When using any radioactive emitting device, some precautions are necessary. The manufacturer will provide a shield that must be used at all times. The only time the probe leaves the shield is when it is lowered into the soil l access tube. When the guidelines and regulations regarding radiation hazard stipulated by the manufacturers and health authorities are followed, there is no need to fear exposure to excessive radiation levels, regardless of the frequency of use. Nevertheless, whatever the type of radioactive emitting device is used, the operator should wear some type of film badge that will enable personal exposure levels to be evaluated and recorded on a monthly basis.

2) NEUTRON SCATTERING METHOD

In neutron soil moisture detection a probe containing a radioactive source emitting high-energy (fast) neutrons and a counter of slow neutrons, is lowered into the ground. The hydrogen nuclei, having about the same mass as neutrons, are at least 10 times as effective for slowing down neutrons upon collision as most other nuclei in the soil. Because in any soil most hydrogen is in water molecules, the density of slow 'thermalized' neutrons in the vicinity of the neutron probe is nearly proportional to the volumetric soil-water content. Some fraction of the slowed neutrons, after a number of collisions, will again reach the probe and its counter. When the soil water content is large, not many neutrons are able to travel far before being thermalized and ineffective, and then 95 per cent of the counted returning neutrons come from a relatively small soil volume. In wet soil the "radius of influence" may be only 15 cm, while in dry soil that radius may increase to 50 cm. So the measured soil volume varies with water content, and also thin layers cannot be resolved. This method then is less suitable to localize water-content discontinuities, and also it cannot be used well in the top 20 cm of soil on account of the soil-air discontinuity.

Several arrangements of source and detector in a neutron probe are possible, but it is best to have a probe with a double detector and a central source, typically in a cylindrical container. Such an arrangement allows for a nearly spherical zone of influence and leads to a more linear relation of neutron count to soil-water content. A neutron probe will be attached to the main instrument electronics by cable, so that the probe can be lowered into a previously installed access tube. The access tube should be seamless and thick enough (at least 1.25 mm) to be rigid, but not so thick that the access tube itself slows neutrons down significantly. The access tube must be made of non-corrosive material, such as stainless steel, aluminium, or plastics, though polyvinylchloride should be avoided as it absorbs slow neutrons.

Usually a straight tube of 5 cm diameter is sufficient to have the probe lowered into the tube without risk of jamming. Care should be taken in installing the access tube to ensure that no air voids exist between the tube and the soil matrix. At least 10 cm of the tube should extend above the soil surface, in order to allow the box containing the electronics to be mounted on top of the access tube. All access tubes should be fitted with a removable cap to keep rainwater from entering the tubes. In order to enhance experimental reproducibility, the soil-water content is not derived directly from the number of slow neutrons detected, but rather from a count ratio (CR), given by:

CR = C soil/Cback ground

Where Csoil is the count of thermalized neutrons detected in the soil, and C background is the count of thermalized neutrons in a reference medium. All neutron probe instruments now come with a reference standard for these background calibrations, usually against water. The standard in which the probe is placed should be 0.5 m at least in diameter so as to represent an infinite medium. Calibration to determine background can be done by a series of averaged 10 one-minute readings, to be averaged, or by a single one--hour reading. C soil is determined from averaging several soil readings at a particular depth/location. For calibration purposes, it is best to take three samples around the access tube and to average the water contents corresponding to the average CR calculated for that depth. A minimum of five different water contents should be evaluated for each depth. Although some calibration curves may be similar, a separate calibration for each depth should be conducted. The lifetime of most probes is more than 10 years.

Neutron probes are highly accurate and are mainly used by crop consultants who are licensed to use these instruments. These radioactive sensors emit neutrons which are slowed down by collision with hydrogen in water molecules. The number of slow returning neutrons is used to measure the amount of water in the soil.

3) GAMMA RAY ATTENUATION

Whereas the neutron method measures the volumetric water content in a large sphere, gamma ray absorption scans a thin layer. The dual-probe gamma device is nowadays mainly used in the laboratory since dielectric methods became operational for field use; also because gamma rays are more dangerous to work with than neutron scattering devices, and because the costs of gamma ray operation are relatively high. Changes in gamma attenuation for a given mass absorption coefficient can be related to changes in total soil density. As the attenuation of gamma rays is due to mass, it is not possible to determine water content unless the attenuation of gamma rays due to the local dry soil density is known and remains unchanged with changing water content. Determining accurately the soil-water content from the difference between the total and dry density attenuation values is therefore not simple.

4) Soil-water dielectrics

When a medium is placed in the electric field of a capacitor or a waveguide, its influence on the electric forces in that field is expressed as the ratio between the forces in the medium and the forces, which would exist in vacuum. This ratio, called permittivity or ”dielectric constant‘, is for liquid water about 20 times larger than for average dry soil, because water molecules are permanent dipoles. Dielectric properties of ice, and of water which is bound to the soil matrix, are comparable to those of dry soil. Therefore the volumetric content of free soil water can be determined from dielectric characteristics of wet soil by reliable, fast, non-destructive measurement methods, without the potential hazard associated with radioactive devices. Moreover such dielectric methods can be fully automated for data acquisition. At present, two methods which evaluate soil-water dielectrics are commercially available and used extensively, namely time-domain reflectometry and frequency domain measurement.

5) TIME DOMAIN REFLECTOMETRY (TDR)

Time-domain reflectometry is a method which determines the dielectric constant of the soil by monitoring the travel of an electromagnetic pulse, which is launched along a waveguide formed by a pair of parallel rods embedded in the soil. The pulse is reflected at the end of the waveguide and its propagation velocity, which is inversely proportional to the square root of the dielectric constant, can be measured well by actual electronics. Soil-specific calibration is desirable for soils with low density or with much organic content. The coaxial cable from the probe to the signal processing unit should not be longer than about 30 m. Soil-water profiles can be obtained from a buried set of probes, each placed horizontally at a different depth, linked to a field data logger by a multiplexer.

1.5.3. SOIL-WATER POTENTIAL INSTRUMENTATION

The basic instruments capable of measuring matric potential are sufficiently inexpensive and reliable to be used in field-scale monitoring programmes. However, each instrument has a limited accessible water potential range. Tensiometers only work well in wet soil, while resistance blocks do better in moderately dry soil.

i. Tensiometers

The most widely used and least expensive water-potential measuring device is the tensiometer. Tensiometers are simple instruments, usually consisting of a porous ceramic cup and a sealed plastic cylindrical tube connecting the porous cup to some pressure-recording device at the top of the cylinder. They measure the matric potential, because solutes can move freely through the porous cup. The tensiometer establishes a quasi-equilibrium condition with the soil -water system. The porous ceramic cup acts as a membrane through which water flows, and therefore must remain saturated if it is to function properly. Consequently, all the pores in the ceramic cup and the cylindrical tube are initially filled with de-aerated water. Once in place, the tensiometer will be subject to negative soil -water potentials, causing water to move from the tensiometer into the surrounding soil matrix. The water movement from the tensiometer will create a negative potential or suction in the tensiometer cylinder that will register on the recording device.

Figure 1.6: Tensiometer

ii. Resistance blocks

Electrical resistance blocks, although insensitive to water potentials in the wet range, are excellent companions to the tensiometer. The most common block materials are nylon fabric, fiber glass, and gypsum, with a working range of about 50 kPa (for nylon) up to 1500 kPa (for gypsum). Gypsum blocks are less sensitive to soil saltiness effects because the electrodes are consistently exposed to a saturated solution of calcium sulphate. Resistance blocks do not protrude above the ground and so are excellent for semi-permanent agricultural networks of water potential profiles, if installation is careful and systematic. When installing the resistance blocks it is best to dig a small trench for the lead wires before preparing the hole for the blocks, in order to minimize water movement along the wires to the blocks. A possible field problem is that shrinking and swelling soil may break contact with the blocks. On the other hand, resistance blocks do not affect the distribution of plant roots. Resistance blocks are relatively inexpensive. However, they do need to be calibrated individually. This is generally accomplished by saturating the blocks in distilled water and then subjecting them to a predetermined pressure in a pressure-plate apparatus, at least at five different pressures before field installation. Unfortunately, the resistance is less on a drying curve than on a wetting curve, generating hysteresis errors in the field because resistance blocks are slow to equilibrate with varying soil wetness. As resistance-block calibration curves change with time, they need both to be calibrated before installation and to be checked regularly afterwards, either in the laboratory or in the field.

Figure 1.7: Electrical Resistance Blocks & Meters

iii. Water Potential Sensors

This measures how hard it is for plants to remove water from the soil. Readings from these sensors give farmers an idea of the how much water is available to the plant and when to irrigate. Water content sensors measure the amount of water in the soil. They do this by measuring the time it takes for a signal to pass between two metal electrodes. The more water there is in the soil, the quicker the signal passes between the electrodes. Sensors can be accurate to within 2-3% of the actual soil moisture, but must be calibrated correctly. Currently different research output demonstrates about Wetting Front Detector (WFD) which was developed in an attempt to attain maximum simplicity for an irrigator, especially those farmers who cannot read and write. The Wetting Front Detectors are the mechanical version having a float visible at the surface to provide the signal that a wetting front had reached the prescribed depth. The WFD comprises a specially shaped funnel, a filter and a mechanical float mechanism. The funnel is buried in the soil within the root zone of the crop. When the soil is irrigated, water moves downwards through the root zone. The infiltrating water converges inside the funnel and the soil at the base becomes so wet that water seeps out of it, passes through a filter and is collected in a reservoir. This water activates a float, which in turn operates an indicator flag above the tool.

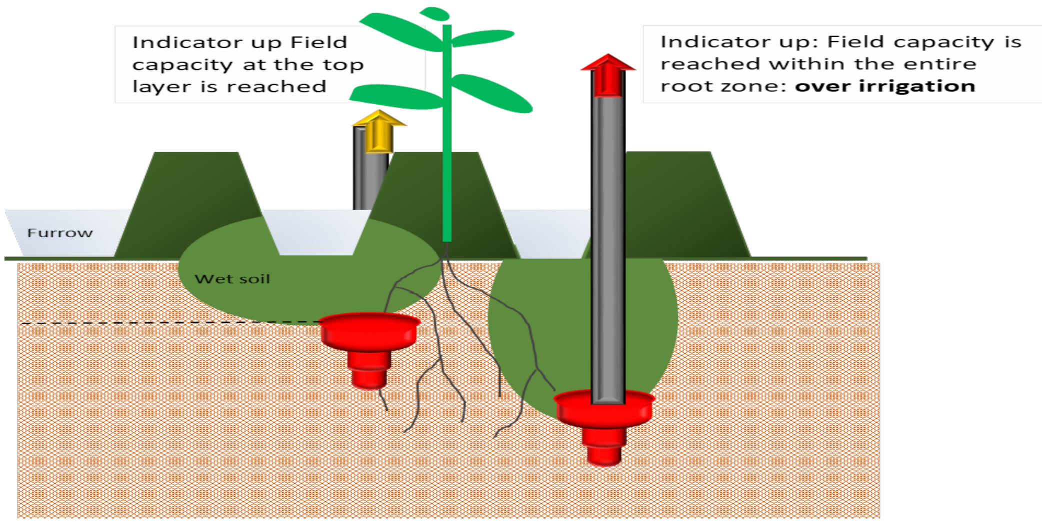


Figure 1.8 Schematic representation of Water Front Detector (WFD)

iv. Remote sensing of soil moisture measurement

A single observation location cannot provide absolute knowledge of regional soil moisture, but only relative knowledge of its change because soils are often very heterogeneous. However, nowadays measurements from space-borne instruments using remote sensing techniques are available for determining soil moisture in the upper soil layer. This allows interpolation at mesoscale for estimation of evapotranspiration rates, evaluation of plant stress and so on, and also facilitates moisture balance input in weather models. Two uncommon properties of water in the soil make it accessible to remote sensing. First, as already discussed above in the context of TDR, the dielectric constant of water is an order of magnitude larger than that of dry soils at microwave lengths. In remote sensing this feature can be used either passively or actively. Passive sensing analyses the natural microwave emissions from the Earth's surface, while active sensing refers to evaluating backscatter of a satellite-sent signal. The second remote-sensible feature of soil water is its relatively large heat capacity and thermal conductivity. Therefore moist soils have a large thermal inertia. So, if cloudiness does not interfere, remote sensing of the diurnal range of surface temperature can be used to estimate soil moisture.

UNIT 2

IRRIGATION WATER REQUIREMENTS, SCHEDULING AND METHODS

2.1. DETERMINATION OF CROP WATER REQUIREMENT

Crop water requirements refer to the amount of water required to raise a successful crop with optimum yield in a given period or season. In another words crop water requirement is defined as “the depth of water needed to meet the water loss through evapotranspiration of a disease- free crop growing in large fields under no- restricted conditions including soil water and fertility and aimed at achieving full production potential of the crops under consideration. It comprises the water lost as evaporation from the crop field, water transpired and metabolically used by crop plants, water lost during application which is economically unavoidable, but can be reduced to some extent and the water used for special operations such as for land preparation and for leaching to bring the salinity level of the soil to salt tolerance level of the crop.

Water is one of the most critical inputs for obtaining maximum production of crops. Each crop has its own water requirement and maintains its own tolerance limits within which the moisture variations don’t affect crop yields. Therefore, the moisture availability in the root zone of the crop could be maintained within the crop tolerance limits by adopting proper water management practices.

Crop water requirements are normally expressed by the rate of evapotranspiration (ET) in mm/day or mm/period and this may be formulated mathematically as:

$$CWR=E+T+IP+W_m+W_u+W_s=ET+W_m+W_u+W_s=CU+W_u+W_s$$

Where: CWR = Crop Water Requirement
E = evaporation from crop field
T = transpiration by crop plants
IP = intercepted precipitation by crop plants that gets evaporated

W_m = water metabolically used by crop plants to make their body weight

W_U = economically unavoidable water losses during application (seepage, evaporation & percolation)

W_S = water applied for special operations /pre- irrigation, leaching, etc

ET = evapotranspiration from crop field, E+T+IP
CU = consumptive use of water by the crop, ET + Wm

The water required by crops is essentially met from rainfall /precipitation/, irrigation, soil water and ground water sources. Considering the different source of water the water requirement of crops (CWR) may be expressed as,

$$CWR = P + I_r, + \Delta SW + \Delta GW - (R + PW) \text{ or } CWR = P_e + I_r + \Delta SW + \Delta GW$$

Where: CWR = Crop Water Requirement
P = Precipitation
Ir = Irrigation requirement of crop
ΔSW = Soil water contribution for crop use. Difference between soil water contents at sowing and at harvest

ΔGW = Ground water contribution (usually from shallow water table)

R = Run-off
PW = Deep percolation
Pe = Effective rainfall

Effective rainfall is the portion of rainfall that goes to the soil water reserve for use of crops. This may be expressed as,

$P_e = p-(R=PW)$
= Rainfall - (run off + deep percolation)

In fact, not all precipitation received is being used by crop plants; there are losses through surface run- off and deep percolation beyond the active root zone, as part of an ineffective rainfall.

Actual crop evapotranspiration involves the use of a crop factor called; crop coefficient (Kc) while computing it from reference crop (ETO) estimated by different empirical formulae or evaporation rates from evaporimeters. The ETC varies under different soil water and atmospheric conditions and at different stages of crop growth, geographical locations and periods of the year.

The crop Evapotranspiration is formulated mathematically as:

$$ET_c = ET_0 x\, K_c$$

Where:	ETC	=	Crop Evapotranspiration
	ETO	=	Reference Crop Evapotranspiration
	KC	=	Crop coefficient

Overall, the calculation procedures of crop water requirements should follow the following steps:

(1) Reference crop evapotranspiration (ETO): Collect and evaluate available climatic and crop data; based on meteorological data available and accuracy required, select prediction method to calculate ET0. Compute ETO for each 30-or 10-day using mean climatic data;

(2) Crop coefficient (kc): Select cropping pattern and determine time of planting, rate of crop development, length of crop development stages and growing period. Then select kc for a given crop and stages of crop development under prevailing climatic conditions;

(3) Crop evapotranspiration (ETC): Calculate ETC for each 30- or 10- day period using the formula:

2.1.1. SELECTION OF CROP COEFFICIENT

As discussed earlier, the reference crop evapotranspiration (ETo) has been determined using different prediction methods. The reference crop evapotranspiration (ETo), then further related to the effect of crop characteristics, crop coefficients- kc in order to determine the crop water requirements (ETcrop). The crop coefficient value (kc) relates to evapotranspiration of a disease- free crop grown in large fields under optimum soil water and fertility conditions and achieving full production potential under the given growing environment. The crop coefficient (Kc) is crop specific and used to modify potential evapotranspiration of a particular crop in relation to ET0. The value of Kc largely depends on the level of ground cover and the frequency with which the soil is wetted by rain and/or irrigation. For most crops, Kc increases from a low value (0.5–0.9) during the initial stages of growth, to a maximum value (0.9–1.2) during the period when the crop reaches full development, and declines again (0.3–0.9) as the crop matures. The factors that affect the crop coefficient values are: (1) Sowing dates; (2) Stages of crop development and length of each growth stage; (3) Length of total growing season; (4) Crop characteristics and (5) Climatic conditions.

The effect of crop characteristics on the relationship between ETcrop and ET0 is summarized as variations of crops, due to the resistance to transpiration and differences in crop height, roughness, reflection and ground cover. The crop planting or sowing date will affect the length of the growing season, the rate of crop development to full ground cover and onset of maturity. Crop development will also affect the overall ETcrop, since there are time variations of crops to reach full development or maximum water demand. Therefore, in selecting the appropriate kc value for each period or month in the growing season for a given crop, the rate of crop development must be considered. In addition, climatic conditions, especially wind and humidity should also be considered. Wind will affect the rate of transpiration of taller crops more, due to air turbulence above the rougher crop surface. This is more pronounced in dry climates than in humid climates and KC values for rougher crop surfaces are, therefore, greater in dry climates. Once the total growing period is known, then the duration of the various stages of growth of a crop can be determined. The crop growing period, in general is divided into four stages: initial stage, crop development stage, mid- season stage and late season stage. Descriptions of the four crop development stages are indicated in Table-1.

Table-1: Description the Four Crop Growth Stages

Crop development stages	**Distinguishable characteristics**
Initial stage	This is a period from sowing or transplanting through germination and plant emergence until about 10 % ground cover is achieved. Water loss is practically all evaporation at this time
Crop development	This period starts from the end of initial stage to attainment of effective full ground cover (ground cover @ 70 - 80 %
Mid- season stage	This period starts at the end of crop development stage to the time of start of maturing /ripening/ of a crop as indicated by discoloring of leaves or leaves falling off. The crop is physiologically capable of the highest water use during this time. The crop coefficient is therefore, highest at this particular growth stage of crops.
Late- season stage	This period starts at the end of mid- season stage until full maturity or harvesting of a crop.

The steps that should be followed to determine kc values or crop factor for different crops are:

- Establish planting date from local information: This may vary significantly from dry land to irrigated conditions, well fertilized to non-fertilized crops, and even for plantings at different times;
- Establish the length of the crop development stages: Collect information on the length of each crop development stage from local information sources; local research centers and extension service, interviews with farmers and agricultural technicians, or crop data from similar climatic zones can be used to establish the crop development stages. Very often research or extension personnel or farmers do not typically record these data, therefore, it is often necessary to correlate these dates with more identifiable crop growth characteristics. For example, for grain crops, 10% ground cover is usually reached from 10 to 15 days after emergence. Effective cover for annual crops occurs approximately at the time of flowering. Discoloring or dropping of leaves indicates the start of maturity for many crops. At the end the total growing period of a given crop should be determined.
- Determine the KC values for the corresponding growth stages: Kc values are taken from Tables (refer to Annex III Table 37 of this training manual).

Therefore, determine the irrigation requirements for each crop development stage for 30- or 10- days' period, considering the predetermined ET_o and K_c values of the corresponding crop development stages. The value kc varies with development stages of the crop and to some extent with wind and humidity. For most crops, the kc value increases from a low value at the time of emergence to a maximum value during the period when the crop reaches full development, and decline as the crop matures. For most crops the K_c value for the total growing period is between 0.85 and 0.9 with the exception of crops like banana, rice, coffee and cocoa, which have higher values and a lower value for citrus, grape, sisal and pineapple. However, the need to collect local data on the growing period and rates of each crop development stage of irrigated crops is highly important (if local data are not available, use crop coefficients provided in annex III).

Example 4:

Determine the crop water need of tomato, taking into consideration the following data:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec;
ET_o (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5;					

Humidity: Medium (60 %);

Wind speed: Medium (3 m/sec);

Duration of growing period (from sowing) = 150 days and planting date: 1 Feb (direct sowing).

Calculation procedures:

Estimate the duration of the various growth stages, using approximate values of crop growth stages as indicated in Annex IV, Table 38;

Indicate on a Table the ET_o values and the duration of the growth stages;

Crop	Total growing period	Initial st.	Crop dev't	Mid S.	Late S.
Tomato	150	35	40	50	25

Estimate the K_c factor for each of the four growth stages, using Annex II, Table 37 and bearing in mind that the humidity and wind speed are medium and the kc values for the corresponding growth stages are 0.45, 0.75, 1.15 and 0.80;

Calculate on a monthly basis, the crop water need, using the formula: $ET_c = ET_o \times K_c$ (mm/day);

Calculate the monthly and seasonal crop water need (assuming all months have 30 days). Following the calculation procedures described above sample calculations are illustrated how to determine the water requirement of tomato taking into account the available data provided above are shown in Table 2.

Crop- Tomato   Planting date: 1 Feb   harvesting - 30 June

Table-2: Calculation Sheet of crop water need

Parameters	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
ET_o (mm/day)	4.0	5.0	5.8	6.3	6.8	7.1	6.5					
Growth stages		In.st	dev't stage	Mid-season stage		Late stage						
K_c per gr.st.		0.45	0.75	1.15		0.8						
K_c per month		0.45	0.70	0.95	1.15	0.85						
ET_c(mm/day)		2.3	4.1	6.0	7.8	6.0						
ET_c (mm/month)		69	123	180	234	180						
ET_c for growing season = 786 mm (786 mm x 10 m^3 = 7 860 m^3/ha)												

Example 5: Maize, planted 1 May, harvested 31 Aug.; initial stage - 20 days, development stage - 35 days, mid-season stage- 40 days and late season stage- 28 days; wind speed is lighter to moderate and Rh is low.

Calculation: Crop - maize, K_c values are 0.4; 0.75; 1.15 and 0.85 for each crop development stage respectively. So based on the ET_o value obtained earlier using the modified Penman method, which is equal to 5.65 mm/day, then the ET_c can be calculated for each crop development stage using the appropriate K_c values for the respective growth stage using the formula, $ET_c = ET_o$ x kc. Therefore, the calculated ET_c values for each crop development stage of maize are 2.26, 4.24, 6.50 and 4.80 mm/day.

Once the actual crop evapotranspiration or crop consumptive use of water is found, then the next step is to determine the depth of water to be applied. Of course, this depends on the soil type and crop, since different soil types have different water-holding capacity and the availability of water varies depending on the water-holding capacity of the soil. Considering the water holding capacity of the soil and the crop root depth the total water requirement for a particular crop can be determined. For example; if we consider maize crop with rooting depth of 1 m, which is grown in medium textured soil with moisture available capacity of Sa = 140 mm/m, the total water required is: WR = D x Sa = 1.0 m x 140 mm/m = 140 mm, if the allowable depletion for maize is 55 %, then the water required can be determined as: 1.0 m x 140 mm/m x 0.55 = 77 mm.

2.1.2. ESTIMATING REFERENCE CROP EVAPOTRANSPIRATION (ET_O)

The influence of climate on crop water need is given by the reference crop evapotranspiration (ETO). The ET_o is usually expressed in millimeter per unit of time (mm/day, mm/month, or mm/season) and is defined as the rate of evaporation from a large area, covered by green grass, 8 to 15 cm tall, which grows actively, completely shades the ground and which is not short of water. ET_o can be determined using various methods and these include: (i) direct methods, (ii) pan evaporimeter method and (iii) empirical methods. However, the most appropriate method of estimating ETo is the one which generates more reliable results in determining the crop water requirement. In this case, the direct methods, which include the water balance or hydrologic methods such as Lysimetric, field experimentation, soil water depletion or soil moisture studies and the water balance method. These methods are more reliable in generating better results, but require adequate equipment and precise measurements. However, costly, laborious and time consuming, due to they are not widely applied for estimating reference crop water requirement.

Methodologies have been developed to predict the amounts of water needed to obtain optimal crop yields based on climatological data, crop coefficients and to some extent by taking into account the influence of other factors on CWR. Different researchers in the world have been involved and developed various empirical formulae for computing CWR. The panel of experts recommended the adoption of the Penman-Monteith method as a standard in estimating ET_0 and is considered as the more accurate method to calculate ET_0 for periods of 30- day period or as short as 10 days, but not accurate as the direct methods.

i. Pan evaporation method

There exists a close relationship between the rate of consumptive use by crop and the rate of evaporation from properly located pan evaporimeter. Evaporation pan provides a measurement of the combined effect of all atmospheric factors such as temperature, humidity, wind speed and sunshine on evaporation from a specific open water surface. It is, therefore, gives more accurate estimate of short-term change in evapotranspiration computed from it than computed with the empirical formulae that depends on fewer climatic factors. For determination of ET_o data required are mean pan evaporation (E pan in mm/day), estimated values of mean relative humidity in % and mean wind run (U in km/day at 2 m height) and information on whether the pan is surrounded by a cropped area or by dry fallow area. Actually there are different types of evaporation pans being used. However, the best- known evaporation pans are the class- A pan evaporimeter, a standard pan made by US Weather Bureau (circular pan) and the Sunken Colorado pan (square). The class- A pan is, however, most widely used method for determination of ET_o.

The working principles of the class- A pan evaporimeter are summarized as follows: (1) The pan is installed in the field, mounted on a wooden frame elevated 15 cm above ground level so that air may circulate beneath the pan; (2) The pan is filled with a known quantity of water /the surface area of the pan is known and the water depth is measured/, usually 5 cm below the rim; (3) The water is allowed to evaporate during a certain period of time /usually 24 hours/; (4) After 24 hours, the remaining quantity (i.e. water depth) is measured (measurement is usually taken at 7:00 hours in the morning). In addition, rainfall, if any, is measured simultaneously; (5) The amount of evaporation per unit time /the difference between the two measured water depths/ is calculated and this is the pan evaporation rate: E pan (in mm/24 hrs) and (6) Therefore, as the rate of evaporation from pan evaporimeter is higher than that over a large free water surface, the pan evaporation value is multiplied by a pan coefficient, k pan, to obtain the ET_0 over the large free water surface (E_0). The pan has actually 120.7 cm diameter and 25 cm depth.

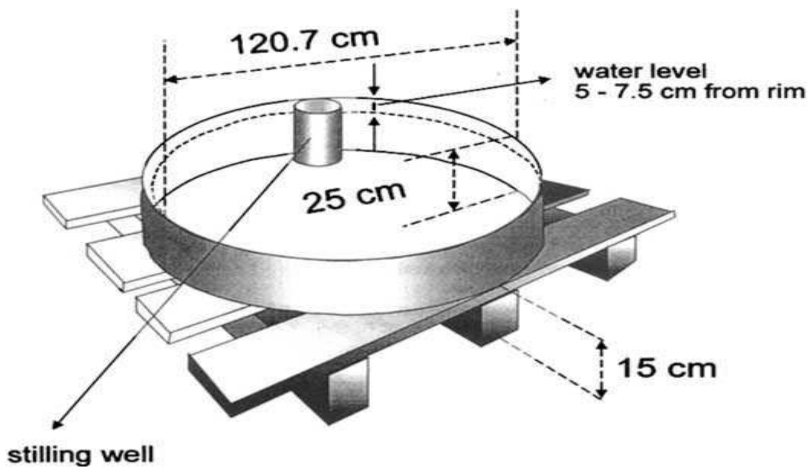


Figure 2.1: Class-A Evaporation pan

For class- A evaporation pan, the k pan varies between 0.35 and 0.85, then on average a commonly used value of k pan is 0.7. For the Sunken Colorado pan, the k pan varies between 0.45 and 1.1 and the average value of k pan is 0.8. The supplier of the pan usually provides details of the pan coefficient. If the pan factor is not known the average value could be used (For further details of k pan, please refer Annex VI Table 47). The pan coefficient, k pan, depends on: The type of the pan used, the pan environment; if the pan is placed in a fallow or cropped area, the climate- humidity and wind speed.

The k pan is high if:	the k pan is low if:
the pan is placed in a fallow area;	the pan is placed in a cropped area;
the humidity is high or humid;	the humidity is low or relatively dry
the wind speed is low	the wind speed is high.

As the rate of evaporation from pan evaporimeter is higher than that over a large water surface, the pan evaporation value for class- A pan is multiplied by 0.7 to obtain the evaporation rate over the large free- water surface (E_o). The relationship between actual evaporation and pan evaporation rates may be expressed as:

Crop evapotranspiration rates (ET_C) for various crops may be estimated from pan evaporation rates multiplied by a factor, called crop factor (K_C). The value of the crop factor for any crop varies with stages of crop growth, extent of ground cover with foliage, foliage characteristics, climate and geographical locations. Consumptive use by crops is usually low at the early stages of crop growth. It increases with the crop vegetative stages and reaching the maximum at flowering and then declines towards the crop maturity. The relationship between pan evaporation rate (E pan) and crop evapotranspiration rate ET_C may be given by:

$ET_O = c[W.R_n + (1\text{-}W).f(u).(ea - ed)]$

Where: ET_O = reference crop evapotranspiration in mm/day

K_{pan} = pan coefficient

E_{pan} = Pan evaporation in mm/day (class A pan).

