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Ministry of Water and Irrigation

Water Quality Improvement and Conservation Project

Micro Irrigation Systems Training Modules - Vol. 1 Systems Operation

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MICRO IRRIGATION SYSTEMS
Training Modules

SYSTEM MANAGEMENT

2-1 Soil-Water System
2-2 Use of Saline Irrigation Water
2-3 Crop Water Requirements
2-4 Irrigation Scheduling

WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT
United States Agency for International Development
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MICRO IRRIGATION SYSTEMS

SOIL-WATER SYSTEM

[Supplemental]

1 INTRODUCTION

The principal direct effect of irrigation is the addition of water to the soil-water system The effect on the plant is brought about by conditions existing in the soil-water system after an irrigation Some knowledge of soils and the soil-water system is therefore desirable in understanding how irrigation affects plants

2 SOIL CHARACTERISTICS

Soil is composed of particles of different sizes and material and the spaces between them, which are called pores Most soil particles originate from the degradation of rocks and are called mineral particles Coarse, medium and fine solid particles are known as sand, silt, and clay respectively, and determine the texture of the soil Some particles originate from residues of plants and animals and are called organic particles Pores in a dry soil are mainly filled with air After an irrigation or rainfall the pores are mainly filled with water

2 1 SOIL TEXTURE

The mineral particles of the soil differ widely in size and can be classified as shown in Table 1

Table 1 Soil textural classifications

Particle Name	Size limits, mm	Distinguishable with the naked eye
gravel	larger than 1	obviously
sand	1 to 0 5	easily
silt	0 5 to 0 002	with difficulty
clay	less then 0 002	impossible

The amount of sand, silt and clay in the soil determines the soil texture Soil texture is considered a permanent feature, the farmer is unable to easily modify or change it

Coarse textured soils are gritty Individual particles are loose and fall apart in the hand, even when moist, and sands predominate A coarse textured soil is called light because it is easy to work

Medium textured soils feels very soft (like flour) when dry They can be easily pressed when wet and feel silky, silts predominant

Fine textured soils stick to the fingers when wet and can form a ball when pressed These soils are called heavy because they are hard to work clays predominant

Figure 1 is a textural triangle for classifying soils given the percent by weight of the sand, silt, and clay in the soil

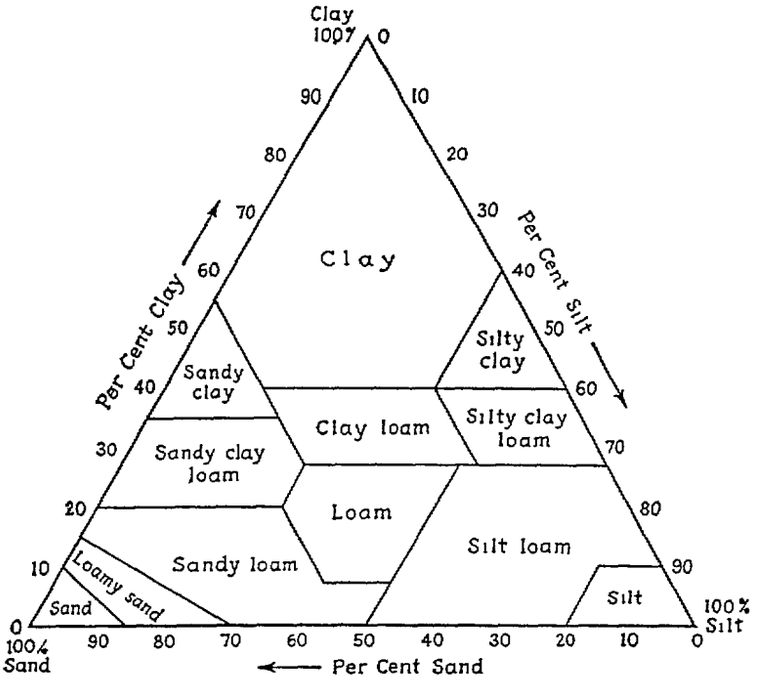

Figure 1 Texture triangle for soil given sand, silt, and clay percentages

2 2 SOIL STRUCTURE

Soil structure refers to the grouping of soil particles (sand, silt, clay, organic matter and fertilizers) into porous compounds These are called soil aggregates Soil structure also refers to the arrangements of these aggregates separated by pores and cracks

The basic types of soil aggregates are granular, blocky, prismatic and massive structure When present in the top soil, a massive structure blocks the entrance of water and seed germination is difficult due to poor aeration If the top soil is granular, the water enters easily and seed germination is better