ET_C = Crop evapotranspiration

K_C = crop coefficient

Example 2:

Given: type of pan – class- A pan, water depth in the pan on day 1 = 150 mm, water depth in the pan on day 2 = 144 mm, no precipitation during 24 hours and k pan = 0.75. Then calculate ET_o:

Calculation: ET_o = k pan x E pan; E pan = 150- 144 = 6 mm/day Þ ET_o = 0.75 x 6 = 4.5 mm/day;

ii. Estimating evapotranspiration by empirical formulae

In view of the difficulties in direct measurement of water requirement of crops, methodologies have been developed to predict the amounts of water needed to obtain optimal crop yields based on climatological data, crop coefficients and to some extent on other factors. Different researchers of the world have been developed various empirical formulae, of which the Blaney- Criddle, Thornwaite, Penman and Radiation methods are commonly used. However, among these, the modified Penman method is the one widely used in estimating ET_0. In general, the modified Penman and Radiation methods are considered as the more accurate methods to obtain more appropriate results even for periods of 30- days or as short as 10 days, but not accurate as that of the experimental method. The empirical formulae make use of only one to several climatic parameters for estimating the PET or ET_0, which is expressed in mm per day and represents the mean value over that period and that way they do not give very accurate estimates.

Table-3: Climatic data required for determination of ET_o using different empirical formulae

Method	Temperature	Humidity	Wind	Sunshine	Radiation	Evaporation	Environment
Blaney-Criddle	*	0	0	0	-	-	0
Radiation	*	0	0	*	(*)	-	0
Penman	*	*	*	*	(*)	-	0
Pan evaporation	-	0	0	-	-	*	*

NB: * - measured data, 0- estimated data, (*) - measured data if available but not essential

Source: FAO, J. Doorenbos and W.O Pruitt, Crop Water Requirement, Irrigation and Drainage Paper (Revised) No. 24, 1977

Primarily, the choice of the method in determining the ET_o using any of the aforementioned empirical formulae must be based on the type of climatic data available and on the accuracy required in determining the water needs of crops. Before calculating ET_c, a review should be made of specific studies to determine crop water requirements in the area and available measured climatic data. In this regard, meteorological and research stations should be visited and environment, types of instruments and observation and recording practices should be appraised to evaluate accuracy of available data. Data related to crop type and development stages, and cultural practices, should be collected.

iii. Modified Penman Method

The modified Penman method is recommended to be adapted for areas where measured data on temperature, humidity, wind and sunshine duration or radiation are available. The Penman method is consisted of two terms: the energy /radiation/ term that include the temperature and sunshine duration, whereas the aerodynamic term includes wind and humidity. The relative importance of each term varies with climatic conditions. In this regard, in more arid regions the radiation term becomes relatively more important than the aerodynamic term, but in humid and sub- humid areas the aerodynamic term becomes more important than the radiation term.

The reference crop evapotranspiration (ET_O) is usually calculated by using Crop Wat software program that uses the FAO (1992) modified Penman- method. The method is given as:

Where	ET_O	=	the reference crop evapotranspiration, mm/day- adjusted
	W	=	temperature and altitude related weighting factor for the effect of radiation on ET_O
	R_n	=	net radiation in equivalent evaporation (mm/day)= R_{ns}-R_{nl}
	R_{ns}	=	net incoming short wave solar radiation = R_A(1-r)(0.25+0.50 n/N) in which R_A is extra –terrestrial radiation expressed in mm/day, n/N is the ratio between n= actual sunshine duration of bright sunshine hours and N = maximum possible duration of bright sunshine hours and r is the reflection coefficient
	R_{nl}	=	Net long wave radiation= f(t) . f(e_d) . f(n/N)
	ea	=	saturation vapor pressure in mbar at the mean air temperature in ^{0}C
	ed	=	mean actual vapour pressure of the air in mbar, ed = ea x RH/100, in which, RH = mean relative humidity expressed in percentage
	f(u)	=	wind function, f(U) = 0.27 (1 + U/100), U is wind speed in km/day measured at 2 m height; = /Table 39/ and mean actual vapour pressure of air (ed) in mbar;
	(I-W)	=	a temperature and elevation related weighting factor for the effect of wind and humidity on ET_0
	(ea- ed)	=	distance between saturation vapour pressure at mean air temperature
	c	=	adjustment factor to compensate for the day and night effects of wind for RHmax and Rs

The procedures to calculate ET_0 may seem rather complicated. This is, due to the fact that the formula involved different measured climatic data or derived from measured related climatic data when there is no measured data available locally. For instance, for places where there is no measured climatic data on sunshine duration, solar radiation or cloudiness observations, humidity and temperature, then these can be obtained from related measured data source, provided very often in literatures, where computation techniques and Table values are given to facilitate the calculations (FAO, Irrigation and Drainage Paper No. 33, J. Doorenbos and A.H. Kassam, 1986). Despite, its accuracy the Penman modified method has drawbacks as the method requires various climatological parameters that may not be available in all meteorological stations and the computation procedure is cumbersome. Furthermore, it is important, here, to highlight that, due to the interdependence of the variables composing the equation, the correct use of units of measurement, in which variables need to be expressed, is essential.

Example 3:

Compute the reference crop ET_0 in mm/day for a given area located at 10^0 N and at an elevation of 1, 000 m, using the modified Penman formula from the data provided below. Given data for the month of April: (1) Monthly average daily maximum temperature, (T max) = 34.4 ^{0}C; (2) Monthly average daily minimum temperature, (Tmin) = 25.6 ^{0}C; (3) Monthly average daily wind speed measured at 2 m, (U_2) = 2 m/s ; (4) Monthly average daily actual duration of sunshine hours (n) = 8.5 h/day; (5) Mean monthly average temperature, (Tmonth, i) = (34.4 + 25.6) /2 = 30 ^{0}C; (6) RH mean for the month of April is 50 % and RH max for the same month is 75 %.

Based on the information or data provided above the calculation procedures is presented in Table 4 below.

Table-4: Standard calculation sheet of ET_0 using the Penman modified method

Parameters	Calculation procedures	Results	Unit
T max	Given	34.4	^{0}C
T min	"	25.6	^{0}C
T mean	T mean = (T max + T min) /2 = (34.8 + 25.6) /2	30.0	^{0}C
Altitude		1, 000	M
U_2	0.27(1 + U/100) ; U_2 = 17.28 km/day, U_2 = wind speed at 2 m height	0.32	
e_a	For T mean = 30 ^{0}C , Table 39	42.4	mbar
e_d	= e_a x RH/100	21.2	mbar
Vapour pressure deficit (e_a - e_d)		21.2	mbar
T max		34.4	^{0}C
Calculation for extraterrestrial radiation and daylight hours (N) for the month of April			
	Latitude = 10^0 N	10^0	N
	Ra = Table 40	15.7	mm/day

Parameters	Calculation procedures	Results	Unit
	N = day length = Table 41	12.3	hours
	n/N = 8.5/12.3	0.69	-
Rs	Rs = (0.25 + 0.50n/N) Ra = [0.25 + 0.50 (0.69)] (15.7)	9.34	mm/day
Rnl	= f(T).f(ed). f(n/N) = (d T max, k^4 + d T min, k^4) /2		
	Tables 42, 43 & 44 = 16.7 x 0.135 x 0.73 =	1.65	mm/day
Rn	Rn = 0.75Rs – Rnl = 0.75 (9.34)– 1.65 =	5.36	mm/day
T April		30.0	^{0}C
W	Tmean = 30 ^{0}C, 1, 000 m; Table 45	0.8	
C	RH max 75 %, Rs = 9.34; Uday/ Unight = 1.5; Table 46	1.06	
ET_o	C{w.Rn + (1-W).f(u).F(ea - ed)		
	= 1.06 {0.8 x 5.36 + (1- 0.8)} x 0.32 x 21.2	5.65	mm/day

Evapotranspiration is influenced by various factors such as climate, growing season, crop characteristics, soil characteristics and cultural practices.

a) Climatic factors

Climate is one of the most important factors determining the crop water requirements needed for unrestricted optimum growth and increased crop yields. The principal climatic parameters such as precipitation, solar radiation, temperature, wind and humidity influence the crop water requirement (ET_c). Precipitation influences the ET_c to the extent that it reaches the soil surface and supplies water to the crop plants. Evaporation and transpiration occur at a potential rate when the supply of water is unlimited and ET_c becomes higher. Solar radiation supplies the energy for the ET processes. With increasing day length or solar radiation evapotranspiration also increased. The rate of ET in any locality is probably influenced more by temperature than any other factor. Temperatures of plant body and soil rise because of increased radiant energy received which leads to increased evaporation (E) and transpiration (T). Unusually low or high temperatures may retard plant growth activities and consequently the transpiration process. Rates of E and T are inversely related with atmospheric humidity, which means the consumptive use of crop plants increases with a fall in relative humidity in any given growing season. Similarly, evaporation from the soil surface and transpiration from plants occur at a higher rate on a windy day than under calm air conditions.

Effect of major climatic factors on crop water needs

Climatic factors	Crop water need	
	High	Low
Sunshine	Sunny /no clouds	Cloudy /no sun
Temperature	Hot	Cool
Humidity	Low /dry	High /humid

Wind speed	Windy	Little wind

As it is clearly indicated in the table above, the highest crop water needs are thus, found in areas, which are hot, dry, windy and sunny conditions. The lowest values are found when it is cool, humid and cloudy with little or no wind. Evaporation losses are much larger in climates where the relative humidity is low. Here, it is clear to understand that a crop grown in different climatic zones will have different water need depending on the prevailing climatic conditions of each specific area. This means that a certain variety of maize crop grown in a cool climate will need less water per day than the same variety grown in a hotter climate. Even, in the same locality, a certain crop variety grown during the cooler months will need substantially less water than the same crop variety grown during the hotter months of the growing season. It is, therefore, useful to take a certain standard crop or reference crop, in this case a grass, and determine how much water the given crop needs per day in various climatic regions or zones.

b) Growing season

The total growing period is defined as the period from sowing or transplanting to the last day of harvesting of the crop. It is mainly dependent on crop type, variety, climate and the planting date. The growing period heavily depends on local circumstances so that data on the duration of the total growing period for various crops grown in the area can best be obtained locally. These data are very valuable for determining the crop water requirements within a specific locality. In general, it can be assumed that the growing period of crops or even a specific crop may have a longer period in cooler climates and shorter in warm climates. This is particularly associated with the effect of temperature, which usually determines the rate of crop development and consequently affects the length of the total growing period required for the crop to form optimum yield.

The length of a crop growing season and the actual date of sowing and maturity are important factors that influence the consumptive use of crop plants, particularly the growing period coinciding with the hotter part of the year. In this regard, crops sown in different seasons have different consumptive use owing variations in crop duration and other factors affecting the consumptive use of a crop. This is explained by the fact that varieties of a crop with short growing cycles will need less water while varieties of the same crop with long growing period need more water as compared with the short duration varieties. Of course, for different varieties of a crop having different growing periods grown in the same locality may have the same water need per day but varieties of a given crop with long duration will need much more water than the short duration varieties of the same crop. This is because the long duration varieties stay longer period in the field. Therefore, the crop-growing period has an important role in determining the ETc.

c) Crop characteristics

Crops have variable ET for variations in their growth habit, canopy development, leaf area index, plant density, spacing, duration and time of the year when the crop is planted and matured, drought tolerance nature of crops and as well as their rooting depths. However, plant species that are short, dense and uniformly vegetated, actively growing, infinite in extent and transpiring under unlimited soil water, have virtually an identical ET. A long period of growth favors greater consumptive use. Crops that have a faster rate of growth habit with quick development of foliage parts and roots have higher rates than those growing slowly. The influence of canopy development is also considerable. As the crop cover increases with canopy development, the evaporation from the adjacent soil surface gradually decreases, while the transpiration and resultant ET increase. Crop density influences the ET in the same way as the crop cover influences the ET. The row spacing, seed rate and ultimate plant population decide the density of a crop. The plant population and other crop management practices that affect the net radiation at the soil surface, change the ET unless the soil surface and plants get constant water supply. With low plant population, the ET is low. Plant height increases ET by greater interception of advective heat.

The crop water needs differ depending on the growth stages of the crop. This in a simpler way can be explained by the fact that a fully-grown crop, for instance maize crop, will need more water than a maize crop, which has just planted. As a general rule, when the crop growth stages increase the water needs of a crop gradually increase and reached at the maximum during the flowering and grain filling stages for most crops, whereas towards the maturity period of the crop the water demand is gradually decreasing and ET is low. During early periods of plant growth, while much of the soil surface is exposed to sun and wind, the moisture loss by evaporation predominates. At later stages of crop maturity, much of the soil surface is shaded and protected from wind. Then transpiration water requirements predominate. Crops with longer duration and with large leaf area need more water than crops with short duration and with smaller leaf area, which need less water. Deep- rooted crops will have the capacity to extract water from deep soil layers and can withstand better of the soil moisture deficit as compared with shallow rooted crops.

d) Soil characteristics

Soil factors such as hydraulic conductivity and water-holding capacity affect ET of a crop to the extent that water supply is maintained to plants and the surface soil. Coarse textured and well- aggregated soils retain less water and have low hydraulic conductivity at relatively higher tensions and as a result, they support less ET compared to fine clays, unless frequent irrigations are provided. Crop residues on the soil surface and light colour and rough surface of the soil decrease the ET by reflecting greater amount of radiant energy. The soil moisture content also influences ET as in the case of moist soil ET increases while in dry soil condition ET decreases.

e) Cultural practices

Irrigation practice is the most important contributing factor to the amount of ET. A wet soil contributes more to the ET than dry soil, since water loss by evaporation increases in the case of wet soil. Frequency, method and depth of irrigation influence the ET to the degree of wetness of the soil surface and water availability attained. Frequent irrigation encourages water loss by evaporation because wet soil increases the rate of evaporation as the surface soil remains wet for relatively longer periods and the soil water is maintained at relatively low suction. Irrigation methods such as surface methods and sprinkler to some extent resulting in wetting larger areas are leading to higher ET as compared with drip systems, which are considered as the most efficient method for economic use of the available irrigation water, so far developed.

Tillage practices play their parts in controlling the ET largely through their effects on water storage in the root zone. Very shallow stirring or cultivation of the surface soil to a few centimeters depth is essential for most short season crops, in order to minimize the effect of evaporation by cutting down the supply of water from deep soil layers to the soil surface by breaking the capillary tubes through which water loss to the atmosphere may occur. However, deep stirring of the surface soil more than 8 to 10 cm may increase the water loss, if the crop cover is sparse. Weed control is also necessary to reduce the water loss through transpiration by weeds. Fertilizer application increases the ET and the consumptive use by producing greater biomass and developing a deeper and extensive rooting system. This is mainly, due to increased transpiration by the greater biomass produced and exploration of greater amount of soil water by the root system. However, the consumptive use is not significantly influenced by fertilizer application. Mulching reduces the ET by reducing the evaporation from the bare soil, particularly in areas with limited water supply and at early crop stages when the crop cover is relatively less, reflecting the solar radiation and reducing the weed population that can affect the overall crop water requirement.

2.1.3. DETERMINATION OF CWR USING COMPUTER SOFTWARE

The reference crop evapotranspiration (ET_O) is usually calculated by using Crop Wat software program 8.0 that uses the FAO Penman-Monteith method. The detail procedures to compute ET_o are as follows.

Step 1: Select the most representative meteorology center for the project area or identify climate data source (make sure that the agro-ecological conditions of the meteorological center or selected site in other data sources have to be compatible with the project area agro-ecology and altitude).

Step 2: Make available long-term average (not < 20 consecutive years) climate data including minimum and maximum temperature, relative humidity, wind speed and sunshine hours. Make sure that the measurement units are compatible with CROPWAT 8.0 software data units. The first priority data source is representative meteorology center or National

Meteorology Agency; then can be moved to satellite based climate dataset like CFSR then New LocClim V10.1 or its latest version can be used if the first two sources are inaccessible. If the agronomist prefer to use other data sources like New LocClim V 10.1, due to inconvenience to the available data or unavailability of representative station then the data of the selected town or meteorology site should be exported to CROPWAT 8.0 climate module data table or data in table format can be saved in working file then should be taken and inserted manually on climate module format.

Step 3: the data availed in “step 2” should be inserted in climate module/table after displaying the climate module by clicking Climate/ETo icon on the right side of CROPWAT 8.0 window. In addition to the climate data, the climate module requires information about the meteorology site: country, station name, altitude, latitude and longitude.

Step 4: Insert the rainfall, soils and crop data in respective modules to run the irrigation and crop water requirement calculation.

Step 5: The CROPWAT 8.0 software will calculate the crop water requirement and scheme irrigation requirement and irrigation schedule for the proposed crops.

The ET loss is taken as crop water use or crop water consumptive use. The ETo computation will be demonstrated with recommendable methods FAO Penman-Monteith method, which can be made with CROPWAT 8.0 software.

a) Calculation Procedures of ET_0 using the Penman-Monteith Equation

For areas where measured data of temperature, humidity, wind and sunshine hours or radiation are available, the Penman-Monteith method is suggested for computing. The Penman-Monteith equation consists of two terms:

- The energy (radiation) term and
- The aerodynamic (wind and humidity) term

The empirical formula for the FAO Penman-Monteith combination equation is mathematically formulated as:

$$ET_o = \frac{0.408\Delta(Rn - G) + y\frac{900}{T + 273}u_2(e_s - e_a)}{\Delta + y\,(1+0.34u_2)}$$

Where ET_o reference evapotranspiration [mm day^{-1}],
R_n net radiation at the crop surface [MJ m^{-2} day^{-1}],
G soil heat flux density [MJ m^{-2} day^{-1}],

T mean daily air temperature at 2 m height [°C],
u_2 wind speed at 2 m height [m s^{-1}],
e_s saturation vapour pressure [kPa],
e_a actual vapour pressure [kPa],
$e_s - e_a$ saturation vapour pressure deficit [kPa],
D slope vapour pressure curve [kPa $°C^{-1}$],
g psychrometric constant [kPa $°C^{-1}$].

The above noted background on basic equation description is for general knowledge to grasp about the data requirement and other calculation procedures if the agronomist decided to calculate the ETo manually or by empirical equation. This guideline suggests computing the ET_o estimation by CROPWAT 8 software:

Input data required for ETo computation

The climate data to be used for reference evapo-transpiration computation for FAO Penman Monteith method are:

- Long-term average maximum and minimum temperature in (^oC)
- Long-term average relative humidity in % or Vapor pressure in Kpa
- Wind speed in kilometers per day or meters per sec
- Sunshine in hours sunshine,(optional in % day length, fraction of day length),
- Radiation to be calculated by default by the software MJ/m^2/day.

The above indicated climate parameters' values can be converted from one unit measurement to other instantly by the software during data entry as required.

With CROPWAT 8 software the ETo can be calculated from temperature data only when only temperature data are available.

b) Source of data

As described in Chapter II, the agronomist able to collect the climate data from meteorology centers, reliable websites, FAO data base like New LocClim V 10.1. The data from this source can be exported to CROPWAT software for analysis. On the other hand, the data from meteorology centers and other datasets like CFSR should be entered manually.

The agronomists should bear in mind that the long-term data from local meteorology centers and re-corrected climate data should be given priority to use for ET_o analysis. Moreover, the latter sources can be used as required where there is deficiency.

c) ETo computing procedures

Computing reference evapotranspiration is the primary step to calculate the crop water requirements of the proposed crops in which it can be undertaken by different software. However, the CROPWAT 8.0 software is recommendable and comprehensive method suggested to calculate CWR for the feasibility study of irrigation projects. The agronomist can collect the climate data and ETo values from the hydrologist or they have to estimate in consultation to provide consistent data

Example demonstration of ETo computation for Bereda Lencha SSIP

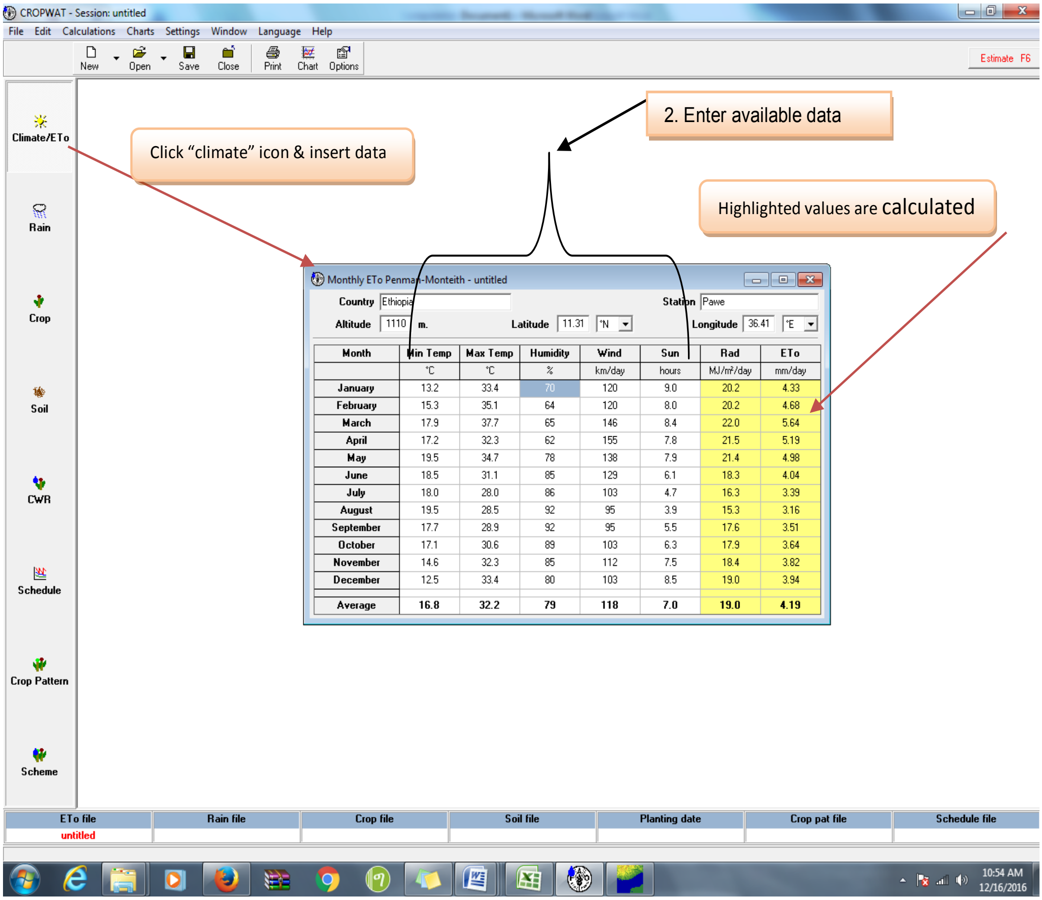
Location: Oromiya National regional State, East Haraghe zone, Gola Oda Wereda, Bereda Lench kebele. Geographical location: The project is located at 8.73 latitude; 41.71 longitudes and altitude: 1300 m.a.s.l.

The closest and representative meteorological station: Burka meteorological station, which is located in lowland agro-ecology.

Select the data source and evaluate the completeness of the climate data: As indicated in step1, the climate data source should be identified based on the meteorological site characteristics similarity with the project area agro-climatic conditions. Accordingly, *Burqa Meteorological station* is selected as a climate data source. It is a lowland agro-ecology found near to the project area.

Once the agronomist ensured the availability of climate data then he shall arrange and insert the monthly average data in climate module of CROPWAT 8.0 software. The Evapotranspiration can be calculated in two ways based on the availability of climate data. The first option is when all the required climate data are available (Fig 2.2) while the second option is when the meteorology centers provide only temperature data (Fig 2.3). Some examples are presented below.

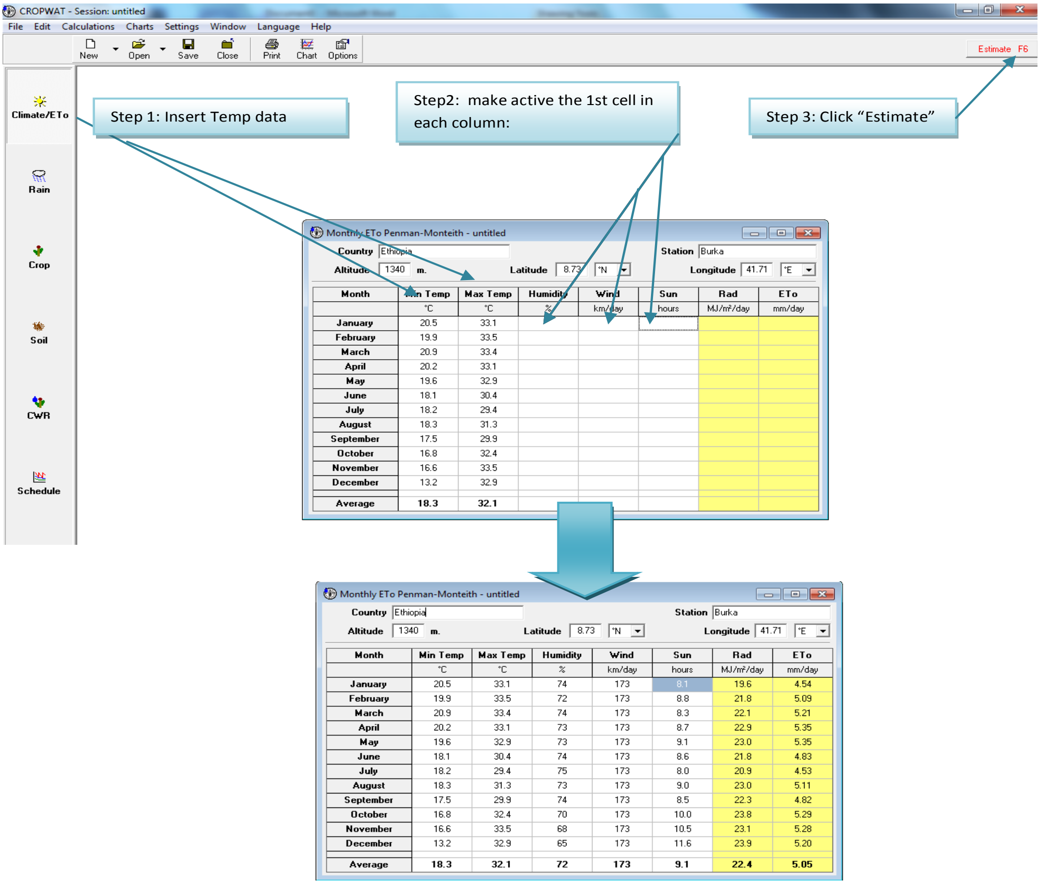
Option 1: the Evapotranspiration calculated by feeding all the above-indicated data including Temperature, Humidity, Wind speed and Sunshine hours as demonstrated in figure below:



Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	13.2	33.4	70	120	9.0	20.2	4.33
February	15.3	35.1	64	120	8.0	20.2	4.68
March	17.9	37.7	65	146	8.4	22.0	5.64
April	17.2	32.3	62	155	7.8	21.5	5.19
May	19.5	34.7	78	138	7.9	21.4	4.98
June	18.5	31.1	85	129	6.1	18.3	4.04
July	18.0	28.0	86	103	4.7	16.3	3.39
August	19.5	28.5	92	95	3.9	15.3	3.16
September	17.7	28.9	92	95	5.5	17.6	3.51
October	17.1	30.6	89	103	6.3	17.9	3.64
November	14.6	32.3	85	112	7.5	18.4	3.82
December	12.5	33.4	80	103	8.5	19.0	3.94
Average	16.8	32.2	79	118	7.0	19.0	4.19

Figure 2.2: CROPWAT 8.0 window and climate module for ETo estimation

Option 2: If the meteorological station has only temperature data the CROPWAT 8.0 software can estimate other data such as humidity, wind speed, sunshine hours and radiation.



Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	20.5	33.1	74	173	8.1	19.6	4.54
February	19.9	33.5	72	173	8.8	21.8	5.09
March	20.9	33.4	74	173	8.3	22.1	5.21
April	20.2	33.1	73	173	8.7	22.9	5.35
May	19.6	32.9	73	173	9.1	23.0	5.35
June	18.1	30.4	74	173	8.6	21.8	4.83
July	18.2	29.4	75	173	8.0	20.9	4.53
August	18.3	31.3	73	173	9.0	23.0	5.11
September	17.5	29.9	74	173	8.5	22.3	4.82
October	16.8	32.4	70	173	10.0	23.8	5.29
November	16.6	33.5	68	173	10.5	23.1	5.28
December	13.2	32.9	65	173	11.6	23.9	5.20
Average	18.3	32.1	72	173	9.1	22.4	5.05

Figure 2.3: Evapotranspiration estimation from temperature data (Bereda lencha SSIP)

The CROPWAT 8 software also gives better estimated ETo values for areas with only min and max temperature data by extrapolating the missing climatic data from global database based on the location (Latitude and longitude) and altitude of the site which are specified in climate module.

d) Effective rainfall determination

This can be expressed as: Precipitation = ET + Runoff + deep percolation + Change in total water content. Therefore, mathematically the effective rainfall is expressed as the difference between the total rainfall and that portions of rainfall, which are lost through surface runoff, evaporation and deep percolation (Pe = P – R – ET – DP) and only the water retained in the root zone can be used by the crop plants. As principal water supply for plant growth the effective rainfall should be estimated to calculate irrigation water requirements

Methods for estimation of effective rainfall by CropWat 8.0 software:

Fixed percentage:
Effective rainfall is a fixed percentage of actual rainfall, being calculated according to:

Peff = Percentage xP .... [1]

The fixed percentage is to be given by the user to account for the losses, due to runoff and deep percolation.

In general, the efficiency of rainfall will decrease with increasing rainfall. For most rainfall values below 100 mm/month, the efficiency will be approximately 80%. Unless and otherwise, more detailed information is available for local conditions, it is suggested to select the Option “fixed percentage” and give 80% as requested value, which is the probability of exceedance.

Dependable rainfall (FAO/AGLW formula)
Based on analysis carried out for different arid and sub-humid climates, an empirical formula was developed in the Water Service of FAO to estimate dependable rainfall, the combined effect of dependable rainfall (80% probability of exceedance) and estimated losses, due to Runoff (RO) and Deep Percolation (DP).

This formula may be used for design purposes where 80% probability of exceedance is required. The effective rainfall can be calculated using the following formula: :

Monthly step:

Peff = (0.6 x P) - 10; for Pmonth < 70mm/month .... [2]

If the recorded rainfall amount is less than 70 mm/month, then the effective rainfall (P_e) is calculated as:

P_e = (Px0.7)-10 = (70 x 0.7) – 10 = 39 mm.

Peff = 0.8 x P - 24; for Pmonth > 70mm .... [3]

Decadal rainfall data:
Peff = 0.6 x Pdec - 10/3 for Pdec ≤ (70/3)mm .... [4]
Peff = 0.8 x Pdec - 24/3 for Pdec > (70/3)mm .... [5]

USDA Soil Conservation Service:
Formula developed by USCS, where effective rainfall can be calculated using the following formulae:

Monthly step:

$$Peff = \frac{Pmonth\ (125 - 0.2 \times Pmonth)}{125 \text{ for } pmonth \leq 250mm} \quad \text{[6]}$$

$$Peff = 125 + 0.1 \times Pmonth \text{ for } Pmonth > 250mm \quad \text{[7]}$$

Rainfall not considered in irrigation calculations (Effective rainfall = 0):

The rainfall data is ignored during the calculations of irrigation requirements. For example; in crop water requirement computation for spate irrigation where the contribution of rainfall in that project area is zero then this option shall be considered. Because the proper spate irrigation in arid areas is usually practicing using the runoff transported from highland area, it is not generated from project area rainfall pattern or complemented by scanty rainfall from project area. If there is a rainfall in the project area even if it is scanty then this formula will not be applicable.

In most cases, in Ethiopia the dependable rainfall (FAO/AGLWA formula) option has been preferred by planners because most of the scheme designs have considered the 80% dependable probability for runoff estimation. Among the effective rainfall estimation options incorporated in CROPWAT 8, the second option will be considered in the following presentation or illustration of effective rainfall calculation.

`f) Procedures to calculate the effective rainfall with CROPWAT 8.0 software

Step 1: Open the CROPWAT window and click the Rainfall module
Step 2: choose and click on one of the five calculation options
Step 3: Insert the monthly actual rainfall data obtained from Climate data source manually
Step 4: instantly the software calculate the effective rainfall
Step 5: save in save as mode or copy the “table with headers” by using right click button and paste on Excel format.

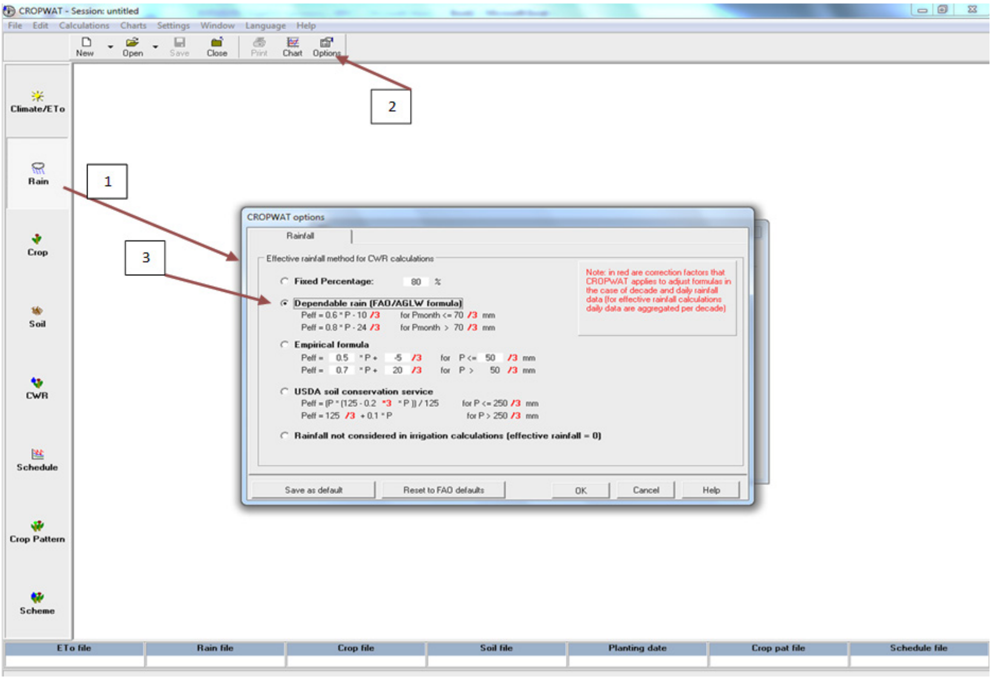


Figure 2.4: CROPWAT 8.0 window with effective rainfall estimation options display

Example 1 Effective rainfall calculation for Bereda Lencha SSI Project:

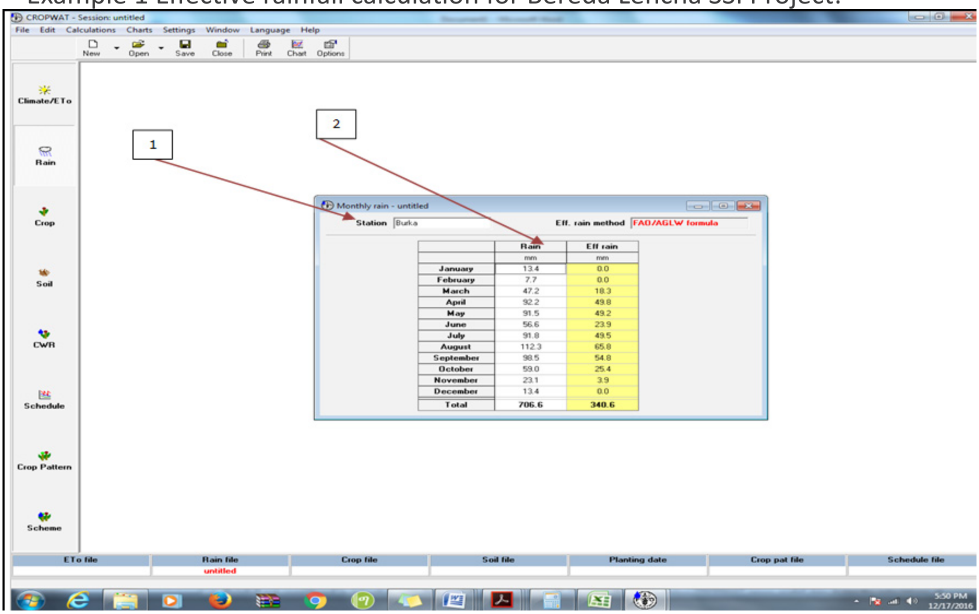


Figure 2.5 : Effective rainfall estimation by FAO AGLW formula

Required crop data for crop water requirement estimation
As a general rule, when the crop growth stages increase the water needs of a crop gradually increase and reached at the maximum during flowering and grain filling stages for most crops, whereas towards the maturity period of the crop the water demand is gradually decreasing and ET is low. During early periods of plant growth, while much of the soil surface is exposed to sun and wind, the moisture loss by evaporation predominates. At later stages of crop maturity, much of the soil surface is shaded and protected from wind. Then transpiration water requirements predominate. Crops with longer duration and with large leaf area need more water than crops with short duration and with smaller leaf area, which need less water. Deep- rooted crops will have the capacity to extract water from deep soil layers and can withstand drought effects.

After calculating the ETo, the next step is to enter the crop data into CROPWAT to enable the program to calculate the crop water requirements for proposed crops. Please, follow the steps to manage the crop data entry.

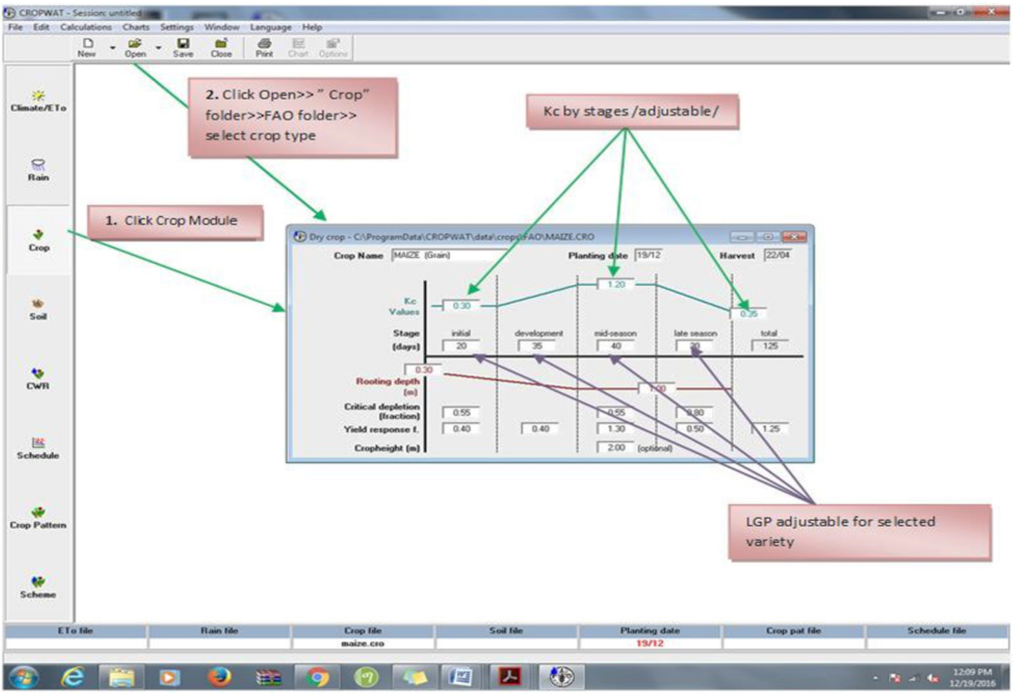


Figure 2.6: CROPWAT 8.0 Windows and Crop Module

h) Planting and harvesting date

Planting and harvesting dates are important input for estimating the crop water requirements. In case of computer program based computation, the harvesting date will be determined by the software from the given planting date and length of growing period.

Box 8
The agronomist is required to set and enter the planting date for each proposed crop and take a note for each crop to transfer the data in cropping pattern module later.
Source of data: the agronomist can refer the planting date from the cropping calendar determined in previous section “cropping pattern” or cropping calendar tables.

i) Crop coefficient (Kc):

ETc is determined by the crop coefficient approach whereby the effect of the various weather conditions are incorporated into ETo and the crop characteristics into the Kc coefficient:

ETc = Kc x ETo ………………………………………………………………………….. [8]

The Kc coefficient incorporates crop characteristics and averaged effects of evaporation from the soil. For normal irrigation planning and management purposes, for the development of basic irrigation schedules, and for most hydrologic water balance studies, average crop coefficients are relevant and more convenient than dual Kc values for transpiration and evaporation from soils separately. *There is usually close similarity in the coefficients among the members of the same crop group, as the plant height, leaf area, ground coverage and water management are normally similar* (FAO ID Paper 56). Here it gives an indication to use the Kc values of crops in the same group having similar plant morphology characteristics.

All crops are not included in the lists of Kc value or in crop data of the FAO CropWat program therefore the Kc values can be collected from research institution where the Kc determination research has been undertaken. In Ethiopia Kc values of limited crops like teff and haricot bean are determined by Ethiopian Institute of Agricultural Research. These research outputs should be used for crop water requirement calculation in any of the methods and some of the available Kc values are presented in this guideline. See Kc values in Appendix XII and Appendix XIII.

j) Length of growth stages

It is one of the crop data can be retrieved from the Crop Wat program while opening the “crop file” from Crop-FAO folder. In most cases, the length of growing period retrieved by default is not compatible to the crop varieties usually grown in different agro-ecologies and released varieties from research institute. Under this condition the Length of growing stages displayed on Crop Module should be adjusted according to the recommended variety growing stage.

The growing period can be divided into four distinct growth stages: initial, crop development, mid-season and late season. See illustration figure 7-6 the general sequence and proportion of the stages

Initial stage

The initial stage runs from planting date to approximately 10% ground cover. The length of the initial period is highly dependent on the crop, the crop variety, the planting date and the climate. The end of the initial period is determined as the time when approximately 10% of the ground surface is covered by green vegetation.

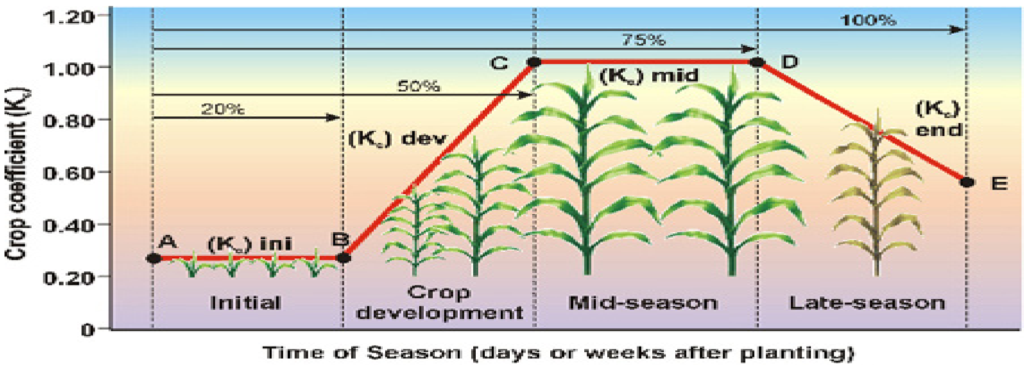


Figure 2.7: Growing stages and Kc distribution

Crop development stage

The crop development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering. For row crops where rows commonly interlock leaves such as beans, sugar beets, potatoes and maize, effective cover can be defined as the time when some leaves of plants in adjacent rows begin to intermingle so that soil shading becomes nearly complete, or when plants reach nearly full size if no intermingling occurs. *Crop development stage ranges from 10% ground cover to 70-80% ground cover by vegetation.*

Mid-season stage

The mid-season stage runs from effective full cover to the start of maturity. The start of maturity is often indicated by the beginning of the aging, yellowing or senescence of leaves, leaf drop, or the browning of fruit to the degree that the crop evapotranspiration is reduced relative to the reference ETo. The mid-season stage is the longest stage for perennials and for many annuals, but it may be relatively short for vegetable crops that are harvested fresh for their green vegetation. At the mid-season stage the Kc reaches its maximum value.

Late season stage

The late season stage runs from the start of maturity to harvest or full senescence. The calculation for Kc and ETc is presumed to end when the crop is harvested, dries out naturally, reaches full senescence, or experiences leaf drop. (Torsten Arnold, 2006).

Table-5: Example: Adjustment for length of growing stage for maize BH 540 variety

Crop	**LGP days determination by development stages**					
	Initial	**Development**	**Mid-season**	**Late season**	**Total**	
Maize	20	35	40	30	125	LGP data from CropWat 8.0
Maize BH 540	25	40	45	34	145	Variety LGP

Table-6: Indicative values of the total growing period

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

Crop rooting depth

For crop water requirement computation the crop module require data at early and late stages of growth. The module of the CROPWAT 8.0 software provides the rooting depth data as default and if the agronomists have different figures or the local research centers provide specific rooting depth for given variety then it's better to rely on local data rather than using the tabulated values. The agronomist can also refer the root depth from Appendix XIV attached in this guideline.

Allowable soil moisture depletion levels

Allowable soil moisture depletion (P) values are considered in crop water requirement that varies by crop types. The P value as other values is available from Appendix XIV in this guideline. The agronomist working with CropWat 8 software, the P values are displayed with other crop data on crop module and possible to adjust as required.

Yield response factors (Ky).

A simple, linear crop-water production function was introduced in the FAO Irrigation and Drainage Paper N_33 to predict the reduction of actual crop yield Y_{actual} under water stress. The ky values for most crops are derived on the assumption that the relationship between relative yield (Y_{actual} / Y_{max}) and relative evapotranspiration (ETc_{real} / ETc_{pot}) is linear and is valid for water deficits of up to about 50 percent or $1 – ETc_{real} / ETc_{pot} = 0.5$

Values for Ky for individual growth periods and for the complete growing season have been included in the FAO Irrigation and Drainage Paper N_33. Water stress during specific growth stages Water deficit of a given magnitude, expressed in the ratio actual evapotranspiration (ETc real) and maximum (potential)

Ky is a factor to estimate yield reductions due to water stress, the Ky value can be referred from FAO ID 33 or use the default figures in CropWat program.

While running the crop module of the CropWat 8 for crop water requirement computation the agronomist should give considerable attention and checking data appropriateness of the figures inserted for sowing date and length of growing stage distribution. After the completion of the data entry the information of each crop should be saved. The print format of the crop data can be retrieved or copied by clicking the print icon and save the ASCII file in……

Make available the crop in crop module   Click print   select ASCII file   click preview icon and save where you need.

DRY CROP DATA

(File: C:\Program Data\CROPWAT\data\crops\Petu SSIP\Haricot-dry.CRO)

Crop Name: Haricot bean dry Planting date: 20/12 Harvest: 08/04

Stage	Initial	develop	mid	late	total
Length	20	30	40	20	110
Kc values	0.40	→	1.15	0.35	
Rooting depth (m)	0.30	→	0.90	0.90	
Critical depletion	0.45	→	0.45	0.60	
Yield response f	0.20	0.60	1.00	0.20	1.15
Crop height (m)		0.40			

Cropwat 8.0 Beta 20/12/16 12:10:03 PM

Figure 2.8: Crop data retrieved from CropWat 8.0 Program

Finally the crop water requirements of the proposed crops will be estimated and presented in crop water requirement format the detail information can be seen by clicking the CWR icon on the left side of the CropWat window.

The CWR information as presented in Fig 7-8 can be only copied and past by "right clicking" for reporting and presentation of the crop water requirement information of individual crops.

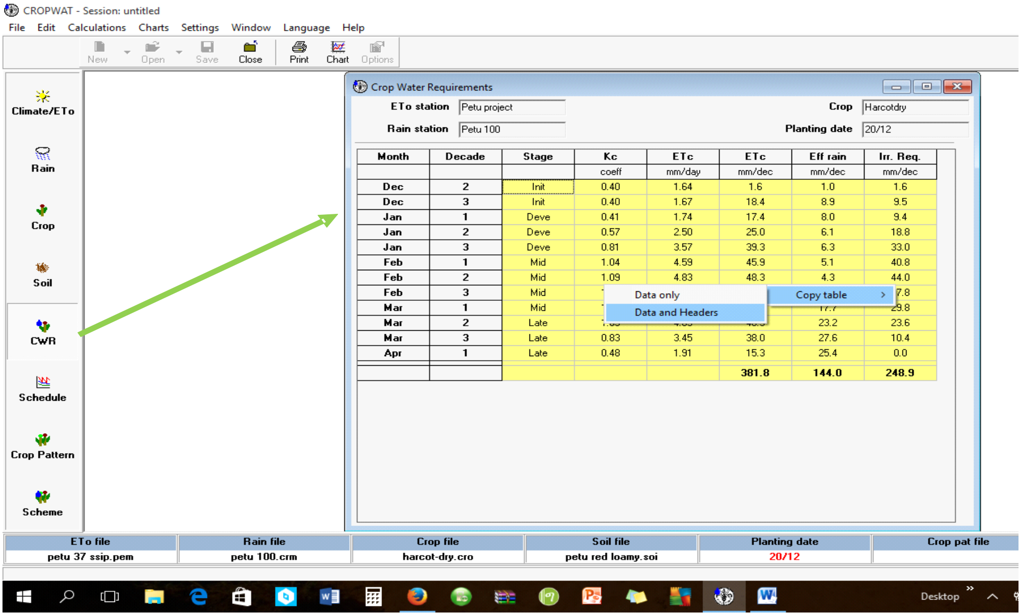


Figure 2.9:Crop water requirement of individual crop as output of crop module

k) Soil data input

The soil data is important in crop water requirement calculation for rice production only in other cases the soil data require for irrigation scheduling in which the CropWat program estimating the available water holding capacity in the root zones of selected crops. The soil module is selected by clicking on the "Soil" icon in the module bar located on the left of the main CROPWAT window. The Soil module is essentially requiring the following soil data, which should be referred from soil survey results of the project:

Total Available Water: It is the difference in water content of soil water content at field capacity and soil water content at wilting in root zone, and it should be expressed in mm/m for crop program computation.

The total available water data should be collected from soil experts after the required soil analysis results. In most of the previous studies the experts have been relied on reference /literature/ recommendations which might lead to ineffective water utilization because of water requirement exaggeration. Therefore, the agronomist and soil expert should pay attention to the TAW and other soil water parameters to be realistic.

Maximum infiltration rate: It is an important soil physical characteristic determining the water holding capacity of the soils. The data also should be sourced from the project area soil analysis results. Here the agronomist should be curious and discuss with soil expert when the result seems not appropriate for given soil type and texture, otherwise the data could mislead the output of the *irrigation requirement of the scheme*. Infiltration rate is expressing in mm/day, and if the data given in m/sec it should be converted to mm/day (use http://www.convertunits.com). Usually the reports are providing in mm/day.

Maximum rooting depth: Maximum rooting depth in most cases be determined by the genetic characteristics of the plant. In some cases, the root depth can be restricted by limiting layers. it is one of the determinant crop factors that can be referred from Appendix XIV for different irrigable crops.

Initial soil moisture depletion: It indicates the dryness of the soil at the start of the irrigation. This expressed as a depletion percentage from total available moisture. The computer program will calculate the initial available soil moisture by considering the moisture depletion percentage and given total available soil moisture (TAM). In most cases, it is recommended to use 50% initial soil moisture deletion.

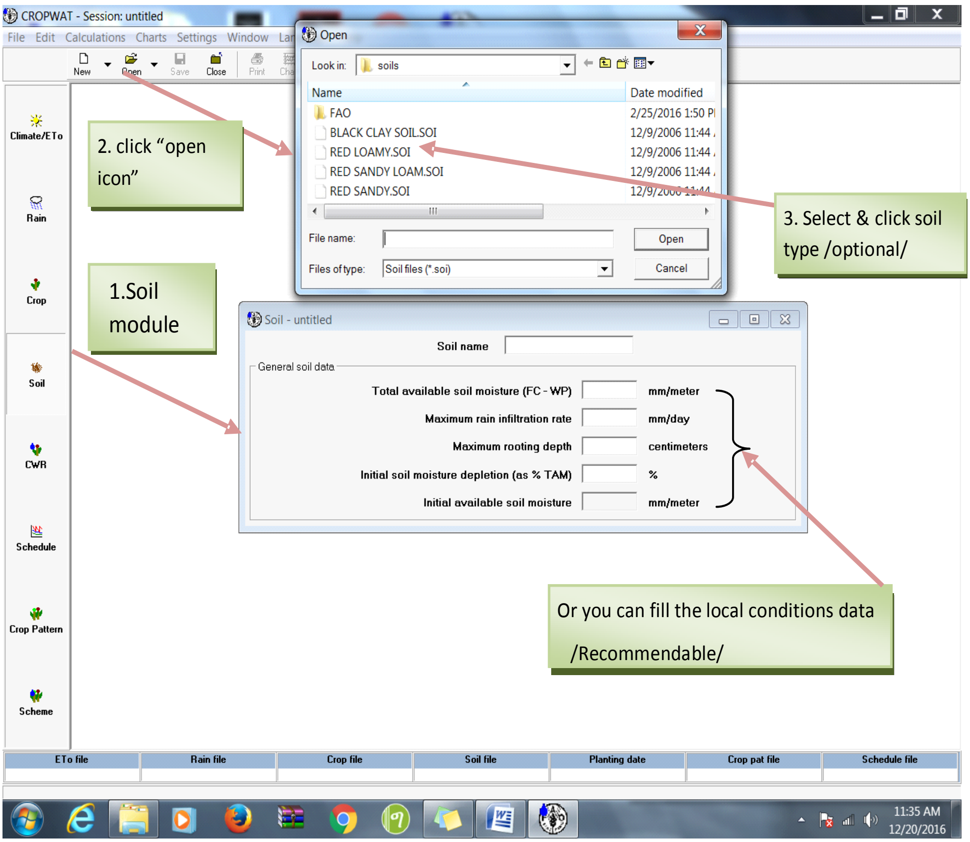


Figure 2.10: Soil data entry process in CropWat 8.0 software

Once the soil data is in place then the computer program will calculate the daily water balance to determine the irrigation schedules of each crop.

I) Cropping pattern input for crop and irrigation water requirements

Cropping pattern is the basic input for irrigation water requirement computation, which needs to be completed after processing the individual crop water requirement determination. The agronomist should transfer the cropping pattern percentage from *cropping pattern section of the report* as presented in crop pattern chapter.

The user has to be aware that cropping pattern module will reject data entry when the total land area with spatial distribution become more than 200%, this indicate that at that particular date the land which you planned to cultivate is not free to accommodate additional crop. Therefore, the agronomist has to readjust the cropping calendar of the proposed crops. The discussion undertaken in cropping calendar section suggested to map the cropping calendar is important at this stage to avoid such overlapping scheduling errors. Once the cropping calendar is approved or checked in previous section, readjustment of the cropping calendar is not required.

To run the cropping pattern module in CropWat window follow these steps:

1. Click the cropping pattern icon at the left side of the CropWat window and display the cropping pattern module (step 1 Fig 11-20)
2. Give file name for cropping pattern file (use the name of the project)
3. Retrieve the crop data from saved crop date file (step 2 Fig 11-20)
4. Insert the planting data of activated crop (make sure this data should be similar with the data given in crop data file) better to have notes on planting dates of all crops. While you enter planting data the module will give the harvesting data based on the previous LGP data (step 3 Fig 11-20)
5. Enter the cropping pattern data and make sure the caution in above paragraph
6. Save the data with project name

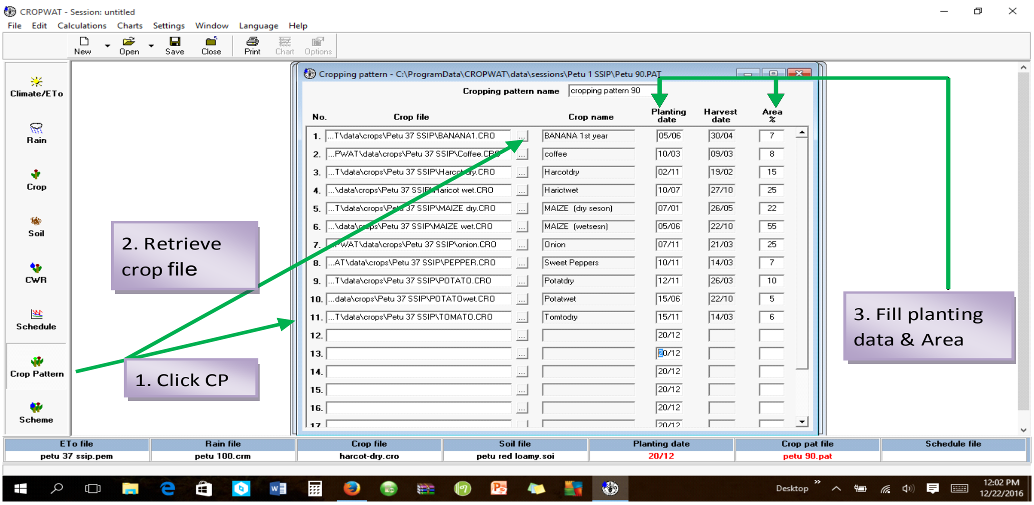


Figure 2.11: cropping pattern data entry procedures

m) Calculating net irrigation requirements

Net irrigation water requirement is the quantity of water necessary for crop growth. It depends on the cropping pattern and the climate. Information on irrigation efficiency is necessary to be able to transfer NIWR into gross irrigation water requirement that consider the water losses.