Unlike soil texture, soil structure is not permanent By means of cultivation practices (plowing discing, ripping, and mulching) the farmer tries to obtain a granular topsoil structure for his fields

3 SOIL-WATER

The primary effect of irrigation is an alteration in the soil-water condition of the root zone The extent of this alteration depends on the amount of water added, how it is added, and the permeability of the soil profile Soil-water condition is a major

component of the root environment affecting the growth and health of roots Other components of the root environment affected by irrigation are soil aeration temperature and salinity

3 1 SOIL-WATER RETENTION

Water is held in the soil pores by attraction between the water molecules and the surfaces of the solid particles At a low water content water is spread as a thin film over the surfaces of all the soil particles The thinness of the film is dependent upon the amount of water present and the total surface area of all the solid particles Fine-textured (clay) soils have a greater particle surface area than coarse-textured (sandy) soils, so that a given amount of water is spread in thinner films An illustration of the total surface area of one kilogram of various-textured soils is presented in Table 2

Table 2 Illustrative total soil particle surface area per kilogram of soil

Soil Type	Surface Area (ha/kg)
Clay	20
Fine sandy loam	4
Loam	2
Sandy loam	0 4

When water films are thin water molecules are very close to the soil particle surfaces and are held tightly The tightness with which water is held is sometimes expressed in energy units, which represent the energy the plant must use to remove a definite amount of water from the soil This energy is more commonly expressed in pressure units of bars or atmospheres, which are about equal numerically and is called soil suction or soil-moisture tension

When all of the pore space is filled with water, a soil is saturated The energy required to remove a unit of water from saturated soil is low, and some water drains from the soil by gravity Drainage removes water from the largest pores, where it is weakly held and air space is created in these pores The remaining water is closer to the soil particles' surfaces and is held tightly enough to prevent rapid drainage by gravity This water condition when measured in the field, is called *field capacity* (assumed to occur 24 to 48 hours after thorough wetting by irrigation or rainfall) and indicates the upper range of water available to the plant, see Figure 2 At field capacity, the water and air contents of the soil are considered to be ideal for crop growth

In the process of water use by plants, first the medium and eventually the smaller soil pores lose water Water films gradually become thinner, and more energy is required to remove each additional quantity of water At first the change in energy requirement is slight and has little effect on the plant Since plant roots do not come in contact with every particle of soil in the root zone, water must move through the soil to reach root surfaces The distance traveled may be no

more than one or two millimeters or it may be several centimeters Water moves more rapidly in thick films than in thin films As water films become thinner the rate of flow decreases and eventually becomes too slow to meet the needs of the plant The ability of a plant to get water from the soil changes as the water film thicknesses change

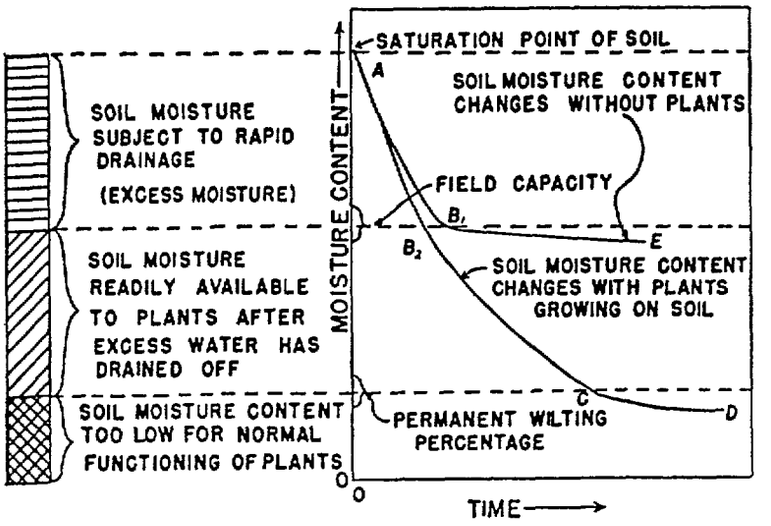

Figure 2 Decrease in water content as a function of time following an irrigation

When soil-water films become so thin that the plant wilts and remains wilted overnight, the soil-water condition is at the *permanent wilting point* At this point, plants do not have enough energy to remove water from the film Plants will generally suffer daytime wilting repeatedly before this condition is reached Permanent wilting point is normally used to indicate the lower range of soil moisture available to plants