Irrigation water requirement for a given period is estimated by performing a water balance study for the selected volume of the root zone area and plant canopy. The principal variables include crop water requirement, carry-over moisture at the beginning of the growing season, moisture recharge from ground and effective rainfall. The net irrigation requirement is calculated as follows:

NIR = ETc - (Pe+Wb + Ge) in mm .... [9]

NIR = Net irrigation requirement

Wb = Soil moisture at the beginning of the growing period

Ge = Recharge water from the nearby ground reserve

In most cases, Wb and Ge are neglected and

NIR will be = *NIR = ETc - Pe* .... [10]

n) Net Irrigation Requirement in the Case of Salt Affected Soils

a. Surface and sprinkler irrigation system

It will be determined

IRn = ET crop - R + LR

Where: IRn = Net irrigation requirement
ETcrop = Crop evapotranspiration
R = Water received by plant from sources other than irrigation (for example rainfall)
LR= amount of water required for leaching of salts

b. In drip irrigation system will be determined

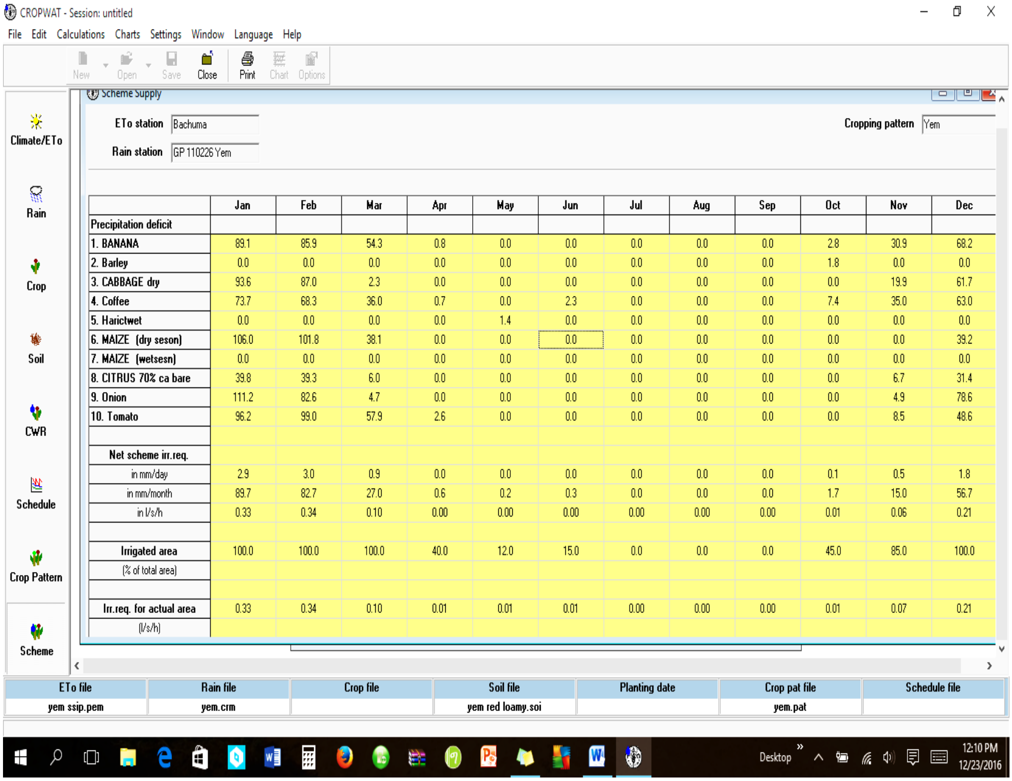
IRn = (ET crop x Kr) - R + LR .... [11]

Where:
IRn = net irrigation requirement
ETcrop = crop evapotranspiration
Kr = ground cover reduction factor
R = water received by plant from sources other than irrigation (for example rainfall)
LR= amount of water required for leaching of salts

o) Cowpat 8.0 software based calculation of Net Irrigation Requirement

In CropWat 8.0 computer program, the Net irrigation requirement is being computed from combined crop water requirement data of the crops which are irrigated in the same months and the results are summarized in Scheme water supply output as illustrated in Figure 7-11. The crop data for each crop in the cropping pattern have to be inserted and saved as indicated in previous section. Based on the available climate and crop data the scheme module of the CropWat program will calculate the following outputs:

- Irrigation requirement of all crops by months
- Net irrigation requirement in mm/day, mm/month, and l/s/h
- Irrigated land area coverage in %
- Irrigation requirement for actual area in l/s/h
- Please see the scheme supply cropwat output below (Fig 11-20)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. BANANA	89.1	85.9	54.3	0.8	0.0	0.0	0.0	0.0	0.0	2.8	30.9	68.2
2. Barley	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0
3. CABBAGE dry	93.6	87.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.9	61.7
4. Coffee	73.7	68.3	36.0	0.7	0.0	2.3	0.0	0.0	0.0	7.4	35.0	63.0
5. Harictwet	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6. MAIZE (dry seson)	106.0	101.8	38.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.2
7. MAIZE (wetsesn)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8. CITRUS 70% ca bare	39.8	39.3	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	31.4
9. Onion	111.2	82.6	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	78.6
10. Tomato	96.2	99.0	57.9	2.6	0.0	0.0	0.0	0.0	0.0	0.0	8.5	48.6
Net scheme irr.req.												
in mm/day	2.9	3.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.8
in mm/month	89.7	82.7	27.0	0.6	0.2	0.3	0.0	0.0	0.0	1.7	15.0	56.7
in l/s/h	0.33	0.34	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.21
Irrigated area (% of total area)	100.0	100.0	100.0	40.0	12.0	15.0	0.0	0.0	0.0	45.0	85.0	100.0
Irr.req. for actual area (l/s/h)	0.33	0.34	0.10	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.07	0.21

Figure 2.12: Monthly crop water and Net irrigation requirements outputs

Further the agronomists will determine the gross water requirement of the scheme considering the project irrigation efficiency and net irrigation requirement.
Determination of irrigation efficiency
Setting the irrigation efficiency

Irrigation efficiency refers to the amount of water removed from the water source that is used by the crop. This value is determined by irrigation system management, water distribution characteristics, crop water use rate, weather and soil conditions. The amount of loss depends on the efficiency of the irrigation system. There are three basic irrigation efficiency concepts.

These are:

$$\textit{Conveyance efficency (Ec)} \; \frac{\textit{Water received at inlet to block of fields}}{\textit{Water released from the headwork}} \quad \ldots\ldots\ldots\ldots\ldots [12]$$

$$\textit{Distribution efficency (Ec)} \; \frac{\textit{Water received at fields inlet}}{\textit{Water released at inlet to block of fields}} \quad \ldots\ldots\ldots\ldots\ldots [13]$$

$$\textit{Application efficency (Ea)} \; \frac{\textit{Water stored in the root zone}}{\textit{Water received at field inlet}}$$

Project efficency (Ep) = Ec x Ed x Ea .... [14]

In consultation with the irrigation engineer about the designed structures and their efficiency, the agronomist and the engineers should jointly set the conveyance, distribution and field efficiencies.

Table-7: Conveyance, field canal and field application efficiencies (Adapted from: FAO, 1992)

1	Conveyance efficiency (Ec)	Efficiency
1.1	Continuous supply with no substantial change in flow	0.9
1.2	Rotation supply in projects of 70-300 ha, with effective water management	0.65 – 0.70
2	Field canal efficiency (E_d)	
2.1	Blocks larger than 20 ha	
	Unlined	0.8
	lined or piped	0.9
2.1	Blocks up to 20 ha :	
	Unlined	0.7
	lined or piped	0.8
3	Field application efficiency (Ea)	
3.1	Surface methods	
	light soils	0.55
	medium soils	0.7
	heavy soils	0.6
	Graded border	0.6-0.70
	Basin and level border	0.60-0.80
	Contour ditch	0.50-0.55
3.2	Sprinkler :	
	hot dry climate	0.6
	moderate climate	0.70-0.60
	humid and cool	0.8

Source: FAO-SFAR Irrigation Manual 2006

Example for project efficiency: Based on Yem SSIP database located in SNNPR, Bench Maji zone in Bachuma wereda (the conveyance and distribution structures are lined with furrow irrigation application method)

<u>Given:</u>
Conveyance efficiency Ec = 95%;
Distribution efficiency Ed = 85% and

Field application efficiency Ea = 60%
Project efficiency refer (equation 10.9.2 a)
= 0.95 x 0.85 x 0.60
= 0.48 or 48%

q) Gross irrigation water requirement

It is the net irrigation requirement plus water distribution and application losses in the irrigation system. This can be determined at the outlet head or canal head regulator for calculating the design discharge capacity of the main off taking canal. The losses generally depend upon lined network or unlined network, the surface area and the ground percolation. The agronomist expected to calculate the gross irrigation requirement considering the project irrigation efficiency.

Gross irrigation water requirement (GIR) estimation

The gross irrigation requirement is computed based on the net irrigation requirements and proposed project and field application efficiency depends on the purpose of the computation.

If the focus of the analysis is to get the gross requirement at project level then the formula will be:

GIR = NIR/Ep .... [15]

If the gross irrigation requirement at field level is required then the field application efficiency will be considered for computation:

GIR = NIR/Ea .... [16]

This formula mainly applied at operation and implementation level to compute various parameters at field level.

Table-8: Gross Irrigation Requirement computation based on Cropwat 8.0 scheme supply outputs

Precipitation deficit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. BANANA 1st year	88.9	85.7	54	0.8	0	0	0	0	0	2.7	30.7	68
2. Barley	0	0	0	0	0	0	0	0	0	1.8	0	0
3. CABBAGE	92.6	86.4	2.4	0	0	0	0	0	0	0	19.9	61.3
4. Coffee	73.9	68.5	36.1	0.8	0	2.3	0	0	0	7.4	35	63.1
5. Haricot bean	0	0	0	0	1.4	0	0	0	0	0	0	0
6. MAIZE (dry season)	105.5	101.4	37.7	0	0	0	0	0	0	0	0	39
7. MAIZE (wet season)	0	0	0	0	0	0	0	0	0	0	0	0
8. MANGO	88.6	81	43.8	1.8	0	0	0	0	0	14.8	48.1	76.9
9. Onion	110.4	82.5	4.9	0	0	0	0	0	0	0	4.8	78
10. Tomato	96.3	99.1	58	2.8	0	0	0	0	0	0	8.5	48.6
Net scheme irr. req.												
in mm/day	3	3.1	1	0	0	0	0	0	0	0.1	0.6	2
in mm/month	94.2	86.7	30.8	0.8	0.2	0.3	0	0	0	3.2	19.1	61
in l/s/h	0.35	0.36	0.11	0	0	0	0	0	0	0.01	0.07	0.23
Irrigated actual area %	100	100	100	50	12	15	0	0	0	55	85	100
Irr.req. for actual area in l/s/h	0.35	0.36	0.11	0.01	0.01	0.01	0	0	0	0.02	0.09	0.23
Pro. efficiency (Ep)	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
GIR (irr act % / Ep) for 24hr	0.73	0.75	0.23	0.02	0.02	0.02	0	0	0	0.04	0.19	0.48

The net irrigation requirement calculated for each month should be divided by the proposed project efficiency to get the Gross Irrigation Requirement.

r) Procedures to calculate gross irrigation requirement

1. Consider the Net Irrigation requirement

Transferring the CropWat software scheme supply output by copying to excel format follow this procedure: right click & ➔ copy table ➔ Data and headers and paste in excel file.

2. Determine the project irrigation efficiency (see 8.8.1)
3. Divide the net irrigation requirement by project efficiency (on excel table)
4. Determine the monthly gross irrigation requirements

GIR for January = NIR/Ep = $\frac{0.35 l/s/ha}{0.48}$ = 0.73l/s/h

2.2. IRRIGATION SCHEDULING

Irrigation scheduling is the process of determining when to irrigate and how much irrigation water to apply. The irrigation water will be stored in the root zone and gradually be used by the plants. The irrigation interval has to be chosen in such a way that the crop will not suffer from water shortage.

The soil type influences the maximum amount of water which can be stored in the soil per meter depth of the soil. Sand can store only a little water or, in other words, sand has low available water content. On sandy soils it will thus be necessary to irrigate frequently with a small amount of water. Clay has high available water content. Thus, on clayey soils, larger amounts can be given, less frequently.

The root depth of a crop also influences the maximum amount of water which can be stored in the root zone. If the root system of a crop is shallow, little water can be stored in the root zone and frequent but small irrigation applications are needed. This is the case for most vegetable crops except pepper and tomato. With deep rooting crops more, water can be taken up and more water can be applied, less frequently.

Young plants have shallow roots compared to fully grown plants. Thus, just after planting or sowing, the crop needs smaller and more frequent water applications than when it is fully developed. All plants have very shallow roots early in their development, and the concentration of moisture-absorbing roots of most plants is usually greatest in the upper quarter of the root zone. Further, since roots will not grow into a dry soil, it may be important to measure soil moisture beyond the current root zone to determine irrigation needs associated with full root development. Figure-21 illustrates the typical water extraction pattern in a uniform soil for crop development.

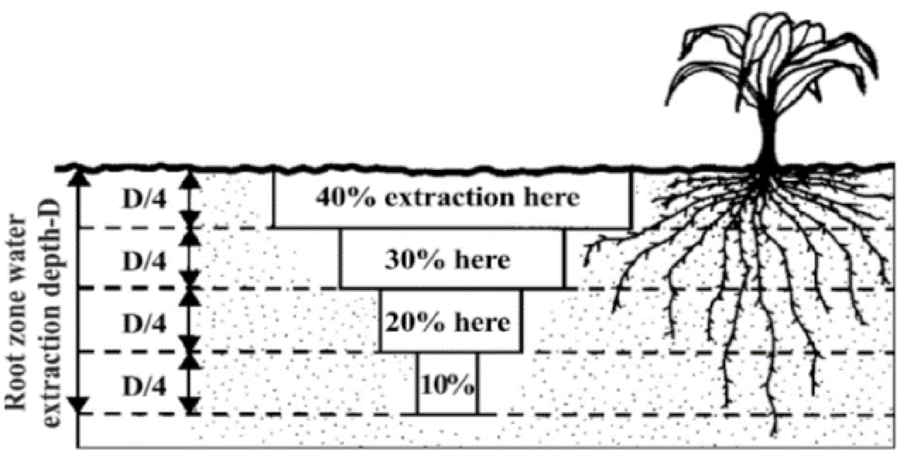


Figure 2.13: typical water extraction pattern in uniform soil profile

2.2.1. FACTORS AFFECTING IRRIGATION SCHEDULING

Following proper irrigation scheduling technique is important for both water savings and improved crop yields. The irrigation water is applied to the cultivated field according to predetermined schedules based upon the monitoring of the soil water status and the crop water need at different growth stages.

- Factors such as:
- Irrigation method;
- slope, type of soil and topography;
- crop type and tillage practices;
- flow rates, irrigation timing and duration;
- availability of irrigation water;

Climatic conditions such as temperature, wind, humidity, and rainfall; are the determining factors to estimate how much water should be applied and when it should be applied to a given crop.

- Effective irrigation scheduling requires knowledge of:
- Soil water-holding capacity,
- current available soil moisture content,
- crop water use or evapotranspiration,
- crop sensitivity to moisture stress at critical crop growth stages,
- availability of irrigation water during the growing period, and
- length of time to irrigate a particular field.

The very basic questions that should be raised and decided upon are therefore:

- Do I need to irrigate the crop?
- When to irrigate the crop?
- How much water should I apply?

If these questions are answered properly, irrigation management will be easy thereafter. Therefore, proper irrigation scheduling based on timely measurement or estimation of soil moisture content and crop water needs, is one of the most important irrigation water management practices.

Table-9: Critical stages of water need for major irrigated crops

Crops	Critical growth stages/periods to water deficit
Maize	Flowering > grain filling > vegetative period, flowering is very sensitive if no prior water deficit
Potatoes	Period of stolonization and tuber initiation > yield formation >early vegetative and ripening
Onions	Bulb enlargement, during rapid bulb growth > vegetative period/and for seed production at flowering
Pepper	Throughout but particularly just prior and at start of flowering
Tomatoes	Flowering > yield formation > vegetative period, particularly during just and after transplanting
Cabbage	During head enlargement and ripening
watermelon	Flowering, fruit filling > vegetative period, particularly during vine development
Beans	Flowering and pod filling, vegetative period, not sensitive when followed by ample water supply
Peas	Flowering and yield formation > vegetative, ripening for dry peas
Pineapple	During period of vegetative growth
Wheat	Flowering > yield formation > vegetative period
Groundnut	Flowering > yield formation, particularly during pod setting
Banana	Throughout but particularly during first part of vegetative period, flowering and yield formation

2.2.2. CRITERIA FOR IRRIGATION SCHEDULING

In a situation, where adequate water is available, farmers often irrigate their crops earlier than the actual time of need, due to their eagerness to obtain good growth and high yield of crops. However, in reality this does not confirm higher yield of crops, since this may lead to waste of valuable water and even can cause damage to crops, due to over irrigation. On the other hand, a delay in irrigation may lead to water stress that might affect the crop yield significantly.

Therefore, optimum scheduling of irrigation based on the crop need of water is considered the right approach to ensure high water use efficiency and obtain a promising high yield of crops. A thorough understanding of the soil- water- plant- atmosphere relationships is essential for proper scheduling of irrigation, since irrigation need of crops are decided by the evaporative demand of the ambient atmosphere, soil water status and plant characteristics. The criteria for scheduling irrigation may be grouped into the following categories:

1. Plant criteria

Plants show up certain characteristic changes in their constitution, appearance and growth behavior with changes in available soil water and atmospheric conditions. These changes are often important indicators for the time of irrigation.

- **General appearance of crop plants:** change of colour, wilting or drooping of plant parts and curling or rolling of leaves.
- **Plant growth:** cell elongation is considered as the growth process that suffers first with water stress in plant. Subsequently, retardation in growth of height or intermodal length occurs.
- **Indicator plant:** sunflower is used to indicate symptoms of water stress before the crop plant is affected by water stress;
- **Stomatal opening:** opening of stomata is regulated by soil- water availability. Stomata remain fully open when the water is adequate and partially or fully closed when there is water scarcity in the soil to reduce transpiration;
- **Plant temperature**: with water deficit in plants, the temperature of leaf tissue is rises.

2. Soil water status criteria

Irrigation scheduling based on soil water content is the most accurate and dependable method. Determination of the available soil- water is rather more important than estimating the total water content of soils. Soil data that must be known to determine the irrigation scheduling include:

- the soil water- holding capacity,
- depths of the different soil layers, and
- the infiltration characteristics of the soil.

Knowledge of soil texture, structure, and organic matter content will also help to determine whether the moisture- holding capacities or the intake rate can be improved. Irrigation is applied when the soil water content reaches the lowest point of optimum soil water regime.

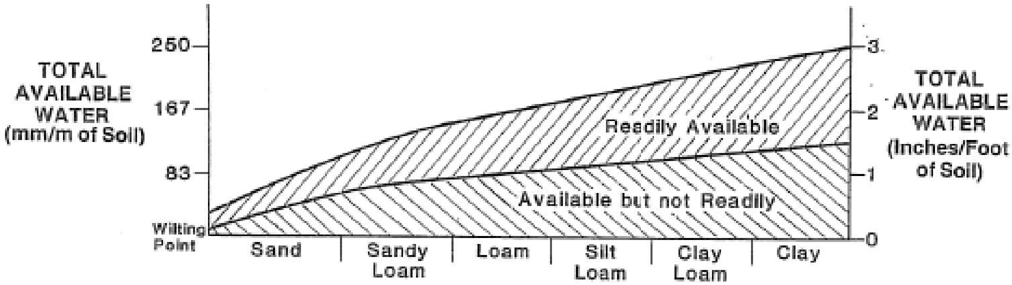


Figure 2.14: Estimated available moisture for various soil textures.

2.3. METHODS OF IRRGTATION SCHEDULING DETERMINATION

Irrigations can be scheduled using methods varying from simple soil water monitoring using the feel and appearance method to sophisticated computer assisted programs that predict plant growth. Crop yield and quality can be improved with most plants by maintaining optimum soil moisture levels.

i) The feel method of monitoring soil moisture

The feel method incorporates the use of a soil probe and the ability of the irrigator to estimate how wet or dry a soil is. Soil textures behave with specific characteristics relative to the amount of water they contain. With experience, an irrigator can provide an accurate description of a soil's moisture content. Following table provides a descriptive guide for determining the available moisture of varying soil textures. By utilizing the feel method, an irrigator can estimate how long the soil moisture reserve will supply a crop without affecting its yield. This is especially crucial during the critical development stages of crops and when determining to shut down the irrigation system prior to harvest.

Soil moisture evaluations by the “Feel” Method

% of available moisture	Sandy loam	Loam	Clay loam
0-25	Dry, loose, flows through finger	Powdery, sometimes slightly crusted but easily broken down into powdery conditions	Hard, baked, cracked; difficult to breakdown into powdery condition
25-50	Appears to be dry, will not form a ball with pressure	Somewhat crumbly, but will hold together from pressure	Somewhat pliable, will ball under pressure
50-75	Tends to ball under pressure but seldom will hold together when bounced in the hand	Forms a ball, somewhat plastic, will stick slightly with pressure	Forms a ball, will ribbon out between thumb and forefinger, has a stick feeling
75-100	Forms a weak ball, breaks easily when bounced in the hand will not stick	Forms a ball, very pliable, stick readily	Easily ribbons out between thumb and forefinger, has a stick feeling
100 (field capacity)	Upon squeezing no free water appears on soil, but wet outline of ball is left on hand, soil will stick to thumb when rolled between thumb and forefinger	Same as sandy loam	Same as sandy loam

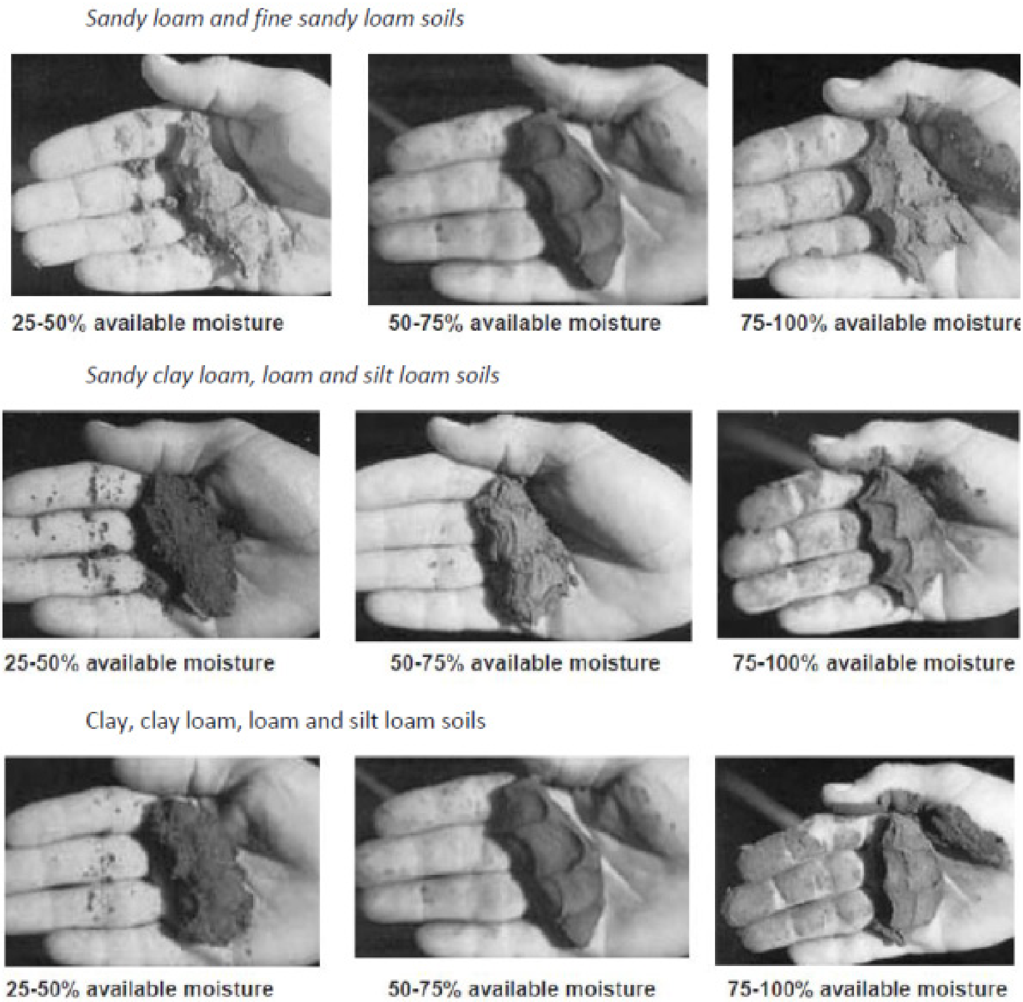


Figure 2.15: feel method of monitoring soil moisture

ii) Plant Observation Method

The plant observation method determines when the plants have to be irrigated on observing changes in the plant characteristics, such as changes in color 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 had come under water stress, its appearance changes from vigorous growth (many young leaves which are light green) to slow or even no growth (fewer young leaves, darker in color, and sometimes greyish and dull). Some crops (such as cassava) react to water stress by changing their leaf orientation: with adequate water available, the leaves are perpendicular to the sun (thus allowing optimal transpiration and production). However, when little water is available, the leaves turn away from the sun (thus reducing the transpiration and production).

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

The disadvantage of the plant observation method is that by the time the symptoms are evident, the irrigation water has already been withheld too long for most crops and yield losses are already inevitable.

It is not advisable to wait for the symptoms. Especially in the early stages of crop growth (the initial and crop development stages), irrigation water has to be applied before the symptoms are evident.

Another indicator of water stress is the leaf temperature. If the leaves are cool during the hot part of the day, the plants do not suffer from water stress. However, if the leaves are warm, irrigation is needed.

iii) Soil Moisture Measurement

Soil moisture measurement method is used to determine the irrigation schedule by measuring soil moisture in the field. When the soil moisture content has dropped to a certain critical level, irrigation water is applied. Instruments to measure the soil moisture include gypsum blocks, tensiometers, neutron probes, wetting front detectors and gravimetric (Details are shown in unit-1).

iv) Computational method

The computational method is an irrigation scheduling decision support system that utilizes the nearest meteorological station data to assist in scheduling irrigation operations.

Step-wise computation of irrigation scheduling for a particular crop

To compute proper irrigation scheduling for crops, it is necessary to know the type of crop, growth stage, effective root zone, available water holding capacity of the soil and daily evapotranspiration rate (ETc) of the crop. Then follow the procedure given below step by step to compute irrigation scheduling.

Step 1. Compute ETo and obtain appropriate Kc-values to get daily ETc,
Step 2. Find out the root zone depth at different growth stages,
Step 3. Find out MAD for selected crops
Step 4. Find out the TAW in the root zone for the respective growth stages
Step 5. Find out the allowable depletion/readily available water
Step 6. Divide step 5 by daily ETc (step 1), this will give irrigation interval in days
Step 7. Multiply step 6 with ETc (step 1). This will give net irrigation requirement for the given growth stage.

v) Literature based Estimation of irrigation schedule

In this section, a table is provided to estimate the irrigation schedule for the major field crops during the period of peak water demand; the schedules are given for three different soil types and three different climates. The table is based on calculated crop water needs and an estimated root depth for each of the crops under consideration. The table assumes that with the irrigation method used the maximum possible net application depth is 70 mm. With respect to soil types, a distinction has been made between sand, loam, and clay, which have respectively, low, medium and high available water content. With respect to climate, a distinction is made between three different climates.

Table-10: available water content in three soil types and reference crop evapotranspiration (ETo) in three different climates

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

An overview indicating in which climate zones of these ETo values can be found is given below:

Table-11 Reference crop evapotranspiration (mm/day)

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

It is important to note that the irrigation schedules given in table below are based on the crop water needs in the peak period. It is further assumed that little or no rainfall occurs during the growing season. Some examples on the use of the information in table 10 are given below.

Examples

1. Estimate the irrigation schedule for groundnuts grown on a deep, clayey soil, in a hot and dry climate? Firstly, the climatic class has to be identified: climate 3 (ETo = 8-9 mm/day) represents a hot climate. The table shows that for climate 3 the irrigation interval for groundnuts grown on a clayey soil is 6 days and the net irrigation depth is 50 mm. This means that every 6 days the groundnuts should receive a net irrigation application of 50 mm.
2. Estimate the irrigation schedule for spinach grown on a loamy soil, in an area with an average temperature of 12º C during the growing season? The average temperature is low: climate 1 (ETo = 4-5 mm/day). The table shows, with climate 1, for spinach, grown on a loamy soil an interval of 4 days and a net irrigation depth of 20 mm.
3. Estimate the irrigation schedule of sorghum grown on a sandy soil, in an area with a temperature range of 15-25º C during the growing season? The average temperature is medium: climate 2 (ETo = 6-7 mm/day). The table shows, with climate 2 for sorghum grown on a sandy soil, an irrigation interval of 6 days and a net irrigation depth of 40 mm.

Table 12: Irrigation interval and net irrigation depth for major crops in shallow, loam and clays soil in different types of climates

S. No.	crops	shallow and/or sandy soil				loamy soil				clayey soil			
		Irrigation interval (days)			Net irrigation depth	Irrigation interval (days)			Net irrigation depth	Irrigation Interval (days)			Net irrigation depth
	Climate	**1**	**2**	**3**	**(mm)**	**1**	**2**	**3**	**(mm)**	**1**	**2**	**3**	**(mm)**
1	Banana	5	3	2	25	7	5	4	40	10	7	5	55
2	Barley/oat	8	6	4	40	11	8	6	55	14	10	7	70
3	Beans	6	4	3	30	8	6	4	40	10	7	5	50
4	Carrot	6	4	3	25	7	5	4	35	11	8	6	50
5	Citrus	8	6	4	30	11	8	6	40	11	8	6	50
6	Coffee	9	6	5	40	13	9	7	60	16	11	8	70
7	Cotton	8	6	4	40	11	8	6	55	14	10	7	70
8	Cucumber	10	7	5	40	15	10	8	60	17	12	9	70
9	Cabbage	3	2	2	15	6	3	2	20	7	5	4	30
10	Egg plant	6	4	3	30	8	6	4	40	10	7	5	50
11	Flax	8	6	4	40	11	8	6	55	14	10	7	70
12	Fruit trees	9	6	5	40	13	9	7	60	16	11	8	70
13	Grains, small	8	6	4	40	11	8	6	55	14	10	7	70
14	Grape	11	8	6	40	15	11	8	55	19	13	10	70
15	Groundnut	6	4	3	25	7	5	4	35	11	8	6	50
16	Lentils	6	4	3	30	8	6	4	40	10	7	5	50
17	Lettuce	3	2	2	15	6	3	2	20	7	5	4	30
18	Maize	8	6	4	40	11	8	6	55	14	10	7	70
19	Melons	9	6	5	40	13	9	7	60	16	11	8	70
20	Onions	3	2	2	15	6	3	2	20	7	5	4	30
21	Peas	6	4	3	30	8	6	4	40	10	7	5	50
22	Peppers	6	4	3	25	7	5	4	35	11	8	6	50
23	Potatoes	6	4	3	30	8	6	4	40	10	7	5	50
24	Safflower	8	6	4	40	11	8	6	55	14	10	7	70
25	Sorghum	8	6	4	40	11	8	6	55	14	10	7	70

S. No.	crops	shallow and/or sandy soil				loamy soil				clayey soil			
		Irrigation interval (days)			Net irrigation depth	Irrigation interval (days)			Net irrigation depth	Irrigation Interval (days)			Net irrigation depth
	Climate	**1**	**2**	**3**	**(mm)**	**1**	**2**	**3**	**(mm)**	**1**	**2**	**3**	**(mm)**
26	Soybean	8	6	4	40	11	8	6	55	14	10	7	70
27	Sugarcane	7	5	4	40	10	7	5	55	13	9	7	70
28	Sunflower	8	6	4	40	11	8	6	55	14	10	7	70
29	Tea	9	6	5	40	13	9	7	60	16	11	8	70
30	Tobacco	6	4	3	30	8	6	4	40	10	7	5	50
31	Tomatoes	6	4	3	30	8	6	4	40	10	7	5	50
32	Wheat	8	6	4	40	11	8	6	55	14	10	7	70

vi) 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 considered. 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 (d) in mm.
Step 2: Calculate the irrigation water need (IN) in mm, over the total growing season.
Step 3: Calculate the number of irrigation applications over the total growing season.
Step 4: Calculate the irrigation interval in days.

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

The net irrigation depth is best determined locally by checking how much water is given per irrigation application with the local irrigation method and practice. If no local data are easily available, Table 11 can be used to estimate the net irrigation depth (d net), in mmwhich gives an indication of the root depth of the major field crops. As can be seen from the table, the net irrigation depth is assumed to depend only on the root depth of the crop and on the soil type. It must be noted that the d net values in the table are approximate values only. Also, the root depth is best determined locally.

Table 13: Approximate net irrigation depths, in mm

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

Table 14: Approximate root depth of the major field crops

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

Not all water which is applied to the field can indeed be used by the plants. Part of the water is lost through deep percolation and runoff. To reflect this water loss, the field application efficiency (ea) is used. The gross irrigation depth (d gross), in mm, considers the water loss during the irrigation application and is determined using the following formula:

$$dgross = \frac{100 \text{ x } dnet}{Ea}$$

Where, d is gross irrigation depth in mm; d net is net irrigation depth in mm and Ea isfield application efficiency in percent.

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

Table 15: field application efficiency for different irrigation methods

Surface irrigation	Ea=60
Sprinkler irrigation	Ea= 75
Drip irrigation	Ea= 90

If, for example, tomatoes are grown on a loamy soil, Tables 11 and 12 shows that the estimated net irrigation depth is 40 mm. If furrow irrigation is used, the field application efficiency is 60% and the gross irrigation depth is determined as follows:

$$dgross = \frac{100 \times 40}{60} = 66.6mm = rounded\ 66$$

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

Assume that the irrigation water needs (in mm/month) for tomatoes, planted 1 February and harvested 30 June, is as follows:

Tomatoes	Feb	Mar	Apr	May	Jun	Total
IN (mm/month)	67	110	166	195	180	718

The irrigation water need of tomatoes for the total growing season is 718 mm. This means that over the total growing season a net water layer of 718 mm has to be brought onto the field.

Step 3: Calculate the number of irrigation applications over the total growing season?

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

Step 4: Calculate the irrigation interval in days

Thus, a total of 18 applications is required. The total growing season for tomatoes is 5 months or 5 x 30 = 150 days. Eighteen applications in 150 days corresponds to one application every 150/18 = 8.3 days. In other words, the interval between two irrigation applications is 8 days. To be on the safe side, the interval is always rounded off to the lower whole figure: for example, 7.6 days becomes 7 days; 3.2 days becomes 3 days.

Conclusion

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

- d net = 40 mm
- d gross = 65 mm
- interval = 8 days

2.3.1. IRRIGATION SCHEDULING USING COWPAT SOFTWARE

Irrigation software packages are becoming more common and accessible that can be used by the agronomists to determine the irrigation schedules, in which CropWat software is considered in this guideline.

The water balance method is used for calculation of irrigation schedules in CropWat 8.0, which means that the incoming and outgoing water flows from the soil profile are monitored. For irrigation scheduling, the program requires data on crop evapotranspiration, rainfall, crop data and soil data.

The schedule module provides many options to be set by the users that can be displayed by clicking the "Option" icon before the start of irrigation schedule determination.

Steps to be followed for determining irrigation scheduling

- After computing the crop water requirement of the first crop choose the schedule module (make active)
- Click "option" icon on main menu tool bar
- Select the appropriate type of irrigation timing
- Select the appropriate type of irrigation application
- Adjust the irrigation efficiency as required which 70% given by default
- The setting will remain the same for all crops

Table-16: Irrigation timing and application alternatives for irrigation scheduling

Irrigation timing options	Irrigation application options
Irrigate at user defined interval	User defined application depth
Irrigation at critical depletion	Refill soil to field capacity
Irrigation below or above critical depletion	Refill soil below /above field capacity

Irrigate at fixed interval per stage	Fixed application depth
Irrigate at fixed depletion	
Irrigate at given ET_c reduction per stage	
Irrigate at given yield reduction	
No irrigation (rainfed)	

Source: FAO, CROPWAT 8.0 software

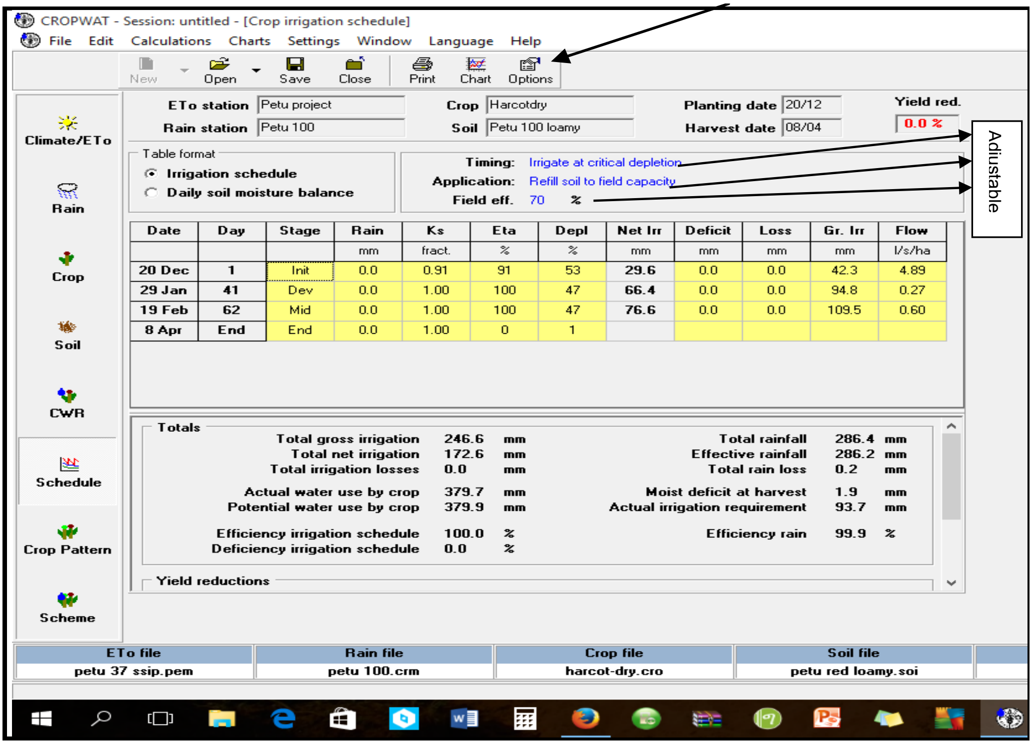


Figure 2.16: Irrigation schedule estimation sample

Empirical formula based determination of Irrigation interval using software: - The irrigation schedule or days interval between two consecutive applications may be determined with simple formula when the agronomist decided to do manually due to different reasons, however, the Cropwat software instantly calculate the depth and schedule based on daily soil moisture balance, therefore the experts not require to compute once they run the cropwat software. The irrigation interval (i) values should be rounded to zero or 5 lower case to be safe from the time fraction cumulative effects.

$$i = \frac{D \times Sa \times P}{ETc\ (peak)}\ \text{, in days}$$

Where: i = Irrigation interval
D = Rooting depth, m
Sa= Total available soil moisture mm/m
P = fraction of available soil water (%)
ETc = Crop water requirement (peak rate)
Source of data:
D = tabulated reference (Appendix XIV) or local experience for given crop
Sa = soil laboratory results for the project area or from references based on soil texture
ETc = calculated peak rate of crop water requirements
P = given in (Appendix XIV)

2.3.2. 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.

2.3.3. 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. 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.

a) Check basin irrigation

Check basin irrigation method consists of dividing the field into several relatively level plots called *checks* surrounded by low soil bunds (figure 4). 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 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.

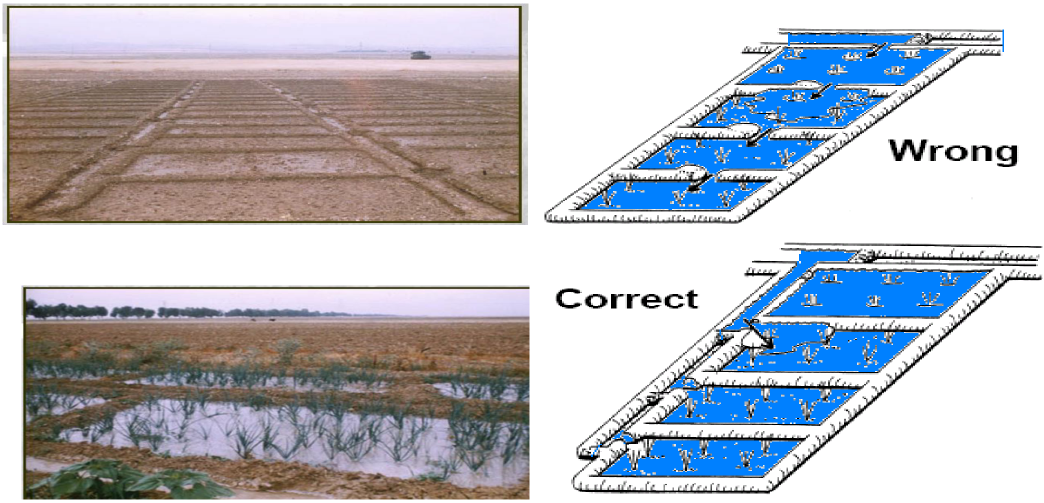


Figure 2.17: A diagram showing a layout of check basin system of irrigation

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 favorable 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, labor 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.

b) Border 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. 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, recommended to cut- off the irrigation water and let the residue pound to irrigate the lower end.

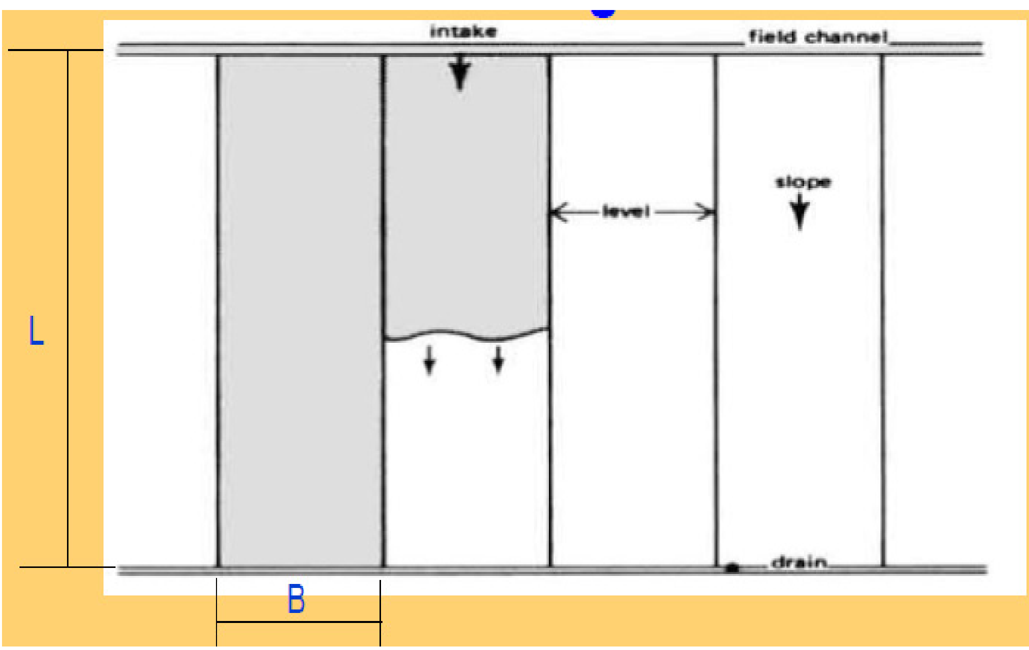


Figure 2.18: Diagram for Border Irrigation

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.

c) 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 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.

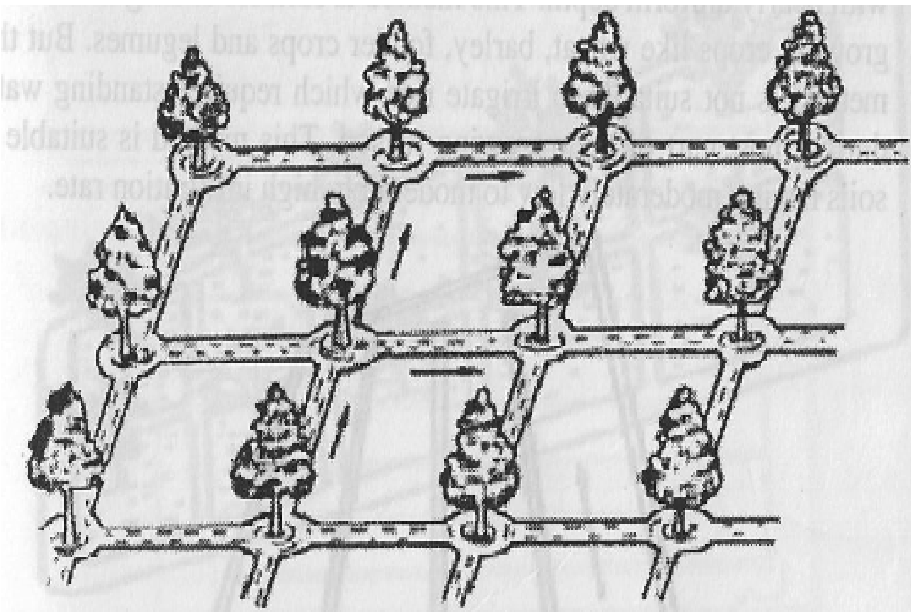


Figure 2.19: Ring irrigation method

Advantages: (1) a considerable amount of irrigation water is saved; (2) it involves only partial flooding of the soils 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.

d) 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 unwetted 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 500 m. 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 17.

Table 17: Recommended furrow lengths for different slopes, soil types and net depth of water application, mm

Furrow Slope, %	Maximum flow of water per second (l/sec)	Furrow length (m)							
		Soil types and available soil moisture in mm/m depth of soil							
		Clays			Loams		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 18 below).

Table 18: 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
Loam	6.25

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 19.

Table 19: 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 of 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*.

Figure 2.20: Straight Level furrow, level contour, graded furrow irrigation types (from left to right)

Advantages of furrow irrigation are great saving of water as compared to other surface methods, variable size of stream can be used, the water application efficiency is high as compared to other surface methods, 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 affected the growing crop on the middle of the ridges. Principal limitations of the furrow method are 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.

2.3.4. SPRINKLER IRRIGATION

Sprinkler irrigation refers to the application of irrigation water under pressure in which water is sprinkled in the form of spray or simulating artificial rains. 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 a riser pipes attached to the system of pipes laid on the ground and spray 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 distorts the even distribution of water and resulted in uneven distribution;
- Small streams of irrigation can be used efficiently;
- Accurate measurement of the applied water;
- 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 operator can operate the system;
- Automation is possible with the system as compared with that of the surface methods and
- High yields with 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; induction of leaf diseases, due to this fact not suitable for crops sensitive to diseases; hazard of salt accumulation on wetted foliage and requires much more sophisticated design skills and on- farm support in terms of maintenance and supply of spare parts.

Evaporation losses from sprinkler depend on the relative humidity, temperature, wind velocity and fineness of drops that in turn depends 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 a 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 need to match with infiltration rate and the slope of the irrigated field. High application rates can result in surface runoff or in ponding and deep percolation losses. 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 sprinkle 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.

i) 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 to irrigate:(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) It suits for areas with steep slopes having erosion hazards, (3) For growing of high value crops and (4) In areas where water is scarce and costly.

Sprinkler irrigation is not suitable for rice and crops susceptible to diseases that can be caused, due to 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 the periods of drought. Sprinkler irrigation is also used for protecting crops from frost.

ii) 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* delivers water from the water source to the field. It may be either permanent or movable; (2) The *lateral pipe* delivers the water from the main line to different sections of the field. 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 to an efficient system and should be installed whenever possible.

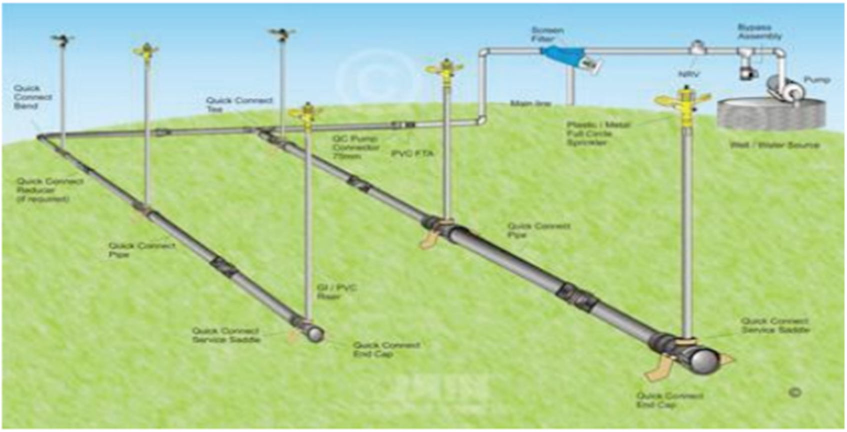


Figure 2.21: Typical Sprinkler Irrigation System Components (Source: FAO, Irrigation and Drainage Paper. Rome, 1984)

2.3.5. DRIP IRRIGATION

Drip irrigation or sometimes called trickle irrigation, refers to the application of water into the soil at slow rates just drop by drop, but frequent and with precise quantities through a small- sized opening 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 having 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 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.

A complete drip irrigation system basically consists of a head control unit, main and sub-main pipelines, hydrants, manifolds and lateral lines with drippers or drip emitters /fig.9/ at 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 LDPE, 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.

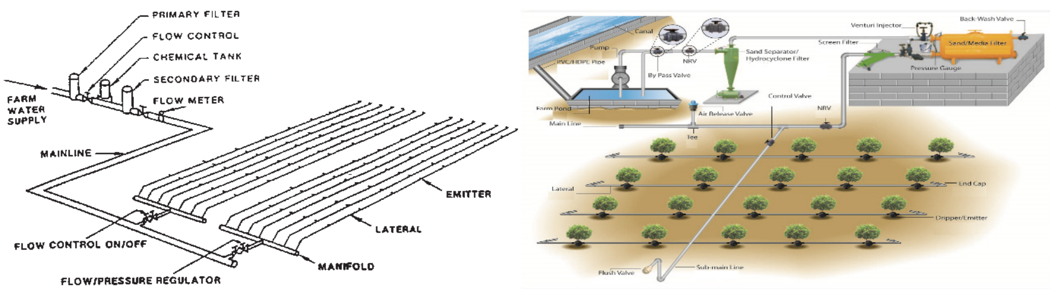


Figure 2.22: Basic components of a drip irrigation system (Source: FAO, Irrigation and Drainage Paper. Rome, 1984)

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:

- More uniform distribution of water and can be obtained higher crop yields;
- More efficient use of available water or water savings /90- 95% efficiency/, minimal evaporation losses and deep percolation is entirely avoided;
- Reduced cost for fertilizer and other chemical application, particularly nutrients can easily be applied with the irrigation water /fertigation/;
- Low labour operating requirements, reduced cultivation, control, and labour cost for leveling;
- Low energy requirement as compared with sprinkler system;
- Utilization of saline water resources, as a result reduced salinity hazard and possibility of using poor quality without causing significant hazard to the crop;
- Possibility of using marginal lands with soils such as porous and shallow depth;
- Physical soil conditions are maintained;
- It is well suited to small and varied plots on small farms,
- Weeds and pest problems are at minimum;
- Well- adopted in sloping lands and irregular topography without causing erosion;
- Lesser amount of tillage operations and a possibility of uninterrupted operation;
- 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; required more skilled labor in design, management and maintenance; clogging of emitters and lateral blockage from sand and silt, chemical precipitation from groundwater and algae from surface water is the most serious problem; restricted root zone and the plant may be susceptible to logging, due to poor plant anchorage; salt accumulation in the root zone that required leaching periodically; exposed to mechanical damages; lack of influence on the micro- climate and poor germination may result.

2.4. SELECTION CRITERIA FOR SUITABLE IRRIGATION METHODS

Factors to be taken into consideration in selecting the most appropriate irrigation methods are:

- The type of crops to be grown and their rooting depth;
- Soil characteristics of the land to be irrigated such as type, depth and infiltration;
- Topography of the land- slope and roughness;
- Available sources of water and size of the stream supplying irrigation water;
- Amount of water to be applied during each irrigation;
- Length of run and time required for wetting the command area;
- Depth of water table;
- Labour requirements and its availability;
- Energy demand;
- Efficiency of the methods;
- Initial investment cost and possible erosion hazard are the main points to be considered in the selection criteria.

The main selection criteria to be used for different irrigation systems are summarized in Table 20.

Technical factors affecting selection of irrigation method

<table>
<tr><th>Irrigation method</th><th>Crops</th><th>Soils</th><th>Labour

(h/ha/ irrig.)</th><th></th><th>Energy demand</th><th>Potential efficiency, %</th><th>Capital cost</th></tr>
<tr><td>Basin</td><td>all crops</td><td>clay, loam</td><td>0.5- 1.5</td><td></td><td>low</td><td rowspan="3">60</td><td rowspan="3">Low</td></tr>
<tr><td>Border</td><td>all crops except rice</td><td>clay, loam</td><td>3.0</td><td></td><td>low</td></tr>
<tr><td>Furrow</td><td>all crops except rice and drilled crops</td><td>clay, loam</td><td>4.0</td><td></td><td>low</td></tr>
<tr><td>Sprinkler</td><td>all crops except rice</td><td>loam, sand</td><td>1.5- 3.0</td><td></td><td>high</td><td>75</td><td>medium</td></tr>
<tr><td>Drip</td><td>row crops, orchards</td><td>all soils</td><td>0.2- 0.5</td><td></td><td>medium</td><td>90</td><td>High</td></tr>
</table>

2.5. MANAGING IRRIGATION ACCORDING TO GROWTH STAGES

The amount of water needed for adequate irrigation depends upon climate and crop growth stage. A certain crop grown in a sunny and hot climate needs more water than the same crop grown in a cloudy and cooler climate. Humidity and wind speed are climate parameters affecting crop water needs. When it is dry, the crop water needs are higher than when it is humid. In windy climates, the crops will use more water than in calm climates. The highest crop water needs are found in areas where the climate is hot, dry, windy and sunny. The lowest values found when it is cool, humid and cloudy with little or no wind.

Different crops require different amounts of water, and the water demand for any particular crop varies throughout the growing season. The crop water needs or crop evapotranspiration consists of transpiration by the plant and evaporation from the soil and plant surface. When the plants are very small the evaporation will be more important than the transpiration. When the plants are fully grown the transpiration is more important than the evaporation.

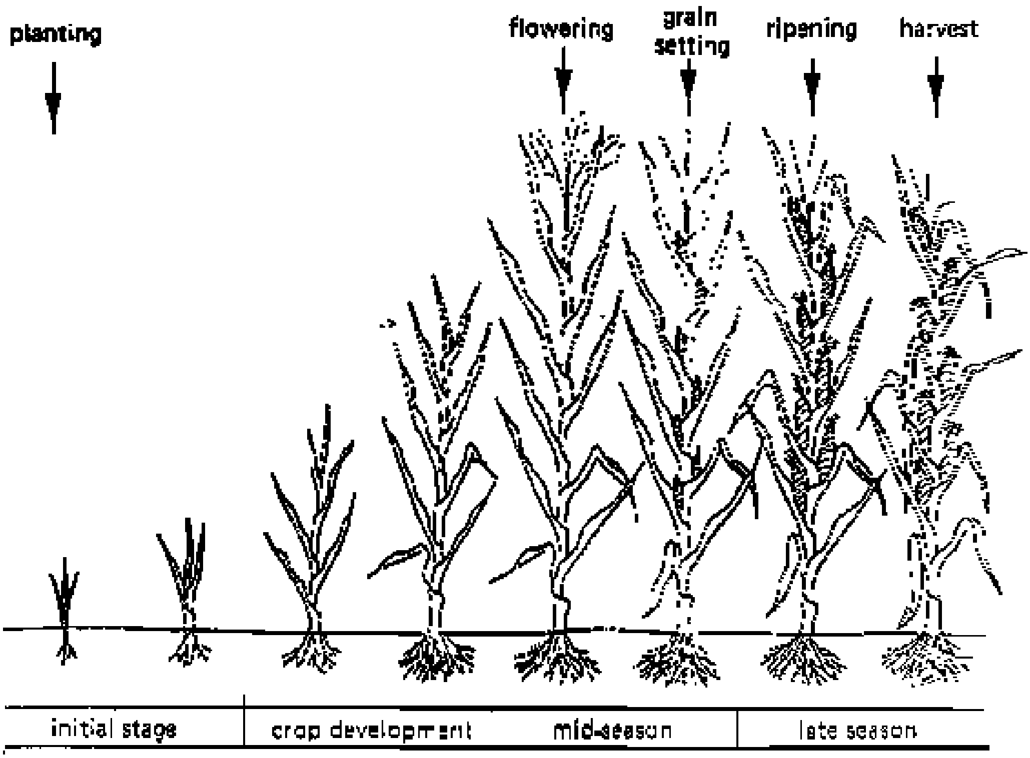


Figure 2.23: Growth stages of a crop

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

During crop development stage the crop water need gradually increases from 50 percent of the maximum crop water need to the maximum crop water need. The maximum crop water need is reached at the end of the crop development stage which is the beginning of the mid-season stage. With respect to the late season stage, which is the period during which the crop ripens and is harvested, a distinction can be made between two groups of crops:

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

Dry harvested crops: such as wheat, maize (for grain production), sorghum, etc. During the late season stage, these crops allowed to dry out and sometimes even die. Thus, their water needs during the late season stage are minimal. If the crop indeed allowed dying, the water needs are only some 25 percent of the crop water need during the mid-season or peak period.

2.5.1. SCHEME IRRIGATION NEED AND WATER SUPPLY

Matching scheme irrigation need with scheme water supply is intended as a guide to solve the practical problems of water shortage in the scheme. If the command area of a water source is larger than the actual area irrigated, there should be no problem of water shortage. When the supply of a water source in a certain month is known, e.g. 250 liters per second, and the gross irrigation need per hectare for the same month is estimated, for instance at 1.8 l/s/ ha, then the command area can be calculated. With a water supply of 250 l/s and a need of 1.8l/s/ha, one can irrigate 250/1.8 or 139 ha. The formula used to calculate the command area is scheme water supply (SWS) divided by gross irrigation need (INgross) or

$$CA = \frac{SWS}{IN\ gross}\ (ha)$$

When the supply of a water source is not constant over the months and seasons of the year, then the command area will also vary. As the amount of water supply varies over the years, the irrigation need also varies. Assume the following values of net irrigation need and size of command area for each month in the following table.