The amount of water stored in the soil at field capacity minus the water that will remain in the soil at permanent wilting point is the amount of water plants can actually use, it is called the *available water content* It depends greatly on the soil texture and structure A range of values for different types of soil is given in Table 3 These values are only approximate and should be replaced by field measured quantities for irrigation system design and operation

Table 3 Soil texture and the normal range of available water contents

Soil Texture	Available water content (mm/m)
Sand	60 → 100
Sandy loam	90 → 150
Loam	140 → 200
Clay loam	160 → 220
Silty clay	180 → 230
Clay	200 → 250

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

3 2 SOIL-WATER MEASUREMENT

From the preceding discussion, it is apparent that water film thickness in the root-zone soil of a plant is an important consideration Instruments have been developed to measure soil suction, which is directly related to water film thickness These instruments use a porous material placed in contact with the soil to be measured Water moves until the films in the porous material of the instrument and in the adjacent soil are of equal thickness The indicating portion of the instrument registers the effect produced by the film thickness

Instruments in common use at present are of two types tensiometers and electrical-resistance blocks The **tensiometer** is a closed water-filled tube with a hollow porous ceramic tip at one end and a vacuum gauge at the other Water films in the ceramic tip exert a suction on the closed water column which registers on the vacuum gauge On commercial tensiometers, the vacuum gauges read directly in centibars (cb) of soil suction or moisture tension Tensiometers operate in the wetter portion of the soil-water spectrum from saturation (zero suction) to a dryness of about 80 cb

Electrical-resistance blocks, composed of a cast-gypsum porous material, are another means used in irrigation to measure the soil-water condition They are installed in the root zone and exchange water films with the soil The gyp n dissolves slightly in the moisture films contained in its pores The dissolved gypsum then acts as a conductor for an electric current applied between two electrodes embedded in the porous gypsum The amount of current conducted is indicated on a meter Thick water films dissolve more gypsum and conduct more current with less resistance than thin water films Gypsum blocks operate in the drier portion of the soil-moisture spectrum from about 50 to 1,500 cb

3 3 SOIL-WATER QUANTITY

Up to this point, we have been concerned with the physical condition of water in the soil and its relationship to plant performance It is sometimes desirable to consider the quantity of water in soil *It should be remembered that a knowledge of the quantity of water in a soil reveals nothing about its relationship to plant performance until it is calibrated in terms of the water-retention properties of the particular soil involved* Since all soils differ in water-retention characteristics, this calibration is required for every site at which a quantitative measurement is made if plant relations are of concern

The soil moisture quantity is commonly expressed as the depth of water, in mm present in one meters depth of soil For example, when 150 mm of water is present in one meter of soil, the soil moisture content is 150 mm/m The soil moisture content can also be expressed as a percent volume For example,

assume 1 m^3 of soil (surface area 1 m^2 and depth 1 m) contains 0 150 m of water (a water depth of 150 mm = 0 150 m over a surface area of 1 m^2) This results in a soil moisture content in percent volume of

$$\frac{0\ 15\ m^3}{1\ m^3} \times 100 = 15\ \%$$

Thus a soil moisture of 150 mm/m corresponds to a volumetric moisture content of 15 percent

To manage an irrigation system, information is needed about the rate at which water is used from the soil by evapotranspiration and the amount of water that can be usefully stored in the soil root zone The difference in water content of the soil between two successive measurements represents the evapotranspiration in a known time interval A succession of soil-water quantity measurements made over an extended period of time provides information on the water-use rate in the area studied

The amount of water that can presumably be stored by a soil is determined by making measurements of water content after the soil has been thoroughly wetted and drained and again when plants have dried the soil as much as seems desirable The difference in water content throughout the entire root zone between these two samplings gives the maximum amount of water that can be applied to the soil without loss by deep percolation This total water-storage factor combined with the water-use rates provides an estimate of the allowable interval between irrigations

The storage capacity of the soil in the root zone, as determined from water-quantity measurements, is sometimes useful in evaluating the efficiency of an irrigation If computation of the approximate storage capacity of the soil shows that it can retain an irrigation of about 9 centimeters in the root zone and a computation of the water application shows that 15 centimeters of water were applied, the inefficiency and waste from the application are quickly revealed

Water-quantity measurements usually are made by two distinct methods The older, most used method involves taking a sample of soil from a known depth in the root zone with a soil tube or auger The sample is weighed while wet and again after being thoroughly dried The loss of water upon drying, divided by the dry weight of the soil, gives the weight ratio of water in the soil When this figure is multiplied by the bulk density of the soil, determined from a separate measurement, the volume ratio of water in the soil is obtained This volume ratio multiplied by the length of soil column sampled gives the depth of water held in the soil Because soils vary from one location to another and because soil moisture samples are usually compared between two different sampling dates with samples taken from different positions in the soil, it is necessary to replicate the sampling several times for any given site to obtain satisfactory results The method of sampling plus the required replication makes the process laborious, and therefore it is not often used

The need for indirect methods for obtaining water content is evident when the time and labor involved in soil sampling are considered In addition to requiring a waiting time for oven drying, such determinations are destructive and therefore each sample must be taken at a different place in the soil system under study

Many of the indirect methods (neutron probe and soil moisture probes) permit *frequent or continuous* measurements in the same place and, after equipment is installed with only a small expenditure of time Thus, if a suitable calibration curve is available, changes in water content with time can be approximated

The relationship between the soil-water content and the soil-water potential is termed the *soil-water characteristic curve* Knowledge of the soil-water characteristic curve can be important in the design and management of irrigation systems Such curves are necessary to convert tensiometer or gypsum block readings in tension to the equivalent soil-moisture content

The characteristic curve gives an indication of the water available for plant growth for different soil types As shown in Figure 3 soil types made up of fine particles such as clays have a higher moisture content at the same tension as soils with coarser particles such as sands

The *feel method* is a practical technique that is used successfully to determine the moisture content of the soil A soil probe is used to obtain a sample from each position in the root zone profile, generally every $^1/_3$ meter in depth Each sample is then felt with the hand or squeezed between thumb and fingers The soil moisture depletion can be determined by comparing the *feel* of the soil sample to the information shown on Table 3 for the appropriate soil texture

Satisfactory results can be achieved with the *feel method* after some training Soil samples taken with the probe can be weighed oven dried, and weighed again to determine actual soil moisture as a check on the estimate made by the *feel method* The moisture removed from the soil profile is generally expressed as percent depletion

3 4 Movement of Water in Soil

The movement of water in soil is just as important as water retention in determining what the condition of the soil water will be during and after irrigations Several characteristics of water movement are considered below, including infiltration, permeability, saturated flow, unsaturated flow, and impediments to water flow

Infiltration – Infiltration is a term that refers to the downward movement of water into the soil The infiltration rate of a soil depends on factors that are constant, such as soil texture, and on factors that vary, such as soil structure and soil moisture, see Table 5 When water falls on the ground from a rain or from a micro irrigation system it enters the soil by the infiltration process When the

pores of the surface soil are large and remain open, infiltration may be a fairly rapid process The infiltration rate of a soil is commonly measured by the depth (in mm) of a water layer that the soil can absorb in an hour An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the surface of the soil, will take one hour to move into the soil