Table-20: Scheme water supply, value of gross irrigation needs and monthly command area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SWS (l/s)	290	420	510	560	650	400	320	280	250	230	200	220
INgross(l/s)	1.0	1.0	1.4	2.0	2.2	2.4	2.2	2.0	1.4	1.2	1.0	1.0
CA(ha)	290	420	364	280	295	167	145	140	179	192	200	220

The month during which the smallest area can be irrigated, i.e. the one with smallest CA, is August, with 140 ha. The month with the largest CA is February with 420 ha. If planting were confined to an area of not more than 140 ha, the crop could be supplied with sufficient water throughout the year. Irrigation in this case is reliable. According to table 20, the area of 140 ha is the smallest area for irrigation. This area is called the critical command area.
In this section, four possible means or methods discussed for matching the Scheme irrigation need with the Scheme water supply, when the irrigation supply is less than the amount required.

Method 1: Enlarge the SWS if the gross scheme irrigation water need is too large.

Enlarging the SWS is only possible when the water source is not fully exploited. This may be the result of a pumping system that does not have enough power to lift the required water flow, or an intake structure or supply canal that is too small or placed too high above the water level in the river or reservoir. These situations can be improved and the supply increased.

Method 2: Matching by advancing or postponing the growing season.

In the case of a variable river flow, the SWS might be too low at the beginning or at the end of the growing season. If a water shortage occurs at the beginning of the season, one may consider postponing the growing season by a month or so. If water problems are more likely to occur at the end of the season, it may help to plant the crop earlier.

Method 3: Stagger the growing season.

Method2 consisted of either advancing or postponing the growing period for the entire irrigation scheme. By doing so, it is sometimes possible to avoid the risk of water shortages at the beginning or at the end of the irrigation season. With method 3, the growing season shifted, but only for a part of scheme. In planning this operation carefully, the scheme irrigation need can be fine-tuned to an even greater extent to the scheme water supply.

Method 4: Diminish the gross scheme irrigation water need

If all other methods of coping with water shortage fail, the only remaining solution is to diminish the gross scheme irrigation water need. The first step in decreasing the gross scheme irrigation water need is to try to increase irrigation efficiency. If irrigation efficiency is still not sufficiently improved to match need with supply, or SIN gross and SWS, three alternatives remain:

- grow a crop with a lower irrigation water need
- decrease the irrigated area
- Accept water shortages and lower production.

In existing schemes, farmers will not easily accept growing other crops or diminishing the irrigated area. When the water shortage is less than 10-20% of the monthly requirement, production losses are not very heavy, and farmers will accept this solution first. When an extension of the scheme is considered, and farmers want to expand beyond the limits of the available water, one has sometimes to convince them to adjust their plans, by cutting a part of the new area, or by growing a crop with a lower irrigation need.

UNIT 3

IRRIGATION WATER MEASUREMENT

3.1. IRRIGATION WATER MEASUREMENT

Measuring water in surface irrigation systems is critical for efficient irrigation water management. Without knowing the amount of water being applied, it is difficult to make decisions on when to stop irrigating or when to irrigate next. A good irrigation manager should know the flow rate of the irrigation water, the total time of the irrigation event and the area irrigated. Irrigation management decisions should be made based on the amount of water applied and how this relates to the consumptive use demands of the plants and the soil water holding capacity. The amount of water applied to a field can be estimated using the following equation:

$$Q + t = d \times A$$

Q is the flow rate, in cubic meter per second (m3/s); t is the set time or total time of irrigation (hours); d is the depth of water applied (mm) and A is the area irrigated (ha). Irrigation water management begins with knowing how much water is available for irrigation. In this module, methods of measuring irrigation flow rate can be grouped into two basic categories:

direct measurement methods,
velocity-area methods,
Choice of method to use will be determined by the volume of water to be measured, the degree of accuracy desired and the financial investment required.

3.2. TECHNIQUES OF FLOW MEASUREMENT

3.2.1. DIRECT MEASUREMENT METHODS

Measuring the period of time required to fill a container of a known volume can be used to measure small rates of flow such as from individual siphon tubes, sprinkler nozzles, or from individual outlets in gated pipe.

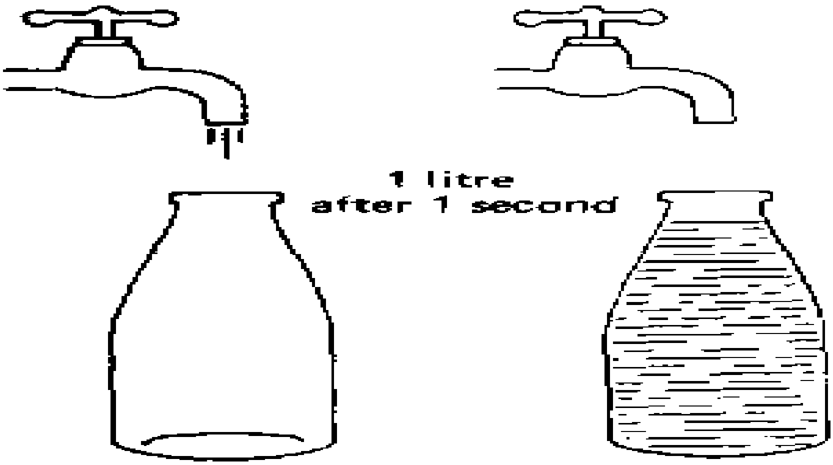


Figure 3.1: A flow-rate of one liter per second

Example;

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

$$Q = \textit{flow rate (l/s)} = \frac{\textit{volume of water (lt)}}{\textit{Time (s)}}$$

$$Q = \frac{\textit{volume of water (lt)}}{\textit{Time (s)}} = \frac{200\ l}{10\ s} = 101/s$$

3.2.2. VELOCITY-AREA METHODS

The most practical method of measuring stream discharge is through the velocity-area method. Discharge is determined as the product of the cross-sectional area of the water time's velocity. Discharge, or the volume of water flowing in a stream over a set interval of time, can be determined with the equation: *Q = VA*

Where; Q is discharge (volume/unit time (m^3/second), A is the cross-sectional area of the stream (m^2), and V is the average velocity (m/s).

This method comprises measuring the mean velocity V and the flow area 'A' and computing the discharge Q from the continuity equation. The site which satisfies the requirements such as straightness, stability, uniformity of cross-section is chosen for discharge measurement.

The discharge measurement site is then marked by aligning the observation cross-section normal to the flow direction. The cross-section is demarcated by means of masonry or concrete pillars on both the banks, two on each side 30 m apart.

i) Measuring of width or average width of an open channel

In order to measure the width of a channel the following procedures are used:

- Select straight canal view and stretch a string from one side of the channel to the other side;
- Put marks on the string to indicate the exact water surface on both sides of the channel;
- Measure the distance between the two marks and this is the width of the channel. If the field channel does not have equal width along the straight line selected it is better to take measurements at more places and take the average width of the channel.

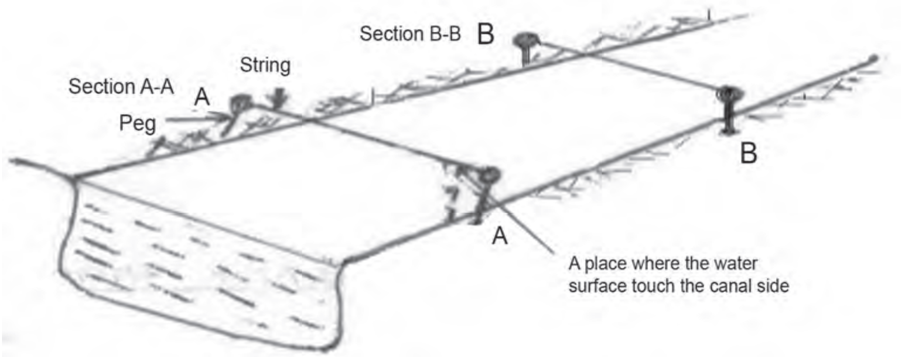


Figure 3.2: Schematic illustration how to measure width of a canal

ii) Measuring the average depth of water

In order to measure the average depth of water it is possible to use bamboo or a piece of wood circular at the base. The wooden piece should have a thickness of 3- 8 cm in order to resist the pressure of the water and delineated on it in meter and centimeter. The height preferably is more than one meter. On the measuring stick numeration should be written starting from 0 following bottom to up approach and zero should be marked at the flat bottom of the stick. The measuring can be done on the same area where the width is measured and measurements are taken at 30 cm interval. The average depth can be determined by dividing the sum of all the measured depths by the number of measurements taken.

Table 21: Sample data for measuring depth

Number of tests	1	2	3	4	5	6	7	average
Depth, m	0.30	0.40	0.51	0.52	0.51	0.50	0.35	3.09/7= 0.44

Number of trials for measuring depth are 7 and an average depth of an open channel is therefore, equal to 0.44 m (Total depths measured divided by the number of trials; 3.09/7 = 0.44 m).

iii) Measuring the cross- sectional area

The cross- sectional area is calculated by multiplying the width by the average depth of the canal. To do this first it is recommended summing up of all the partitions subdivided to measure the depths at certain intervals and then multiply the result with the average depth.

cross sectional area, m² = average width, m x average depth, m

$$2.30m \times 0.44m = 1.012m^2$$

iv) Measuring of the water velocity in an open channel

For the float method: measure out some convenient distance along the stream bank (try at least 30 meters). Station one person at the upstream end of your selected reach and one at the downstream end. The person at the upstream end has the stop-watch and the oranges. The person at the top releases an orange and starts the clock when the orange floats over the top boundary of your reach. When the orange passes the bottom boundary of your reach, the person at the bottom signals to the top person to stop the clock. Someone records the time and notes the distance traveled. Do this at least three times.

Calculations: *Surface velocity = distance / time*

Average surface velocity = sum of surface velocities / number of trials

Finally, knowing the cross- sectional area of the channel and the average velocity of the water in the channel, the discharge of the water in the open channel could be calculated by multiplying the cross- sectional area by the velocity of the water.

Table-22: Estimated average velocity from different data set

Test #	Time in second	distance in m	Velocity of water in m/s
1	20	10	0.50
2	21	10	0.48
3	22	10	0.45
average	21	10	0.48

At the end of the test the results should be added and divided by the total number of tests. Therefore, an average velocity is 10/20.6 = 0.48 m/s.

Q (l/s) = A x V = $1.012m^2$ *x 0.48m/s =* $0.49m^3/s$

3.3. COMMON CALIBRATED STRUCTURES OF ON-FARM WATER MEASURING DEVICES

Preferred methods are through the use of calibrated structures (weirs, flumes, orifices, and others), and current metering.

3.3.1. PARSHALL FLUMES

The Parshall flume is a widely-used discharge measurement structure. The characteristics of Parshall flumes are:

- Small head losses
- Free passage of sediments
- Reliable measurements even when partially submerged
- Low sensitivity to velocity of approach

Figure 3.3: Partial flume

The Parshall flume consists of a converging section with a level floor, a throat section with a downward sloping floor and a diverging section with an upward sloping floor. Flume sizes are known by their throat width. Care must be taken to construct the flumes accurately if the calibration curves have to be used. Each size has its own characteristics, as the flumes are not hydraulic scale models of each other. In other words, each flume is an entirely different device (see Table 23).

The flow through the Parshall flume can occur either under free flow or under submerged flow conditions. Under free flow the rate of discharge is solely dependent on the throat width and the measured water depth, ha. The water depth is measured at a fixed point in the converging section. The upstream water depth-discharge relationship, according to empirical calibrations, has the following general form:

Equation-

Q = Kx(ha)ˆu

Where;
Q= discharge (m^3/sec)
h_a = water depth in converging section (m)
K=A fraction, which is a function of the throat width
u= variable, lying between 1.522 and 1.60.

Table-23: Standard dimensions of Parshall flumes (the letters are shown in figure 3-4) (Adapted from: FAO, 1975b)

b		A	a	B	C	D	E	L	G	H	K	M	N	P	R	X	Y	Z
' + "	mm	mm																
1"	25.4	363	242	356	93	167	229	76	203	206	19	-	29	-	-	8	13	3
2"	50.8	414	276	406	135	214	254	114	254	257	22	-	43	-	-	16	25	6
3"	76.2	467	311	457	178	259	457	152	305	309	25	-	57	-	-	25	38	9
6"	152.4	621	414	610	394	397	610	305	610	-	76	305	114	902	406	51	76	-
9"	228.6	879	587	864	381	575	762	305		-	76	305	114	1080	406	51	76	-
1"	304.8	1372	914	134	610	845	914	610	914	-	76	381	229	1492	508	51	76	-
1'6"	457.2	1448	965	1419	762	1026	914	610	914	-	76	381	229	1676	508	51	76	-
2'	609.6	1524	1016	1495	914	1206	914	610	914	-	76	381	229	1854	508	51	76	-
3'	914.4	1676	1118	1645	1219	1572	914	610	914	-	76	381	229	2222	508	51	76	-
4'	1219.2	1829	1219	1794	1524	1937	914	610	914	-	76	457	229	2711	610	51	76	-
5'	1524.0	1981	1321	1943	1829	2302	914	610	914	-	76	457	229	3080	610	51	76	-
6'	1828.8	2134	1422	2092	2134	2667	914	610	914	-	76	457	229	3442	610	51	76	-
7'	2133.6	2286	1524	2242	2438	3032	914	610	914	-	76	457	229	3810	610	51	76	-
8'	2438.4	2438	1626	2391	2743	3397	914	610	914	-	76	457	229	4172	610	51	76	-

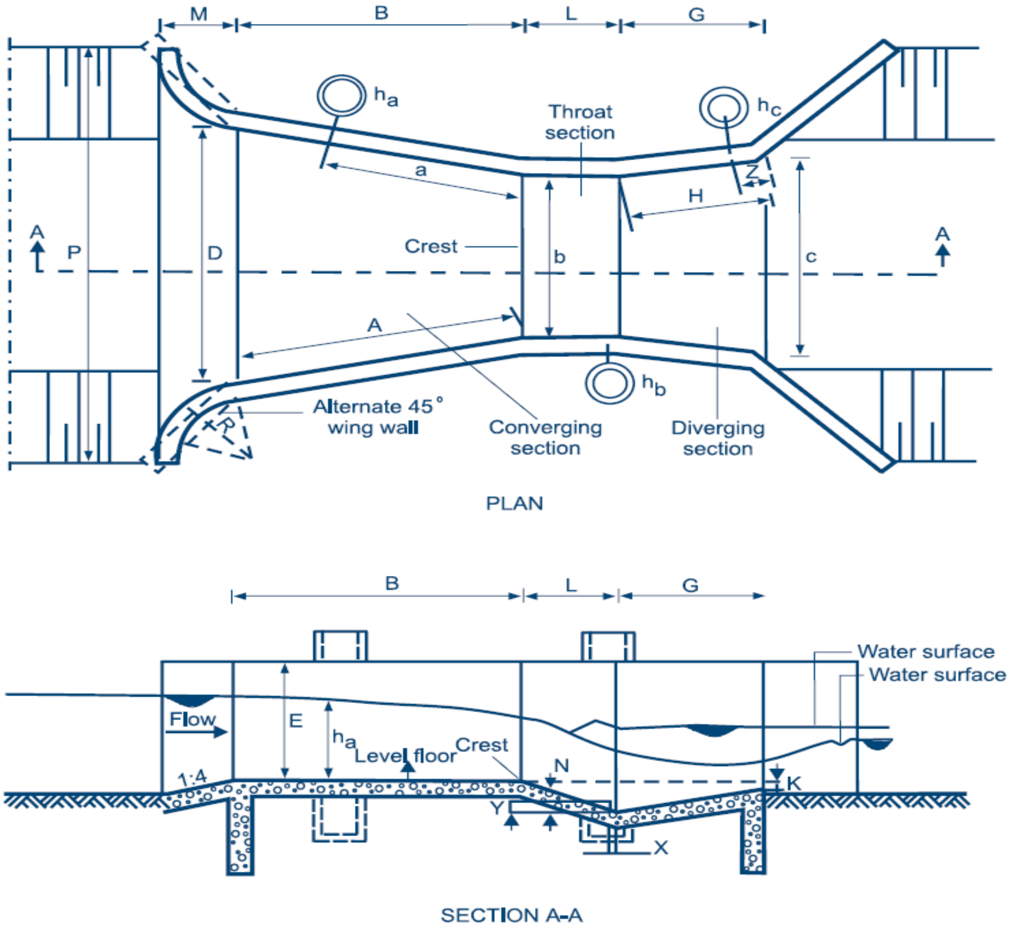


Figure 3.4: Parshall flume diagram showing dimensions given in Table 23

Table 24: Discharge characteristics of Parshall flumes

Throat width b feet + inches	Discharge range		Equation $Q = K \times h_a^u$ (m³/sec)	Head range	
	Minimum (m³/sec x 10⁻³)	Maximum		Minimum (m)	Maximum
1”	0.09	5.4	$0.0604\ h_a^{1.55}$	0.015	0.21
2”	0.18	13.2	$0.1207\ h_a^{1.55}$	0.015	0.24
3”	0.77	32.1	$0.1771\ h_a^{1.55}$	0.030	0.33
6”	1.50	111	$0.3812\ h_a^{1.58}$	0.030	0.45
9”	2.50	251	$0.5354\ h_a^{1.53}$	0.030	0.61
1’	3.32	457	$0.6909\ h_a^{1.522}$	0.030	0.76
1’6”	4.80	695	$1.056\ h_a^{1.538}$	0.030	0.76
2’	12.1	937	$1.428\ h_a^{1.550}$	0.046	0.76
3’	17.6	1 427	$2.184\ h_a^{1.566}$	0.046	0.76
4’	35.8	1 923	$2.953\ h_a^{1.578}$	0.060	0.76
5’	44.1	2 424	$3.732\ h_a^{1.587}$	0.060	0.76
6’	74.1	2 929	$4.519\ h_a^{1.595}$	0.076	0.76
7’	85.8	3 438	$5.312\ h_a^{1.601}$	0.076	0.76
8’	97.2	3 949	$6.112\ h_a^{1.607}$	0.076	0.76

Time based partial flume calculation procedures;

- The flume can be calibrated and a table or a graph can be prepared showing discharge (Q) in l/s against water head (H) in cm. Time required irrigating a given field can be calculated using the following equation;

$$T = \frac{A * D * 10}{Q * 60}$$

Where,
T = time in minutes,
A = area to be irrigated in m^2
D = depth of water to be applied in cm,
Q = discharge in liter/second

Table-25: Discharge & depth relation (Q = lit/sec)

Height, m	Throat width of the Parshall flume, inches												
	1 in	2 in	3 in	6 in	9 in	1 ft	1 .5 in	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft
0.02	0.140	0.281											
0.03	0.263	0.526	0.772	1.496	2.504	3.347	4.803						
0.04	0.411	0.822	1.206	2.357	3.889	5.183	7.475						
0.05	0.581	1.162	1.705	3.354	5.471	7.275	10.536	13.745	20.037				
0.06	0.771	1.541	2.261	4.473	7.232	9.599	13.946	18.233	26.659	34.849	42.941		
0.07	0.979	1.957	2.872	5.707	9.155	12.133	17.678	23.154	33.937	44.446	54.842		
0.08	1.205	2.407	3.532	7.047	11.231	14.863	21.708	28.479	41.830	54.871	67.787	80.440	93.133
0.09	1.446	2.889	4.239	8.489	13.448	17.777	26.019	34.183	50.303	66.078	81.719	97.064	112.461
0.1	1.702	3.402	4.991	10.027	15.801	20.865	30.596	40.247	59.327	78.030	96.592	114.827	133.125
0.11	1.973	3.943	5.786	11.656	18.281	24.117	35.426	46.654	68.877	90.695	112.365	133.679	155.070
0.12	2.258	4.513	6.621	13.374	20.885	27.528	40.499	53.390	78.932	104.043	129.004	153.581	178.249
0.13	2.557	5.109	7.496	15.177	23.605	31.089	45.805	60.442	89.472	118.050	146.477	174.495	202.620

3.3.2. CUTTHROAT FLUMES

- A cutthroat flume is a rectangular open channel constriction with a flat bottom and zero length in the throat section.
- Because the flume has no throat section, the flume was given the name “cutthroat” by the developers (Skogerboe et al. 1967).
- *The floor of the flume is level*, which has the following advantages; (1) ease of construction the flume can be placed inside a concrete lined channel; and (2) the flume can be placed on the channel bed.
- The cut-throat flume has a converging inlet section, throat and diverging outlet section.
- The flume has a flat bottom and vertical walls. It is preferable to have the cut-throat flume operating under free flow conditions.
- This facilitates measurements and ensures a high degree of accuracy. Free flow conditions through the cutthroat flume are described by the following equations:

Equation-2

Q = Cx(ha)^n

Equation 3

Q= Kx(W)^1.025

Where:

Q = Discharge (m3/sec)

C = free flow coefficient

h_a = upstream water depth (m)

K = flume length coefficient

W = throat width (m)

For a given flume length, the values of n and K are obtained from Figure 13. In order to ensure free flow conditions, the ratio between the water depths h_a and h_b should not exceed a certain limit, which is called the transition submergence, St.

Figure 3.5: Cutthroat flume operation at Koga irrigation field

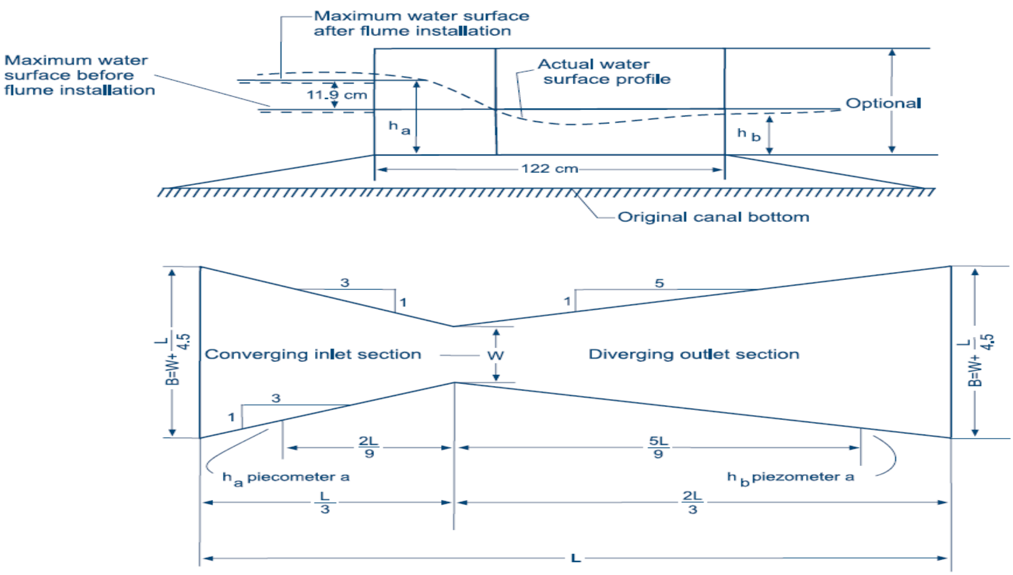
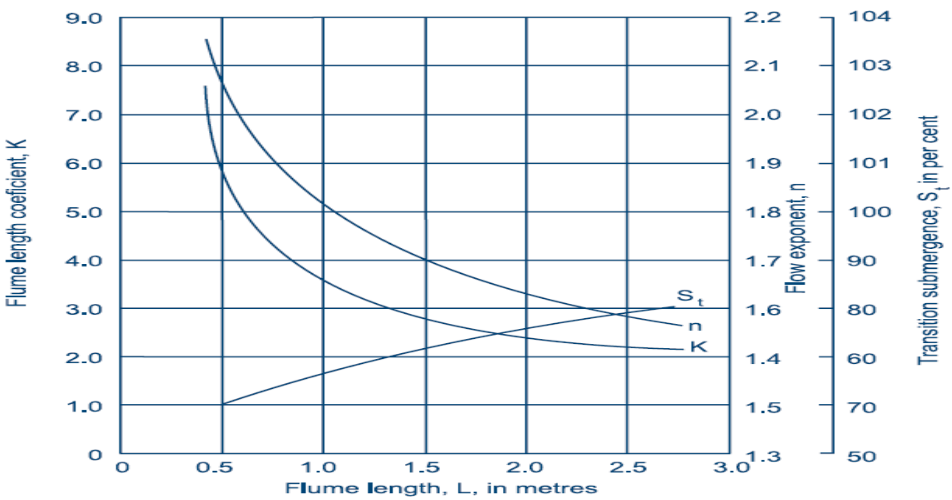


Figure 3.6 Cut-throat flume coefficients (Source: FAO, 1975b)



3.3.3. V-NOTCH WEIR

- A V-notch weir has two edges that are symmetrically inclined to the vertical to form a notch in the plane perpendicular to the direction of flow.
- The most commonly used V-notch weir is the one with a 90° angle.
- Other common V-notches are the ones where the top width is equal to the vertical depth (1/2 x 90° V-notch) and the one where the top width is half of the vertical depth (1/4 x 90° V-notch) (Figure 14).
- The V-notch weir is an accurate discharge-measuring device, particularly for discharges less than 30 l/sec, and it is as accurate as other types of sharp-crested weirs for discharges from 30 to 300 l/sec (U.S. Department of Interior, 1975).
- To operate properly, the weir should be installed so that the minimum distance from the canal bank to the weir edge is at least twice the head on the weir.
- In addition, the distance from the bottom of the approach canal to the point of the weir notch should also be at least twice the head on the weir (U.S. Department of Interior, 1975).
- The general and simple discharge equation for a V-notch weir is:

Equation 4

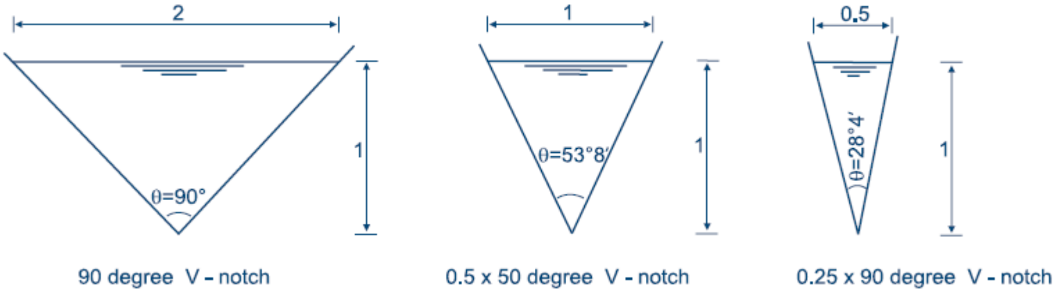


Figure 3.7 V-notch Weir (FAO 1975)

$Q = 1.38x\tan(\frac{1}{2}\theta)h^{5/2}$

Q = design discharge over the weir (m^3/sec)

ϑ = angle included between the side of the noch (degree)

h = design water depth (m)

Table 18: Discharge Q (m3/sec x 10) for a 90° V-notch weir, depending on h (head)

Head (m)	Discharge (m^3/sec x 10)	Head (m)	Discharge (m^3/sec x 10)	Head (m)	Discharge (m^3/sec x 10)
0.050	0.008	0.160	0.142	0.270	0.523
0.055	0.010	0.165	0.153	0.275	0.548
0.060	0.012	0.170	0.165	0.280	0.573
0.065	0.015	0.175	0.177	0.285	0.599
0.070	0.018	0.180	0.190	0.290	0.626
0.075	0.022	0.185	0.203	0.295	0.653
0.080	0.025	0.190	0.217	0.300	0.681
0.085	0.029	0.195	0.232	0.305	0.710
0.090	0.034	0.200	0.247	0.310	0.739
0.095	0.039	0.205	0.263	0.315	0.770
0.100	0.044	0.210	0.279	0.320	0.801
0.102	0.050	0.215	0.296	0.325	0.832
0.110	0.056	0.220	0.313	0.330	0.865
0.115	0.062	0.225	0.332	0.335	0.898
0.120	0.069	0.230	0.350	0.340	0.932
0.125	0.077	0.235	0.370	0.345	0.966
0.130	0.084	0.240	0.390	0.350	1.002
0.135	0.093	0.245	0.410	0.355	1.038
0.140	0.102	0.250	0.432	0.360	1.075
0.145	0.111	0.255	0.454	0.365	1.113
0.150	0.121	0.260	0.476	0.370	1.152
0.155	0.131	0.265	0.499	0.375	1.191
				0.380	1.231

3.3.4. SIPHONS

Siphon irrigation is the most common form of irrigation in Ethiopian state farms (sugar farms). Siphon tubes, usually black poly pipes, transfer water over the bank of an irrigation channel or head ditch. The siphon uses gravity and air pressure to run water up and over a bank and down into the field. Once flowing and positioned correctly, siphons will continue to transfer water for an extended period. The role of gravity and air pressure plays an important role in the operation of a siphon.

Basic Principles:

- The discharge through siphons depends on the *diameter of the siphon and the head.*
- For drowned or submerged discharge, the head is the difference between the water level in the canal and the water level in the field (Figure 3-3a).
- For free discharge, the head is the difference between the water level in the canal from where the siphon takes the water and the outlet from the siphon (Figure 3-3b).
- *Discharge can be altered by change in pipe diameter or change in the head (*figure3-4).

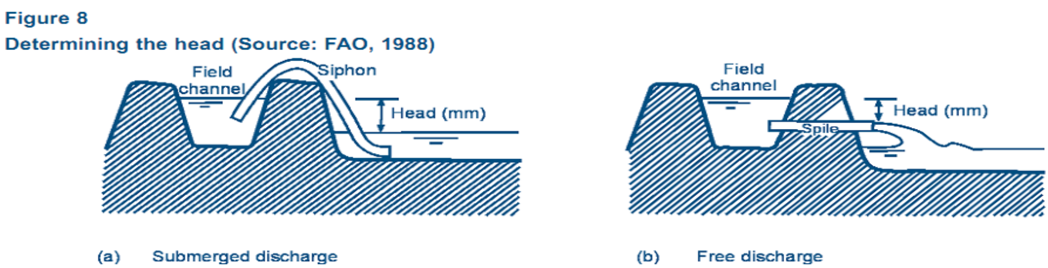


Figure 3.8 Case of syphon in determining discharge

Derivation of equation;

From continuty equation potential energy = Kenitic energy = $mgh = \frac{1}{2} mv^2$

By rearranging this we get; V (velocity (m/sec) = √(2gh) where h head of water in the canal.

Discharge (Q) = AV; where A = πr2

Table 4

Discharge for siphons, depending on pipe diameter and head (l/sec)

Pipe diameter (cm)	Head (cm)			
	5	10	15	20
2	0.19	0.26	0.32	0.73
3	0.42	0.59	0.73	0.84
4	0.75	1.06	1.29	1.49
5	1.17	1.65	2.02	2.33

Figure 3.9 Discharge head relationships of syphon

Rate of discharge formula

$Q = CA \sqrt{2 \ gh}$

Where,

Q = discharge in cm^3,

C =discharge coefficient,

A = cross sectional area of syphon (cm^2)

g = acceleration due to gravity, h = head in cm

Assuming g = 981 cm/sec and also converting Q into l/s, the above equation can be re-written

$Q = CA \quad 0.44 \quad A\sqrt{h}$

The value of C can be found during siphon calibration. This value comes to about 0.66. Putting this value in the equation, the equation becomes;

$Q = 0.029 \quad A\sqrt{h}$

Operation of Siphon

The siphon is a length of poly pipe (around 3 to 4 meters long) that transfers water from the head ditch to the field. One end is called the head ditch end, the other, the field end. The following is a step-by-step guide on how to operate a siphon:

1. Place one end of the siphon below the water surface in the head ditch.
2. Push the head ditch end further into the water leaving the field end open.

3. Seal off the field end of the siphon with the palm of your hand.
4. Keeping the field end sealed, pull the siphon away from the head ditch towards the field. Always keep the head ditch end below the water level.
5. Release the seal (palm of your hand) from the field end. The aim is to push the air out of the siphon tube and fill it with water.
6. Repeat steps 3 and 4 until the siphon fills with water. This usually takes 1 or 2 thrusts depending on the amount of head available.
7. Once the air is expelled, the siphon is full and ready to flow
8. Remove the seal formed by your hand and place the field end properly in the furrow. When doing this, make sure the head ditch end remains submerged.
9. Check that all field ends are placed properly at the start of the furrow (or rotobuck, as it is sometimes called).

UNIT 4

IMPROVED ON-FARM WATER MANAGEMENT PRACTICES

Field water use efficiency is of great importance to farmers and the planners, while crop water use efficiency is of great importance for the on farm agronomists, irrigation development agents and researchers. Water use efficiency is influenced by changes on the economic crop yield in one hand that depends on various factors of crop production practices (climatic conditions such as amount, distribution and intensity of rainfall, occurrence of drought, soil characteristics, drainage, irrigation practices, fertilizer use, crop varieties, crop growth stage, crop and pest management practices; weather hazards and environmental conditions. The crop water requirement or evapotranspiration is also influenced by various factors such as plant and soil types, climatic conditions, and soil and crop management practices applied. Therefore, in order to enhance efficiency of irrigation and water management it is highly important to pay special attention to the following:

- Adequate planning and proper design of the irrigation system,
- Adequate maintenance of the conveyance and distribution systems, including regular clearing of weeds growing along the main and field channels,
- Maintain proper land preparation for uniform distribution of on-farm irrigation water,
- Selecting of appropriate irrigation methods by taking into consideration the predetermining factors for selecting proper irrigation methods such as crop types, soil types, topography of the area, cost of the irrigation method under consideration and skills of the users,
- improved on-farm irrigation water management by putting in place and maintaining of field water measuring devices, regular maintenance of field distribution channels from weeds and avoiding of water losses through seepage and evaporation,
- Application of improved crop management practices such as crop and variety selection, land preparation, planting method, time of planting, water application to satisfy the crop needs, irrigation method being used, fertilizer application, weed and crop pest management practices, etc.

- Irrigating crops only at the most sensitive physiological stages of crop growth stage

4.1. LAND PREPARATION AND FIELD LEVELING

To improve OFWM practices, the use of appropriate method of irrigation is very important. Irrigation method improvement can be achieved by the following:

Field leveling and Land preparation

- Field leveling involves grading and earthmoving to eliminate variation in field gradient (smoothing the field surface and often reducing field slope).Field leveling helps to control water advance and improve uniformity of soil saturation under gravity-flow systems. Precision leveling is generally undertaken with a laser-guided system. It is very important to remove soil from immediate upstream of furrows due to the risk of siltation.
- Land Preparation is an agronomic practice used for higher crop yields by providing optimum soil environment for crops. Appropriate land preparation is essential for the following purposes.
  - Permits optimal soil water air relations,
  - Creates good physical conditions for early root penetration and proliferation
  - Incorporate preceding crop residues and organic manures
  - Destroy weeds and hibernating pest & disease organisms
  - Facilitate proper soil chemical and microbial activity

Shortened water runs

Shortened water runs reduce the length of furrow (or border) to increase uniformity of applied water across the field. Reduced water runs are most effective on coarse soils with high soil-water infiltration rates. Water runs may be reduced to 3 to 10 meters

4.2. IRRIGATION WATER MANAGEMENT PRACTICES

Irrigation efficiency is the ratio of the average depth of irrigation water beneficially used (consumptive use plus leaching requirement) to the average depth applied, expressed as a percentage. Improved water-conveyance systems are an important potential source of farm-level water savings. System upgrades include ditch lining, ditch reorganization, and pipeline installation and precision field-levelling, shortened water runs, alternate furrow irrigation, and tail water reuse are some of the tools used to improve irrigation efficiencies. Carefully managed deficit irrigation on crops would provide the greatest potential for substantially reducing agricultural water use because of long season growing period and the larger land areas that are involved. High-value crops may also produce some water savings through various deficit irrigation strategies, but their impact will be much lower because they generally occupy less than 10% of irrigated area (location specific). However, deficit irrigation strategies still must be developed for most crops

4.2.1. ALTERNATE FURROW IRRIGATION

Alternate furrow irrigation involves wetting every second furrow only. This technique limits deep percolation losses by encouraging lateral moisture movement. Applied water and time required per irrigation may be significantly less than under full furrow systems, but more irrigation may be required to supply crop needs. This technique is very effective when the desired strategy is to irrigate to a “less than field capacity” level in order to more fully utilize rainfall.

Figure 4.1: Alternate Furrow Irrigation Method

Experiences: regional, national; Experiments done on Alternate furrow irrigation at Adet, Debre Birhan (Bakelo), Gondar (East Belesa) and Srinka (Kobo) Agricultural Research Centers using potato as a test crop showed consistent result. At Adet (West Gojam): Alternate Furrow Irrigation on potato gave 50% reduction in irrigation water with insignificant yield loss and improved water use efficiency (3rd proceeding). In Kobo Girrana (south Wello) and Bakelo (North Shewa), AFI on potato gave optimum yield as compared to the other methods. AFI application with 50% crop water requirement saved 50% of water without yield penalty and reduces the labour required to carry out the irrigation compared to every furrow irrigation with 100% crop water requirement application. Similarly, at east Belesa (North Gondar), two years combined result showed alternate furrow irrigation with 22 mm of applied water at 7 days interval gave the highest yield of potato compared with other treatment combination. Hence, it is advised that farmers in East Belesa should use alternate furrow irrigation for better and efficient production of potato (Biru et al., 2010).

At Jima: Experiment on coffee showed that the difference between full irrigation and partial root zone drying (PRD) with alternate furrow method was not significant for crop yield and yield components. PRD and normal deficit irrigation (NDI) significantly improved the quality of coffee beans. In addition, PRD saved 50% of the irrigation water required for irrigation and resulted in significantly higher irrigation water use efficiency (IWUE) than full irrigation and NDI. Hence, it was concluded that PRD is an effective irrigation strategy that could save water, increase IWUE and improve crop quality without a significant reduction in crop yield in areas where water is scarce for irrigation and the dry spells are prolonged (Tesfaye et al. 2013).

Deficit Irrigation (DI) is an irrigation practice whereby water supply is reduced below maximum levels and mild stress is allowed with minimal effects on yield. In other words, it is the application of water below full crop-water requirements (evapotranspiration), to optimize the water use of the crop. The reduction of the applied water could be consistent or variable throughout the crop growth periods. If it is consistent it is called regulated deficit irrigation (RDI) where constant reduction of planned irrigation volume is practiced. Deficit Irrigation is an efficient way to increase the productivity of the applied water. If properly implemented, it can help to reduce agricultural water use to pronounced extent in a given area (FAO, 2002).

Description of the technology (When, where and how to apply the technology) : Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains than maximizing yields per unit of water for a given crop; farmers are more inclined to use water more efficiently, and more water efficient cash crop selection helps optimize returns. However, this approach requires precise knowledge of crop response to water as drought tolerance varies considerably by species, cultivar and stage of growth (FAO, 2002). Irrigation may be applied during drought-sensitive growth stages of the crop. Water restriction is limited to drought-tolerant phonological stages, often the vegetative stages and the late ripening period. This inevitably results in plant drought stress and consequently in production loss. In other words, DI aims at stabilizing yields and at obtaining maximum crop water productivity rather than maximum yields (Zhang and Oweis, 1999).

Research Experiences: At Adet: the results of the combined analysis of the two years data showed that deficit irrigation on potato did not significantly affect most biological parameters. Here, 60% deficit irrigation (375 mm net irrigation) at crop development stage (day 25 to day 55) gave highest marketable yield (16 ton ha-1) and total yield (21ton ha-1) and dry matter content (22%) which is within the acceptable industrial standard (20-25%). Moreover, results of the experiments revealed that 51 mm (510 m3 ha-1) of irrigation water, which is about 12% of the total net irrigation, could be safely saved without significant potato yield loss at Adet (Mekonnen, 2013).

At Lalibela, North Welo: the results of studies made on mung bean indicated that application of 25% ETc (75% deficit) either at initial, development and late growth stages in one period stress or 75% ETc (25% deficit) throughout the growth stages is recommended. Here, water use efficiency was improved by 6-23% using deficit irrigation application (Gizaw and Menelik, 2014). At Arba Minch: the highest maize yield (8842 Kg/ha) was found with water deficit of 50 % during mid and maturity-stages (Mekonnen, 2013).

4.2.2. PITCHER IRRIGATION

Definition; Pitcher irrigation uses a buried, unglazed clay pot filled with water to provide controlled irrigation to plants as the water seeps out through the clay wall at a rate that is influenced by the Plant's water use (Bainbridge et al., 2012).

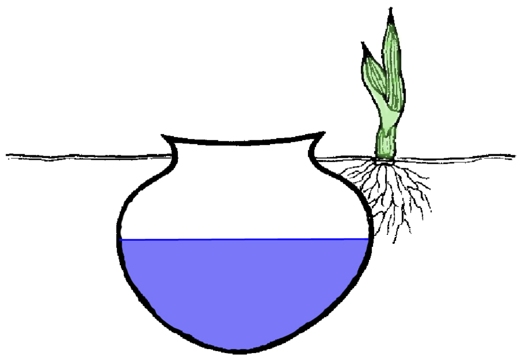


Figure 4.2: Pitcher irrigation (Source Bainbridge et al., 2012)

Description of the technology (When, where and how to apply the technology)
Buried clay pot irrigation should be considered wherever water conservation is important. It will probably continue to prove most valuable for producing high value crops in dry lands. Buried clay pot irrigation is also valuable for food production and revegetating areas affected by salinity or where only saline water is available for irrigation. Buried clay pot irrigation is also valuable for gardening, landscaping, and growing plants in containers. It can be very effective for plants that are prone to diseases from over watering or wetting leaves by sprinkling (Bainbridge et al., 2012).

Pitcher irrigation has very high efficiency--considerably better than drip irrigation and many times better than conventional surface irrigation. Buried clay pots can be used without pressurized, filtered water supplies. The clay pots can be made with locally available materials and skills and are less likely to be damaged by animals or clogged by insects than drip systems. And finally, while even a brief interruption of water supply to a drip irrigation system due to a pump or filter failure can lead to serious problems and costly crop failure, the buried clay pot systems may require water only once every few days or once a week (Bainbridge et al., 2012).

Buried clay pot irrigation is simple and straightforward. The first step is obtaining or making suitable clay pots. The size of buried clay pot will depend on the type of crop, the density of planting, and the time desired between refills. Two to five liter sizes are convenient. Larger pots may be more suitable for trees or for long refill intervals. Make pit and bury an earthen jar in the center of the pit. Let its mouth be level with the ground. Fill the jar with water. Plant 4 seeds around the jar. Cover the jar with a tile. Fill the jar to the brink when the water level falls. A small amount of water should be added to the seed spot or transplant to help wet the soil and establish capillary action from the buried clay pot. The seeds or plants should be placed within 1-2 cm of the edge of the buried clay pot in most soils (Bainbridge et al., 2012).

The spacing of the clay pots depends on the crop and size of the pot. In general they will be 3-6 m apart for vine crops and 1-1.5 m apart for corn and other plants that grow up more than out. A double clay pot can be set up specifically for propagating cuttings. Fill the buried clay pot regularly and try to keep it from becoming completely dry. This may require refilling every 2-3 days for small pots or perhaps only once every week for larger ones. This may vary over the growing season. It is also possible to hook buried clay pots up to a drip system or float fill valve to keep them full automatically (Bainbridge et al., 2012).

4.2.3. SERGE IRRIGATION PRACTICE

Surge irrigation or surge flow intermittently applies water to an irrigation furrow. Continuous flow for the entire irrigation set time is the normal process of applying water. Surge irrigation was first studied as a method of reducing the amount of runoff that occurred during irrigation. It was discovered that water moved to the end of the field more quickly when applied intermittently than when applied continuously.

Water can be applied intermittently by cycling irrigation water between two sides of a surge valve. Prior to the development of the surge valve, water was cycled when it was not getting to the end of a field. The irrigator would move on to subsequent sets and return in one or two days to finish irrigating the partially watered sets. The second time, the irrigation water could be moved all the way to the end of the field because the soil surface had sealed and more water was available at the point where flow had stopped. This same process is used with modern surge irrigation, except the cycling is done automatically for short durations of 20 minutes to two hours. A typical surge irrigation system is shown in Figure 4-3.

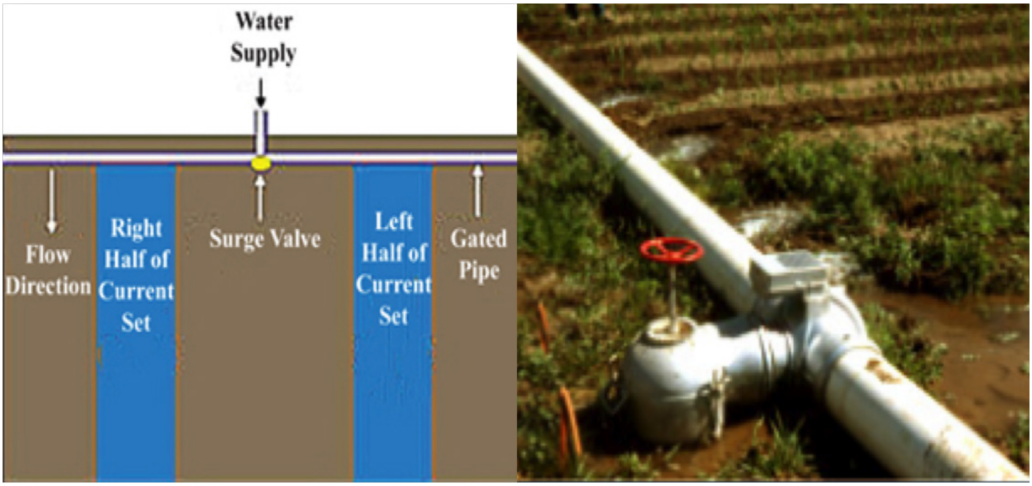


Figure 4.3 A typical Surge Irrigation

High infiltration rates can lead to poor irrigation system performance due to deep percolation and poor water distribution across the field. Surge flow can increase irrigation performance by providing a more uniform application. In Figure 4-4, the infiltration pattern of surge and continuous flows show the potential difference in uniformity of water application between the two systems.

Rather than turning the water on and off to achieve intermittent flow, an irrigation surge valve is used to alternate flow between open gates on either side of the surge valve. Cycle times used with surge irrigation vary with soil texture, slope and field length. Fine-textured soils respond less to surge irrigation than do coarse-textured soils that have higher initial intake rates. If field slope is so steep that it causes a rapid rate of advance, the effects of surge irrigation will be reduced. If a soils intake rate is low due to soil texture, tight soils or compacted layers, surge irrigation is likely to be ineffective in reducing the irrigation advance times below those for continuous flow.

Surge flow has been used in some cases to reduce irrigation runoff by using short duration cycles after the water has reached the end of a field. This helps maintain high uniformity of water application and improve the overall irrigation performance. Another advantage to surge irrigation, unrelated to the improvements in irrigation system performance, is that the surge valve can be used to improve irrigation system management without a large increase in labor requirements. The surge controller provides a two-set automated furrow irrigation system.

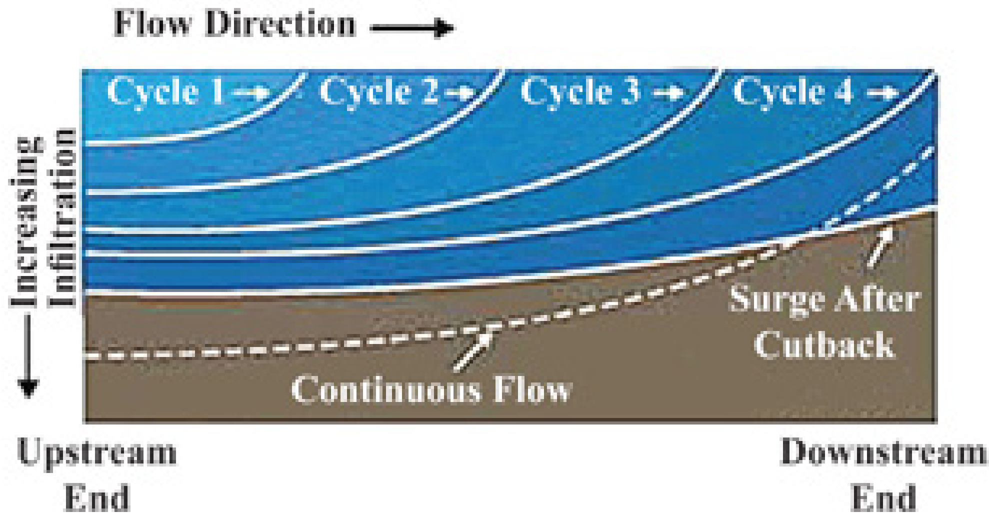


Figure 4.4: Potential infiltration patterns for surge and continuous flow irrigation

4.2.4. SUPPLEMENTARY IRRIGATION

Definition

Supplementary irrigation (SI) may be defined as the addition of limited amounts of water to essentially rain-fed crops, in order to improve and stabilize yields during times when rainfall fails to provide sufficient moisture for normal plant growth. Supplemental irrigation is an effective response to alleviating the adverse effects of soil moisture stress on the yield of rain-fed crops during dry spells (Oweis and Ahmed, 2012).

Description of the technology (When, where and how to apply the technology)
A shortage of soil moisture in the dry rain-fed areas often occurs during the most sensitive stages of crop growth (flowering and grain filling). As a result, rain-fed crop growth is poor and consequently the yield is low. Supplemental irrigation, with a limited amount of water applied, especially during the critical crop growth stages, results in a substantial improvement in yield and water productivity (WP). Research results show substantial increases in rain-fed crop yields in response to the application of relatively small amounts of water. When rainfall is low, more water is needed, but the response is greater, and the increases in yield are remarkable even when rainfall is as high as 500 mm. Unlike full irrigation, the timing and amount of SI cannot be determined in advance given the rainfall variability. If the onset of the seasonal rain is delayed, early sowing can be realized with the help of a SI system. With SI it is possible to decide on the sowing date of the basically rain-fed crops without

needing to wait for the onset of the seasonal rain (Oweis and Ahmed, 2012).

Different authors agree in stating that for most of the cultivated species, the stages of maximum sensitivity to water stress are those from pre-flowering to fruit-setting both for herbaceous and tree crops; moreover, for the latter, irrigation proves to be quite useful also during the stage of cellular extension of fruits. Therefore, for a given species the growth stages sensitive to water stress are different and of a different sensitivity level. Irrigation at a given growth stage depends on the crop sensitivity to water stress, on the climatic pattern and on the need to exploit natural water resources (Caliandro and Boari, 1996). Four critical periods in crop growth: sowing, panicle initiation, flowering and grain filling are considered to be the most sensitive to drought stress. Any one of these stages are considered moisture deficit if the rain fall in the corresponding week is less than 20mm (Athavale, 1985).

Supplemental irrigation provides multiple benefits: higher and more stable yields, lower risk of crop failure, and significantly higher water productivity (the amount of grain or biomass produced per liter of water) (Oweis and Ahmed, 2012).

Experiences: regional, national

In the highlands of Turkey, applying 50 mm of SI to wheat sown early has increased grain yield by more than 60%, adding more than 2 t/ha to the average rain-fed yield of 3.2 t/ha. Similar results were found in the Iran highlands for wheat and barley (Oweis and Ahmed, 2012).

At kobo (south Wello) experiment done on sorghum showed that supplementing sorghum every eight days starting from development stage about 330 mm water increased sorghum yield by 1.88 ton which is 60% yield increment as compared to the traditional sorghum production practice in the area.

4.2.5. SPATE IRRIGATION

Definition : Spate irrigation is the art and science of water management whereby water from mountain catchments is diverted from river beds (wadis) and spread over large areas. It is a type of water management unique to arid and semi-arid regions bordering highlands (FAO, 2010).

Description of the technology (When, where and how to apply the technology)

Arid and Semi-Arid areas are endowed with numerous seasonal rivers that bring huge seasonal, short and heavy floods. These floods are often unpredictable and can be destructive, if not managed properly, leading to eroded and degraded river valleys, loss in arable and pasture land, and depletion of soils. Flood-based farming systems (FBFS) are the only option to transform such seasonal floods from forces of destruction to sources of livelihood for the most vulnerable ASAL community. FBFS are for multiple uses: crop, rangeland and agro-forest production, domestic and livestock water supply, recharging groundwater, soil conservation and rehabilitation of degraded land as well as climate change adaptation (Mekele University, 2014).

Spate systems are made in such a way that ideally the largest floods are kept away from the command area. Very large floods would create considerable damage to the command area. They would destroy flood diversion channels and cause rivers to shift. Spurs and bunds are generally made in such a way that the main diversion structures in the river break when floods are too big.

The structures are sometimes spectacular: earthen bunds, spanning the width of a river, or extensive spurs made of brushwood and stones. Spate systems are very risk-prone. The uncertainty comes both from the poorly predictable nature of the floods and the frequent changes to the river beds from which the water is diverted (FAO, 2010).

Figure 4.5: Traditional spate irrigation intake in Ethiopia (b) Field to field water distribution (Source FAO, 2010)

Sudden floods, or spates, usually originate from sporadic rainfall in macro catchments. After the land is inundated, crops are sown – sometimes immediately, but often the moisture is stored in the soil profile and used later. Spate irrigation systems support farming systems – usually cereals and oilseed, but also cotton, pulses and even vegetables (FAO, 2010).

Spate irrigation systems are generally situated in remote areas where there is deep-seated poverty and support systems are weak. There is often little equipment and few market facilities that could upgrade production systems. In several spate irrigated areas in Ethiopia, there is no access to the earth-moving equipment that would make a big difference in developing diversion structures and rehabilitating land and channel systems. This type of water management is very risk-prone and requires high levels of cooperation between farmers to divert and distribute flood flows (FAO, 2010).

Experiences: regional, national

Spate irrigation is highly practiced in various regions. There are no accurate data on the area under spate irrigation globally, but estimates place it at 2.0-2.5 million hectares (ha). The largest area under spate irrigation is in Pakistan which is about 1,402,000 ha. There are substantial areas under spate irrigation in Somalia (150,000 ha), Sudan (146,000 ha), Yemen (115,000 ha), Algeria (110,000 ha), Ethiopia (140,000 ha) and Morocco (79,000 ha) (Steenbergen and Mehari, 2009). In Ethiopia also there are good experiences of spate irrigation practices in various areas of Konso, Eastern Harargie, Northern Tigray, and Afar regions (IFAD, 2010).

Spate irrigation is practiced in southern region at Konso by a project support from Konso development Association and FARM- AFRICA. The project aimed to build the local capacity to withstand the recurrent drought affecting this region (Camacho, 2000).

4.2.6. APPROPRIATE IRRIGATION SCHEDULING

Irrigation scheduling involves the application of irrigation water based on a systematic monitoring of crop soil-moisture requirements. Different scheduling methods may be used to determine the optimal timing and depth of irrigation to meet changing crop needs over the production season. Proper use of irrigation scheduling is one means of improved OFWM practices. For efficient irrigation water use during scheduling:

- Schedule irrigation based on a good knowledge of crop water needs for each stage of development from seedling to mature crop
- Schedule irrigation according to rainfall. Monitor rainfall with a rain gauge
- Schedule irrigation according to soil types and their soil water holding capacity
- Make sure irrigation never extends over non-cropped surfaces
- Schedule irrigation during the night, early morning or on cloudy days for overhead irrigation

4.3. IMPROVED AGRONOMIC PRACTICES

Improved agronomic practices are steps farmers incorporate into their farm management systems to improve soil quality, enhance water use, manage crop residue and improve the environment through better management.

Agronomic practices encompass many areas of conservation from practicing reduced-tillage methods, which lessen the need to till the soil before each crop, to managing planting populations, which ensures crops are not over- nor under-crowded – and therefore are in optimal growing conditions.

Weed management

Weeds compete with crops for space, light, and water and can reduce crop yields by a considerable amount. Therefore, keep the farm weed-free by manual weeding, cultural method or application of herbicides are important agronomic practices.

Crop rotation

One of the most effective ways to improve on farm water management practices on irrigated agriculture is to adopt crop rotations of various species which include crops with low water requirements both daily and seasonally. It is an agricultural management practice that could save on the applied irrigation water, while improving resources use efficiency of schemes. Furthermore, it could increase land and water productivity. It involves a deliberate arrangement of crops planted on same field; the succeeding crops should belong to different families.

Some of the general benefits of using rotations are to improve or maintain soil fertility, reduce the spread of pests, reduce risk of weather damage, and increase soil water management, which will be reflected on increasing net profit of farmers. The ultimate goal should be to offer alternatives of different forms of crop rotations with less water requirements and same proportions commodities (cereals, sugar crops, oil crops and forage crops), as compared to the prevailing crops rotations, which is less benefit to the soil with high water requirements.

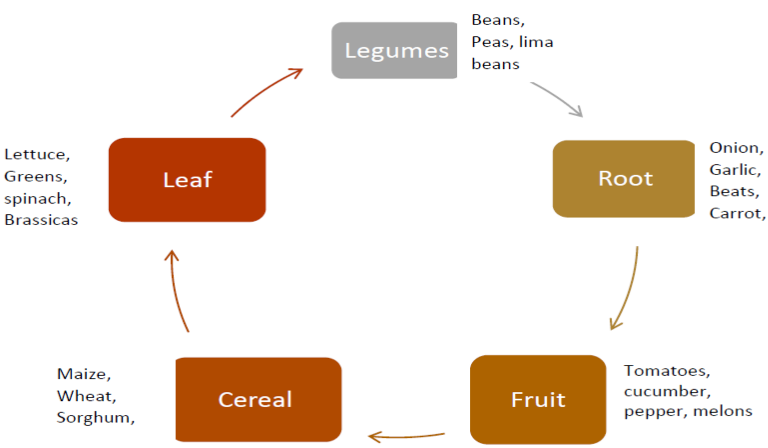


Figure 4.6 Appropriate Crop Rotation Diagram

Conservation agricultural practices

Cultural practices such as reduced or minimum tillage, minimum soil disturbance, can all contribute to improve OFWM practices. Employing tie ridges, zai pits, soil bunds, terraces are also proven technologies to improve water availability to crops.