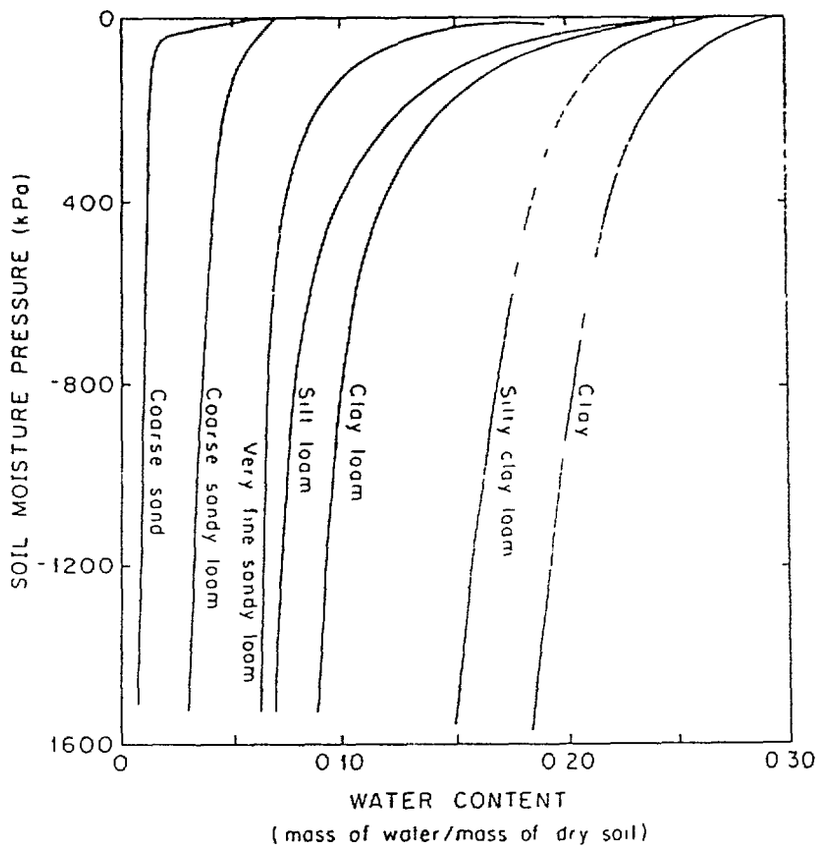

Figure 3 Soil water characteristics curves for several soil types

Table 5 Soil texture and the normal range of infiltration

Soil Texture	Infiltration rate (mm/hr)
Sand	25 → 250
Sandy loam	13 → 76
Loam	8 → 20
Clay loam	2 5 → 15
Silty clay	0 3 → 5
Clay	0 1 → 1

If the pores of the soil are small or if initially large pores become plugged, the infiltration rate will be slow, sometimes reaching values less than 2 5 mm per hour An average infiltration rate that is in the range from 15 mm to 50 mm per hour will generally provide the greatest ease and efficiency of irrigation Soils having infiltration rates above or below this range can be efficiently irrigated, but they require more attention, time, and special practices or equipment

Table 3 Feel method for judging how much of the available moisture has been removed from the soil

Soil moisture deficiency	Feel or appearance of soil and moisture deficiency in centimeters of water per meter of soil depth			
	Coarse texture	Moderately coarse texture	Medium texture	Fine and very fine texture
	Sandy, Loamy sand, Sandy Loam	Sandy loam, Sandy Clay Loam, Loamy Sand	Sandy Loam, Loam, Silt Loam	Clay loam, Silty Clay Loam, Clay, Silty clay, Silt Loam
0% (field capacity)	Upon squeezing, no free water appears on soil but wet outline of ball[1] is left on hand **0 0 cm/m**	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand **0 0 cm/m**	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand **0 0 cm/m**	Upon squeezing, no free water appears on soil but wet outline of ball is left on hand **0 0 cm/m**
0 - 25%	Tends to stick together slightly, sometimes forms a very weak ball under pressure **0 0 → 1 7 cm/m**	Forms weak ball, breaks easily, will not slick[2] **0 0 → 3 3 cm/m**	Forms a ball, is very pliable, slicks readily if relatively high in clay **0 0 → 4 2 cm/m**	Easily ribbons out between fingers, has slick feeling **0 0 → 5 0 cm/m**
25 - 50%	Appears to be dry, will not farm a ball with pressure **1 7 → 4 2 cm/m**	Tends to ball under pressure but seldom holds together **3 3 → 6 7 cm/m**	Forms a ball somewhat plastic, will slick slightly with pressure **4 2 → 8 3 cm/m**	Forms a ball, ribbons out between thumb and forefinger **5 0 → 10 0 cm/m**
50 - 75%	Appears to be dry, will not farm a ball with pressure **4 2 → 6 7 cm/m**	Appears to be dry, will not form a ball **6 7 → 9 2 cm/m**	Somewhat crumbly but holds together from pressure **8 3 → 12 5 cm/m**	Somewhat pliable, will ball under pressure **10 0 → 15 8 cm/m**
75 - 100%	Dry, loose single-grained flows through fingers **6 7 → 9 2 cm/m**	Dry, loose, flows through fingers **9 2 → 12 5 cm/m**	Powdery, dry, sometimes slightly crusted but easily broken down into powdery condition **12 5 → 15 8 cm/m**	Hard, baked, cracked, sometimes has loose crumbs on surface **15 8 → 20 8 cm/m**

1 The **Ball** is formed by squeezing a handful of soil firmly
2 To slick means that the exterior of the ball glistens with moisture though free water is not present

Generally, the infiltration rate is relatively high for a dry soil, steadily decreasing during the period of water application This decrease in rates is caused by the increased resistance to water flow as the soil particles expand or swell and reduce the pore sizes Sometimes the water application breaks down the surface soil structure, dislodging some of the fine soil particles from the soil aggregates to which they were previously attached These fine particles then flow into the soil, plugging some of the pores Another cause of the decrease in infiltration rate during irrigation is the increasing wetness of the soil, which lowers the hydraulic gradient (see explanation below) Reduction of infiltration rate with time is greater for medium- and fine-textured soils than it is for coarse-textured soils See Figure 4

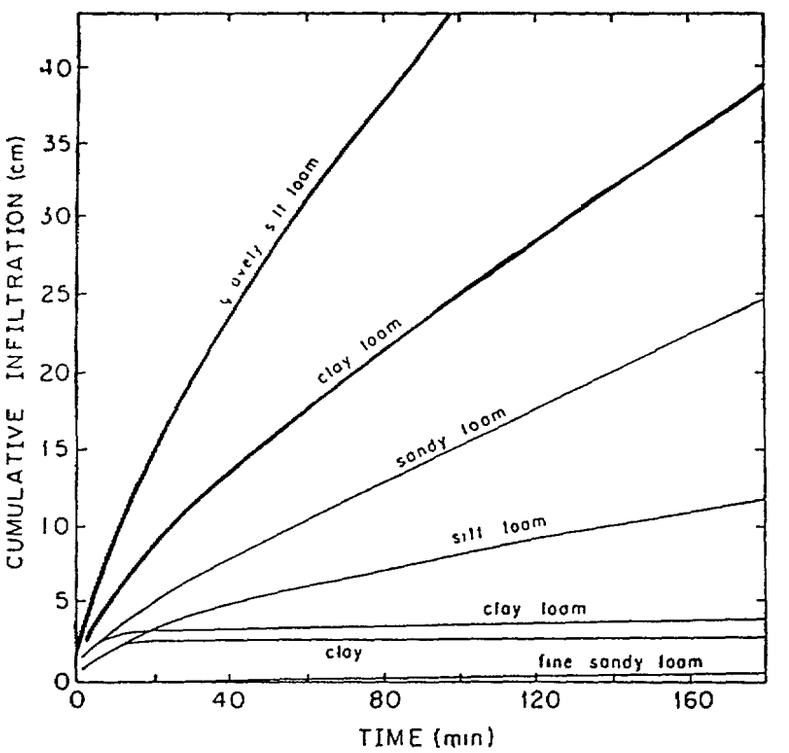

Figure 4 Infiltration curves for different soil types

Water moves not only vertically, infiltration, but also laterally Horizontal movement beyond ponded water for various soil types is given in Table 6 *These are only very general numbers and should be verified in the field.* Actual lateral movement depends upon salinity amounts and type, soil textures, zones impeding soil-water movement, and application rates

Table 6 Lateral movement of water in soil

Soil Type	Lateral Movement, m
Coarse sand	0 15 → 0 46
Fine sand	0 30 → 0 91
Loam	0 91 → 1 37
Heavy clay	1 22 → 1 82

Permeability – Permeability refers to the rate of movement of water *through* a soil and is frequently called hydraulic conductivity It is defined as the rate at which a unit volume of water moves past a unit cross-section area of soil when driven by unit hydraulic gradient Hydraulic gradient is the driving force causing water to flow and results both from gravity and differences in wetness or soil suction Gravity can only act downward and imparts a hydraulic gradient of 1, but the interaction of gravity with impermeable soil layers may provide movement obliquely downward, in which case the hydraulic gradient is less than 1 Difference in soil suction can move water in any direction and may provide large hydraulic gradients

As with infiltration, permeability of a soil is dependent to a considerable extent on the pore sizes in the soil through which water can flow With larger pore sizes, a more rapid rate of water flow will be obtained, and with soil having finer pores a slower rate of water movement will occur When discussing hydraulic conductivity, there are two types of flow with different reactions to be considered saturated and unsaturated flow

Saturated flow refers to the flow of water through soil when all or most of the pores are filled with water little air is left in the soil It is easy to determine in the field if a soil is saturated If a handful of saturated soil is squeezed some water will run between the fingers The period of saturation of the top-soil usually does not last long After the water application stops, part of the water present in the larger pores will move downward under the influence of gravity The flow rate is primarily influenced by the size of the larger pores and their proportion in the soil Saturated flow is therefore most rapid in coarse-textured soils The water drained from the pores is replaced by air In course textured soils (sandy), drainage is completed in a period of a few hours In fine textured (clayey) soils, drainage may take (2-3) days

Much of the time, water movement in soil takes place when the pores are not filled with water, and this is known as **unsaturated flow** Unsaturated flow is essentially film flow, and its rate depends primarily on the thickness of the water films existing in the fine and medium pores To some extent, the rate depends upon the hydraulic gradient, which is usually greater than 1 and may be many times greater if large differences in soil moisture condition exist in the soil profile It is unsaturated or film flow which transports water from a point in the soil where it has not been depleted to a point where it has been depleted by root action If water were unable to move in soil to the root surfaces by unsaturated flow, it would be necessary to keep the soil much wetter than is usually desirable to maintain a sufficient supply for plant use during periods of high evapotranspiration