Conservation tillage helps preserve soil moisture by leaving at least 30% of the soil surface covered with crop stubble, thereby decreasing wind and water erosion. The crop stubble layer reduces evaporation in the soil profile by one-half compared to bare soil.

Appropriate Crops Selection

Plants differ in their ability to withdraw water from soils, their water use rate, and their ability to withstand soil water stress. Choosing adapted and water- efficient crops and varieties is a main component of OFWM practices. In this respect, there will likely be a shift to crops that mature more quickly, high value crops (vegetables), or various pulse crops such as chickpeas, peas and lentils. Shifts to deep rooted, drought-resistant crops such as sunflower and safflower may also occur to maximize use of precipitation stored in the soil.

Irrigation Application at Critical Crop Growth stages

There are some crucial stages in the life cycle of a crop plant when the plant is badly in need of water. Allowing water stress beyond a certain limit during these stages of crop growth causes a definite set back to growth processes and that ultimately affected the yield. These stages are referred as the *critical stages of water requirement of crops* are indicated in Table 16.

Table 16. Sensitive growth periods to water deficit of major irrigated crops

Crop	Critical growth stages /periods to water deficit
Maize	Flowering > grain filling > vegetative period; flowering is very sensitive if no prior water deficit
Wheat	Flowering > yield formation > vegetative period
Groundnut	Flowering > yield formation, particularly during pod setting
Potato	Period of stolonization and tuber initiation > yield formation > early vegetative and ripening
Onion	Bulb enlargement, during rapid bulb growth > vegetative period /and for seed production at flowering/
Pepper	Throughout but particularly just prior and at start of flowering
Tomato	Flowering > yield formation > vegetative period, particularly during just and after transplanting

Crop	Critical growth stages /periods to water deficit
Banana	Throughout but particularly during first part of vegetative period, flowering and yield formation
Cabbage	During head enlargement and ripening
Alfalfa	Just after cutting (and for seed production at flowering)
Citrus	Grapefruit, lemon and orange flowering and fruit setting > fruit enlargement for lemon heavy flowering may be induced by withholding irrigation just before flowering
Cotton	Flowering and boll formation
Grape	Vegetative period, particularly during shoot elongation and flowering > fruit filling
Pineapple	During period of vegetative growth
Rice	During period of head development and flowering > vegetative period and ripening
Sugarcane	Vegetative period, particularly during period of tillering and stem elongation > yield formation
Watermelon	Flowering, fruit filling > vegetative period, particularly during vine development
Bean	Flowering & pod filling, vegetative period not sensitive when followed by ample water supply
Pea	Flowering and yield formation > vegetative, ripening for dry peas
Safflower	Flowering and pod filling > vegetative
Sorghum	Flowering > yield formation > vegetative period less sensitive when followed by ample water supply
Soybean	Flowering and yield formation, particularly during pod development
Sunflower	Flowering and yield formation, particularly during bud development
Tobacco	Period of rapid growth, yield formation and ripening

Source: Irrigation agronomy manual, former MoA- Agricultural Development Department, March 1990, Addis Ababa.

It is true that crops require adequate water supply throughout their life cycle for best growth and development to obtain optimum yield. Only in the later stages of crop maturity, water supply is reduced or cut- off to obtain uniform and quicker crop maturity. In areas of water scarcity crop allowed standing water stress to some extent during the crop growth period, avoiding critical stages for water deficit to save water.

UNIT 5

SOIL-WATER PROBLEMS, PREVENTION AND RECLAMATION METHODS OF IRRIGATED AGRICULTURE

5.1 SOIL-WATER PROBLEMS

Good quality irrigation water is essential to maintain the soil crop productivity at a high level. The essential prerequisite for quality irrigation water is that it should be safe for use to crops and should not damage soils. Poor quality water damages soils usually by making them saline or alkaline with salt accumulation that injures crops and causes a reduction in yield. Irrigated area is increasing every year and simultaneously lands damaged by salinity and alkalinities are also increasing. It is, therefore, necessary to judge the quality of water before its use and follow certain precautions in irrigating lands with saline water when there is a compelling situation for its use. The two major irrigation induced soil water problems are water logging and soil salinization;

5.1.1. WATER LOGGING

Excess water in the root zone is detrimental to crop production as:

- it restricts soil aeration,
- affects soil temperatures,
- hinders with tillage operations, etc.

Excess water slowly builds up the water table, which ultimately comes up to the root zone and even up to the ground level. Water logging is a term used to describe the conditions when the water table comes near the surface such that crop growth is affected.

Causes of water logging:

1. Over and intensive irrigation

Figure 5.1: a typical figure representing over irrigation

2. **Inadequate drainage:** The prolonged flooding or inundation results in heavy percolation of water into the ground, which causes a rise of water table and hence waterlogging in the absence of sub-surface drainage system.
3. **Obstruction of natural surface drainage:** If a natural drainage (stream) near the irrigated land is obstructed by constructing an embankment for a road, a canal, a railway etc., the flooding of the area may occur leading to waterlogging
4. **Obliteration of a natural drainage:** If an existing natural drainage is obliterated (destroyed), it results in stoppage of natural flow and consequent flooding and waterlogging.
5. **Obstruction of natural subsurface drainage:** If there is an impermeable stratum below the land surface at a relatively low depth, it prevents the natural downward movement of water into the subsoil. It may result in the formation of high-perched water table, which may be the cause of waterlogging
6. **Impervious top layer:** if the top layer of the land is impervious such as black cotton soils, it obstructs the flow of water in the downward direction.
7. **Seepage from canal, reservoir and adjoin land:** water seep from the bed and sides of unlined canal. It adds to the groundwater reservoir and there is a general rise in the water table, which may lead to waterlogging.
8. **Defective methods of cultivation:**
   - Construction of high levees (bunds),
   - inadequate preparation of land,
   - failure to smoothen the field after tillage,
   - improper disposal of spoil earth,
   - improper selection of crops
9. **Defective irrigation practices:** Waterlogging may also occur due to defective irrigation, applying high depth of water and using defective method of application of water like wild flooding.

Effects of water-logging:

- Reduction in growth of plants: aeration
- Difficulty in cultivation: slushy and puddle soils
- Swampy land.
- Increase in natural plants and flora: plants such as cat tail, bull rush, grass etc. grow in marshy, waterlogged land and there is a reduction in the crop yield.
- Encourage weed Growth
- Water-logging also leads to salinity
- Increase in plant diseases
- Fall in soil temperature
- Increase in incidence of malaria

5.1.2. SOIL SALINITY

Origin of salinization are categorized in two ways; Primary salinization/minerals and secondary salinization

a) **Primary salinization;** Geologic materials are highly variable in their elemental composition and some materials are higher in salts than others.
   - Shales, especially those of marine origin, can supply large quantities of soluble salts when traversed by water
   - Residual or fossil salts of former alluvial, colluvial, lacustrine or marine environments ,

During the process of chemical weathering which involves hydrolysis, hydration, solution, oxidation, carbonation and other processes, the salt constituents are gradually released and made soluble. The ionic constituents of salt affected soils are released and made soluble from rocks and weather able minerals during the processes of geochemical and pedo-chemical weathering. The released salts are transported away from their source of origin through surface or groundwater streams. The salts in the groundwater stream are gradually concentrated as the water with dissolved salts moves from the more humid to the less humid and relatively arid areas. Those concentration can be seen from;

- collection of saline sediments in catchment areas,
- irrigation waters and/or fertilization

Soluble salts are salts in the soil which readily dissolve and become concentrated in the soil surrounding the root-zone to cause salt affected soils pronounced in arid and semi-arid regions of the earth. The insufficient annual rainfall (evapotranspiration exceeding precipitation) to leach down salts from the plant rooting zone favours the excessive accumulation of salt constituents in soils of arid and semi-arid regions.

b) **Secondary Salinization;** It is manmade salinization due to poor irrigation water management. The processes of secondary salinization and alkalization of soils of arid and semi-arid climatic regions are the consequences of quite diverse and interacting factors of:
   - surface and ground waters,
   - soil physical properties,
   - climate,
   - relief and geomorphology,
   - biological activities and man's interference

Causes of Secondary salinization;

1. **Improper irrigation schemes management, including:**
   - insufficient water application;
   - insufficient drainage;
   - irrigation at low efficiency (where most of the water leaks into the groundwater) and/or over-irrigation contribute to a high water table, increasing drainage requirements and causing water-logging and salinity build-up
   - Irrigation with saline or marginal quality water, which may be caused by intrusion of saline water into fresh water aquifers in coastal zones due to over pumping.
2. **Poor land leveling -** small differences in elevation may result in salinization of the lower parts, as the water table is closer to the surface and is subject to greater evaporation;
3. **Dry season fallow practices in the presence of a shallow water table;**
4. **Misuse of heavy machinery leading to soil compaction and poor drainage;**
5. **Excessive leaching during reclamation techniques;** on land with insufficient drainage;
6. **Use of improper cropping patterns and rotations;**
7. **Chemical contamination;** as a result of intensive farming, where large amounts of mineral fertilizers have been applied over a long period of time.

5.2. CLASSIFICATION OF SALT- AFFECTED SOILS

Based on their chemical properties and ease of reclamation, salt affected soils are classified in to three groups

1. saline (or saline non-sodic) soils,Salt-affected soils may contain an excess of water soluble salts
2. saline sodic (or saline alkali) soils, and both an excess of salts and exchangeable sodium
3. sodic or alkali (or non-saline sodic) soils excess exchangeable sodium

Table-26: Classification of soil salinization

Salt affected soil type	Electrical conductivity of saturation extracts (ECe) at 25 °C (dS/m)	Saturation (%) of cation exchange capacity with Na (ESP)	Reaction (pH value)
Saline soil	> 4	< 15	<8.5
Saline sodic soil	> 4	> 15	<8.5
Sodic (alkali) soil	< 4	> 15	8.5-10
Non-saline non-sodic	< 4	< 15	≈ Neutral

Saline Soils: are soils where soluble salts are present in the soil solution in greater quantity that is enough to interfere with the growth and productivity of most crop plants. They are characterized by an ECe > 4 mmhos/cm (dS/m), ESP < 15 and a pH reading < 8.5. Saline soils are usually recognized with the presence of white crusts of salts on the surface soil during dry weather formed through the loss of water of crystallization. In saline soils the principal anions are chloride, sulfate, small amounts of bicarbonate, and occasionally some nitrate

Figure 5.2: White salt crusts on the surface soils on the ridges of irrigated lands (Sources: Wabi Shebele River basin indicating the presence of high soil salinity)

Saline sodic soils: contain soluble salts and exchangeable Na in quantities high enough to adversely affect the growth and productivity of most crop plants. These soils are characterized by ECe > 4 mmhos/cm, an ESP > 15, and a pH reading < 8.5. As the name indicates that saline sodic soils have the problem of both salinity and sodicity. Therefore, saline sodic soils possess the appearance of and properties of both saline and sodic soils and characterized by hard subsoils and more or less impermeable to water. In saline sodic soils the dispersing effect of the exchangeable Na may counterbalance by the coagulating effect of the soluble salts present in excessive concentrations in the soil. Thus, unlike sodic soils saline sodic soils are typically well-structured and flocculated.

Figure 5.3 : Saline sodic soils at Melka-Sadi irrigated farm

Sodic: contain excessive quantities of exchangeable sodium in their exchange complex as to interfere with the growth and production of most crop plants. These soils are characterized by an ESP > 15, and ECe < 4 mmhos/cm and a pH reading > 8.5 or usually ranging between 8.5 and 10. Sodic soils are typically poorly- structured, characterized by the presence of dispersed colloidal clays and organic matter in the top soil. The presence of dispersed colloidal clays and organic matter on the surface of the soil attributed to swelling of clay and organic colloidal physically damages soil structure that leads to permeability and drainage problems, low infiltration rates, poor aeration, surface crusting and difficult to till and for plant roots to penetrate through. In addition to deterioration of soil physical properties, the presence of Na can exert toxic effects on plants.

Figure 5.4: sodic soils at Melka sedi irrigation land

5.3. WATER QUALITY FOR IRRIGATION

Irrigation waters drawn from different sources, surface or underground contains variable quantities of salts, silts and/or other materials. The quality and the quantity salts and silts present in the water depend on the nature of water sources, and the soils and underground strata over which the water flows. River and tank waters carry silts in suspension and salts in solution, whereas well water contains only dissolved salts. Pumped out underground water contains salts in solution and may sometimes contain silts in suspension. The silt content in running water, as in rivers, is usually higher and coarser in texture than in still water of tanks and reservoirs.

5.3.1. ORIGIN OF SALTS AND ITS CHEMICAL COMPOSITION IN IRRIGATION WATER

Salts in irrigation water originate primarily through weathering of bedrocks, rocks and minerals. In humid climates, these salts usually get drained out to rivers and seas, while in semi-arid and arid climates, they accumulate in soil profile at lower levels or drain out to lower areas. When the soil water from upper soil layers evaporates, salts come up and accumulate in upper layers and on the soil surface. Accumulation of salt is more serious in low laying areas. Ground water has a higher salt content than the surface water.

Salinity is a common problem facing farmers who irrigate in arid climates. This is because all irrigation waters contain soluble salts. Whether derived from springs, diverted from streams, or pumped from wells, the waters contain appreciable quantities of chemical substances in solution, dissolved from the geological strata through and over which the waters have flowed. Waters with a high salt content may have moved from a saline water table. In areas with intensive agriculture, fertilization is a major cause of aquifer salinization.

The composition of salts in water varies according to the source and properties of the constituent chemical compounds. These salts include substances such as gypsum (calcium sulphate, CaSO4.2H2O), table salt (sodium chloride NaCl) and baking soda (sodium bicarbonate NaHCO3). When dissolved in water, salts separate into ions; e.g. sodium chloride breaks down into sodium and chloride ions. Thus, it is customary to refer to ions rather than salts. The principle ions in irrigation water and their characteristics are listed in Table 17.

Table 27: Principle ions present in irrigation water

Ions	Chemical symbol	Equivalent weight
Anions (acidic ions)		
Chloride	Cl^-	35.5
Sulphate	SO_4^{--}	48
Carbonate	CO_3^{--}	30
Bicarbonate	HCO_3^-	61
Nitrate	NO_3^-	62
Cations (basic ions)		
Sodium	Na^+	23
Potassium	K^+	39.1
Calcium	Ca^{++}	20
Magnesium	Mg^{++}	12.2

All ions are expressed in the form of milligrams per litre (mg/litre or ppm) and mill equivalents per litre (meq/litre). The latter unit is preferable because water quality criteria involve mill equivalents per litre calculations.The conversion formula is:

$$meq/litre = \frac{mg}{litre\ equivalenweight}$$

Boron is also present in irrigation waters as un-ionized boric acid expressed as boron element (B) in milligrams per litre. The salt concentration in most irrigation waters ranges from **200 to 4000 mg/litre** total dissolved solids (TDS). The pH of the water is also an indicator of its quality and it normally ranges from 6.5 to 8.4.

The common method for evaluating the total salts content in water is by measuring the electrical conductivity of water (ECw) at 25°C. Electrical conductivities is expressed in Deci Siemens per metre.There is a relation between the electrical conductivity and the concentration of salts in mill equivalents per litre and in milligrams per litre when the ECw is in the range of 1–5 dS/m. Thus, every 10 meq/litre of salts (cation concentration) create 1 dS/m ECw. The relationship between electrical conductivity and total dissolved salts (TDS) is:

$$ECw\ (ds/m) \times 640 = TDS\ (mg/litre)$$

The sum of cations should equal the sum of anions. The accuracy of the chemical water analyses should be checked on the basis of the above relationships.

5.3.2. WATER QUALITY CRITERIA

There have been calls to establish standards as a guide for judging the suitability of water for irrigation. Any classification should be based on the total concentration and the composition of salts. However, the suitability of water for irrigation also depends on other associated factors, such as the crop, soil, climate and management practices. The classification adopted by FAO in 1985 (after Maas), and proposed as an initial guide (Table2), has proved most practical and useful in assessing water quality for on-farm water use. The principal parameters for water classification (crop response to salinity, sodium hazard and toxicity) are quite clear and understood by both the extension engineers and the farmers themselves for proper irrigation management and follow-up purposes.

With the FAO assessment method, the parameters taken into consideration are the four presented below.

Table 28 : Water classification by salinity

Salinity classification	EC ds/m	TDS mg/litre
Non-saline water	< 0.7	< 500
Saline water	0.7-42	500- 30000
Slightly saline	0.7-3.0	500- 200
Medium saline	3.0- 6.0	2000- 4000
Highly saline	> 6.0	>4000
Very saline	>14.0	>9000
Brine	>42.0	>30000

- **Electrical conductivity (EC)**

Water that contains salt is able to conduct electricity. The more salt there is in a solution, the easier it is for and electric current to flow. The potential of a solution to pass an electric current is called electrical conductivity (EC) and it is usually measured in micro Siemens per centimeter (µS/cm). This is often expressed simply as an 'EC Unit'.

As the concentration of salt in a solution increases, so does the EC reading. An EC meter can also be used to measure the amount of salt in soil by mixing a soil sample with water and then testing the EC of the solution. The most commonly used units of EC measurement is 'EC Units' or 'µS/cm'. Other units for measuring salinity are:

- Deci Siemens per meter (dS/m)
- milli Siemens per centimeter (mS/cm)
- millimho per centimeter (mmhos/cm)
- Parts per million in water (mg/litre)

- **Converting units of measurement**

One unit of measurement can be converted to another by using the following information: Eg.1000 EC (µS/cm) = 1dS/m = 1mS/cm = 1mmho/cm = 640 ppm.

Table-29: Converting units of measurement

To convert from this …..	To this ….	Do this
EC (µS/cm)	ds/m	Divide by 1000
ds/m	EC ((µS/cm)	Multiply by 1000
ds/m	Ppm	Multiply by 640

Table-30: Table water quality evaluation guideline

Potential Irrigation Problem		Units	Degree of Restriction on Use		
			None	Slight to Moderate	Severe
Salinity *(affects crop water availability)*[2]					
	EC_w	dS/m	< 0.7	0.7 – 3.0	> 3.0
	(or)				
	TDS	mg/l	< 450	450 – 2000	> 2000
Infiltration*(affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)*[3]					

SAR	= 0 – 3	And EC_w	=		> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6		=		> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12		=		> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20		=		> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40		=		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*							
	Sodium (Na)[4]						
	surface irrigation			SAR	< 3	3 – 9	> 9
	sprinkler irrigation			me/l	< 3	> 3	
	Chloride (Cl)[4]						
	surface irrigation			me/l	< 4	4 – 10	> 10
	sprinkler irrigation			me/l	< 3	> 3	
	Boron (B)[5]			mg/l	< 0.7	0.7 – 3.0	> 3.0
	Trace Elements (see Table 21)						
Miscellaneous Effects *(affects susceptible crops)*							
	Nitrogen (NO_3 - N)[6]			mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)						
	(overhead sprinkling only)			me/l	< 1.5	1.5 – 8.5	> 8.5
	pH				Normal Range 6.5 – 8.4		

Table 31: Laboratory determinations need to evaluate common irrigation water quality problems

Water parameter	Symbol	Unit[1]	Usual range in irrigation water	
SALINITY /salt content				
Electrical Conductivity	Ec_w	dS/m	0 – 3	dS/m
Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
<u>Cations and Anions</u>				
Calcium	Ca^{++}	me/l	0 – 20	me/l
Magnesium	Mg^{++}	me/l	0 – 5	me/l
Sodium	Na^{+}	me/l	0 – 40	me/l
Carbonate	CO_3^{--}	me/l	0 – .1	me/l
Bicarbonate	HCO_3^{-}	me/l	0 – 10	me/l
Chloride	Cl^{-}	me/l	0 – 30	me/l

Sulphate	SO_4^{--}	me/l	0 – 20	me/l
NUTRIENTS[2]				
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^+	mg/l	0 – 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 – 2	mg/l
Acid/Basicity	pH	1–14	6.0 – 8.5	
Sodium Adsorption Ratio[3]	SAR	(me/l)[1], [2]	0 – 15	

5.4. EFFECT OF SALINIZATION

SALINITY: Salts in soil or water reduce water availability to the crop to such an extent that yield is affected.

WATER INFILTRATION RATE: Relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately from one irrigation to the next.

SPECIFIC ION TOXICITY: Certain ions (sodium, chloride, or boron) from soil or water accumulate in a sensitive crop to concentrations high enough to cause crop damage and reduce yields.

MISCELLANEOUS:

- Excessive nutrients reduce yield or quality;
- unsightly deposits on fruit or foliage reduce marketability;
- excessive corrosion of equipment increases maintenance and repairs

Effect of salinization on crop

- The salt concentrations in the soil primarily increased the osmotic pressure of the soil water, and thereby reducing the plants ability to take up water through their roots;
- Soluble salts increased the concentrations of certain ions that have characteristic toxic effects on plant physiological processes;

- Presence of excessive accumulations of specific ions and/or salts in the soil creates nutritional disorders of essential nutrients;
- Excessive exchangeable sodium in the soil causes alteration of soil physical properties by swelling and dispersion of soil colloidal particles and finally resulting in poor water movement and infiltration, aeration root penetration and seedling emergence problems;
- The salt affected soils can also adversely affect the population, composition and activity of beneficial micro- organisms either through osmotic effects or toxicity of certain ions of such soils.

Crop plants vary in their sensitivity to salinity; crops like beans, maize, carrot, onion, lettuce are more sensitive than others, notably, barley, cotton, and sugar beet, which have a high tolerance to salt. The relative salt tolerance nature of crops to salinity is shown in Table1.5 below

Table 32 Relative salt tolerance of crops in decreasing order

Tolerant Semi	Tolerant Sensitive	Tolerant Semi	tolerant Sensitive
Barley	Oats	Potato	Field beans
Sugar beet	Rice	Carrot	Peas
Tobacco	Sorghum	Onion	Green beans
Cotton	Maize	Pea	Apple
Wheat	Sunflower	Cucumber	Orange
Beet root	Sesame	Grape	
Asparagus	Linseed	Guava	
Spinach	Lucerne	Mango	
Coconut	Tomato	Banana	
	Cabbage	Sugar cane	
	Cauliflower	Strawberry	
	Lettuce		

5.5. PREVENTION AND RECLAMATION

The procedure of the prevention, management and reclamation of salt affected soils depends upon the type of the problem under consideration, its cause and other factors influencing its management and reclamation activities.

5.5.1. IRRIGATION WATER MANAGEMENT

- It is one of the best prevention mechanism by providing and controlling;
- Controlling the intensity of irrigation
- Providing a drainage system
- Providing intercepting drains
- Lining of canals and surface of reservoir

For large reservoirs, suitably designed to filters should be provided so that the seepage from the reservoirs is discharged into the natural streams.

- ***Improving the natural drainage of the area: River training***
- ***Adopting well irrigation or conjunctive use of water: water table reduction***

Water logging prevention needs:

- Changing the cropping pattern: crop requiring heavy irrigation
- Adopting better method of application of water:
- Education: the water users should be aware of ill effects of waterlogging

Proper irrigation water management practices means

- ***What to irrigate***
- ***When to irrigate***
- ***How to irrigate***

5.5.2. SOIL AND AGRONOMIC MEASURES:

- Tolerant crop varieties for their tolerance was one of the biological practices in salt affected soils.
- Practice minimum tillage to avoid soil compaction, maintains good soil structure, improve surface and internal drainage, and to facilitate deep leaching.
- Practice surface mulching; organic matter and crop residue management to reduce evaporation, develop desirable soil structures that will improve water movement and root penetration hence facilitate deep leaching and reduce salt accumulation.
- Avoid irregular water intake to prevent accumulation of salts beneath the high spots or ridges through proper or regular land leveling
- Proper land selection, i.e., avoid cultivation of lands with high water table and hard pans that will perch added water and impede drainage;
- Avoid bringing sub-soil with high sodium and salt accumulation to the surface during land leveling; if necessary spreading uniform layer salt free soil on the surface after land leveling operation.

- Use quality irrigation water, practice proper irrigation, applying the required amount of water depending on crop type and growth stages, nature of the soil, level and quality of groundwater, and climatic conditions of a given locality.
- Maintain high level of available water in the plant root zone during critically crop growth stages.
- Pre and post planting leaching removal of accumulated salts from the root zone of saline soils through a heavy application of quality irrigation water to insure adequate surface and sub-surface drainage.
    - **Use lined canals or other salt-free conveyance or water ways** at least for primary and secondary irrigation canals crossing soil layers with high salt accumulation.
- **Select proper seeding/planting method and shaping** properly so that salts will not accumulate in the root zone of germinating seeds and growing seedlings; establish the optimum plant population to avoid competition among plants and to assure normal growth of crops.
    - Grow crops or crop species, which are salt or sodium tolerant and sensitive crops or crop species in rotation.
    - Grow ameliorating crop species and/or perennial forage grasses where the latter in turn may initiate livestock farming, such as beef fattening.
    - Grow salt and sodium tolerant crops, trees, legumes, etc.
    - This practice will be more feasible and advisable in areas having soils with high concentration of salt in the liquid phase due to continues salinization.
- Initiating reclamation of saline-alkali and alkali or sodic soils through chemical amendments where calcium sources such as gypsum ($Ca\ SO_4.2H_2O$) are available and usable.
    - Select proper seeding/planting method and shaping seedbeds properly so that salts will not accumulate in the root zone of germinating seeds and growing seedlings; establish the optimum plant population to avoid competition among plants and to assure normal growth of crops.
- Avoid **rejoining of drained water from lands containing high levels of sodium** and dissolved salts with the irrigation water sources; avoid reusing water from drainage system provided that it contains undesired salt families.
- Lessening the adverse effects of excessive salts and exchangeable sodium on plant growth by increasing the availability of plant nutrients through application of less available elements such as P, K, Fe, Mn, Zn, Cu and in some cases Ca and Mg too due to the high $CaCO_3$ content, high exchangeable sodium and alkaline (high pH value) soil reactions.
    - Select proper seeding/planting method and shaping properly so that salts will not accumulate in the root zone of germinating seeds and growing seedlings; establish the optimum plant population to avoid competition among plants and to assure normal growth of crops.

5.5.3. DRAINAGE OF AGRICULTURAL LAND

Drainage is the natural or artificial removal of a surface's water and sub-surface water from an area. The internal *drainage* of most agricultural soils is good enough to prevent severe waterlogging but many soils need artificial *drainage* to improve production or to manage water supplies. The function of the field drainage system is to control the water table, whereas the function of the main drainage system is to collect, transport, and dispose of the water through an outfall or outlet. In some instances one makes an additional distinction between collector and main drainage systems.

- To produce food and fiber for this growing population, the productivity of the currently cultivated area must be increased and more land must be cultivated.
- Land drainage, or the combination of irrigation and land drainage, is one of the most important input factors to maintain or to improve yields per unit of farmed land
- To enlarge the currently cultivated area, more land must be reclaimed than the land that is lost (e.g. to urban development, roads, and land degradation).

Land drainage, as a tool to manage groundwater levels, plays an important role in maintaining and improving crop yields: It prevents a decrease in the productivity of arable land due to rising water tables Drainage is the only way to reclaim accumulation of salts in the root zone; water-logging and salinity.

Choice of appropriate drainage according to the situation:

- surface drainage systems to collect and control water entering and/or leaving the irrigation site;
- subsurface drainage systems to control a shallow water table below the crop root zone;
- Bio-drainage: the use of vegetation to control water fluxes in the landscape through evapotranspiration.
- Adequate disposal of drainage waters to avoid contamination of receiving waters and the environment.

Figure 5.5: a typical adequate disposal of drainage water

Integrated Management practices for reclamation of salt affected soils:

a) **Biological**
- Organic matter application
- Mulching (e.g plastic mulch)
- Green manuring
- Tree plantation

b) **Hydraulic**
- Flushing
- Leaching
- Improving irrigation and drainage
- Safe disposal of salinized water

c) **Physical and mechanical**
- Scraping
- Land leveling
- Sub soiling
- Sanding
- Improving irrigation planning techniques

d) Chemical

- Chemical amendment
- Soil conditioning
- Use of Mineral fertilizer

e) Other considerations

- Following legal, social and environmental aspects
- Improve extension services
- Operation and maintenance
- Blue green algae
- Improve saline agricultural technology

Of the above integrated management system the following two are practiced largely

SUB-SURFACE DRAIANGE SYSTEM; Sub surface drains, are required for soils with poor internal drainage and a high water table. When no impervious layer occurs below the farm land and the water table is low (lower than about 3m from the ground), internal soil drainage may be sufficient and no tile drains needed. Subsurface drainage refers to the removal of excess water present below the ground surface. Agricultural lands affected by high water table generally need subsurface drainage.

Figure 5.6: sub-surface drainage (Photo: Amibara Irrigation Project)

BIO-DRAINAGE

Bio-drainage may be defined as "pumping of excess soil water by plants using their bio energy." This system consists of fast growing tree species, which absorb water from the capillary fringe located above the ground water table. The absorbed water is translocated to different parts of plants and finally more than 98% of the absorbed water is transpired into the atmosphere mainly through the stomata. This combined process of absorption, translocation and transpiration of excess ground water into the atmosphere by the deep rooted vegetation conceptualizes bio-drainage

Figure 5.7: principle of bio-drainage and Worer research center experimental field

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