Coarse-textured soils have relatively poor unsaturated conductivity Consequently it is necessary to keep a coarse-textured soil wetter than a medium or fine-textured soil to obtain the same degree of plant response Coarse-textured soils conduct water poorly by film flow because of their small surface area which results in relatively few interconnecting water films

3 5 Zones Impeding Soil-Water Movement

Water moving in soil occasionally encounters a zone or soil condition where resistance to flow is great While such a zone is rarely a complete block to all types of flow it may retard flow to an extent which can be important in the soil-water system and in water-plant relations Impeding zones can be grouped in three soil classes, representing the ways in which flow is retarded

The first class is characterized by a lack of large pores or, in extreme cases, by the near absence of pores In normal soil, the rapid flow of water during irrigation or leaching takes place mainly through large pores When a zone lacking large pores is encountered in the soil profile, the flow is reduced to a fraction of its previous rate and may stop entirely The result is a "pile-up" of water resulting in a perched water table, which can be detrimental to plant roots Leaching is difficult in this type of profile Examples in this class include hardpans, tight clay layers, silt layers in sandy soil, and high-density layers, usually caused by compaction

A second class is characterized by a discontinuity or drastic reduction of the medium and fine pores that carry films of water necessary for film flow Compared to normal soil, this soil shows such a marked decrease in unsaturated hydraulic conductivity that unsaturated flow is almost nonexistent Examples of this class include coarse-textured layers of either sand or organic matter underlying finer-textured soils, and vertical mulch layers covered over at the surface by fine materials

If such layers are horizontal in the soil profile, water eventually accumulates just above the coarse-textured layer until saturation occurs at the boundary If water continues to move down from above, free water will drip from the saturated layer into the coarser-textured material below so that no appreciable depth of perched water table is formed However, even after downward flow has ceased, a saturated condition remains just above the textural interface until plant use or evaporation depletes it Saturated layers can be harmful to plant roots and seldom contain roots of plants which are sensitive to excessively wet conditions

The third class represents a complete interruption of the conducting pores It is based on the law of outflow of free water which states "Outflow of free water from soil occurs only if the pressure in the soil water exceeds atmospheric pressure " In the field, pores are interrupted by tile lines, gopher tunnels, mole holes, and gravel or coarse sand layers underlying the soil In no case will water leave the soil to enter large openings unless the soil is saturated at the point of outflow Farmers considering installation of tile drainage should be aware of this characteristic Tile drainage will not reduce the wetness of soil which is not saturated Tile drains function only when they are located below a water table

4 GROUND WATER TABLE

Part of the water applied to the soil surface drains below the root zone and feeds deeper soil layers that are permanently saturated, the top of the saturated layer is called the ground water table or just the water table

The depth of the water table varies from place to place mainly due to changes in topography In one particular place or field, the depth of the water table may vary in time Following heavy rainfall or irrigation the ground water table rises Water can reach and saturate the root zone If prolonged this situation can be disastrous for crops that cannot stand wet roots for a long period

So far, it has been mentioned that water can move downward as well as horizontally In addition, water can move upward Ground water can move upward through the soil in very small pores called capillaries This process is called capillary rise In fine textured soil (clay) the upward movement of water is slow but covers a long distance In coarse textured soil (sand) the upward movement of water is quick but covers only a short distance see Table 7

Table 7 Capillary rise of water in different soil textures

Soil Texture	Capillary Rise in cm
Coarse (sand)	20 to 50 cm
Medium (loam)	50 to 80 cm
Fine (clay)	80 < to several meters

MICRO IRRIGATION SYSTEMS
USE OF SALINE IRRIGATION WATER

[Supplemental]

1 INTRODUCTION

When using saline irrigation water one should work towards increasing irrigation efficiency, defined here as the fraction of water applied to the field that is used by the crop The objective is two-fold to increase the production from each unit of water used, and also to reduce the volume of drainage water needing disposal Remember that leaching salts from the rootzone also leaches nutrients Thus it is critical to reduce the amount of deep percolation to the minimum necessary to maintain a suitable soil-water salt balance This prevents an excessive loss of nutrients and can best be achieved under a uniform irrigation system

Properly designed and managed micro irrigation systems can come close to 'perfect uniformity However, precision irrigation requires access to a reliable water supply on demand Water delivery on fixed (worse unreliable) schedules greatly complicates the task of attaining a high level of on-farm irrigation system efficiency Thus, efficient on-farm water use is predicated on an effective delivery system

1 1 Salt Accumulation in Soil

A soil may be rich in salts because the parent rock from which it was formed contained salts In addition, salt is added by irrigation water The basic difference between rain water and irrigation water is that the first is nearly free from salts while the second contains salts of different degrees The salt content of irrigation water normally varies between 200 part per million to 2000 parts per million (0 2 gm/l to 2 0 gm/l) Hence with every irrigation a certain amount of salt is brought to the soil For irrigation water in the Jordan Valley, the salt content of Yarmouk River water is about 0 4 to 0 5 gm/l while the salt content of the water leaving King Talal Reservoir is about 0 8 to 1 4 gm/l

Since plants use almost pure water, most salts in the applied irrigation water remain in the soil With each 10 mm irrigation using water from the Yarmouk River, about 5 kg of salts are added to each dunum A winter season vegetable crop requiring about 700 mm of water adds about 350 kg of salts to each dunum of land irrigated A citrus orchard using 1200 mm of irrigation water adds about 600kg of salt to each dunum per year The amount of salts added to each dunum of soils is higher when irrigation water from the King Talal Reservoir is used

From the above, it is clear that a considerable amount of salts are brought to irrigated lands even when good quality irrigation water is used If these salts are left to accumulate in the rootzone of the soil profile, the soil will quickly become too saline for the growth of most agricultural crops To avoid reaching this stage, it is imperative that these salts be periodically removed from the rootzone by adding supplemental irrigation water to carry them to drains or to deeper zones

of the soil Table 1 gives guidelines for assessing the risk of soil salinization from an irrigation water

Table 1 Guidelines for interpretation of water quality for irrigation

Salt concentration of irrigation water	Soil salinization risk	Restriction on use
< 0 45 g/l (0 7 dS/m)	None	No restriction on use
0 45 → 2 g/l (0 7 - 3 dS/m)	Slight to moderate	Use with appropriate management practices
> 2 g/l (>3 dS/m)	High	Not generally advised for use unless directed by specialists

Salinity in the soil is estimated by measuring the salt content of water extracted from the soil A soil sample is mixed with distilled water and the water is extracted from the soil with a pressure plate, the extracted water is called a saturation extract If this water contains less than 3 gpl of salts, the soil is said to be non-saline If the salt concentration of the saturation extract is greater than 12 gpl the soil is said to be highly saline Table 2 summarizes the degree of soil salinity as measured by the salinity of the extract from a saturated soil paste

Table 2 Guidelines for interpretation of soil salinization from saturated soil paste extracts

Salt concentration in the saturated paste extract		
(gpl)	EC_e (dS/m)	Salinity status
0 - 3	0 - 4 5	Non-saline
3 - 6	4 5 - 9	Slightly saline
6 - 12	9 - 18	Medium saline
> 12	> 18	Highly saline

A more accurate method of measuring the soil-water salinity is to use a probe that measures soil-water EC Testing should begin shortly after an application of irrigation water and continue until the next irrigation The probe will measure the same salinity level as that faced by the plant Data from the several measurements between irrigations can be used to develop salinity concentration curves, which are used as an irrigation scheduling aid

1 2 Management

When irrigating there is need to undertake appropriate practices to prevent the accumulation of excessive salt levels in the crop rootzone Management need not necessarily attempt to control salts at the lowest possible level, but rather to keep the level within limits that allow sustained productivity Crop, soil, and irrigation practices can be modified to keep the level of salts within these limits

Management practices for the control of salinity include selection of crops or crop varieties that will produce satisfactory yields under the resulting conditions

of salinity, use of land-preparation and planting methods that aid in the control of salinity, irrigation procedures that maintain a relatively high soil-moisture regime and periodically leach accumulated salts from the soil, and maintenance of water conveyance and drainage systems The crop type, water quality, and soil properties determine, to a large degree, the management practices required to optimize production

2 CROPS AND SALINE SOIL-WATER

Most crops do not grow well on soils that have soil-water solutions with high salinity levels As salt concentrations in the soil-water solution increase there is an increase in forces drawing water away from the roots and towards the salts The force drawing water to the salts reduces the rate and amount of water that plant roots can take in from the soil Plants have to exert more force to extract and absorb water from the soil-water solution Also, salts such as sodium, chlorine and boron are toxic to plants when present in high concentrations

2 1 Crop Tolerance to Soil-Water Salts

Some plants are more tolerant to a high soil-water salt concentration than others Table 3 groups common crops by soil-water solution salt levels where the solution salinity is indicated by EC_e The EC_e is determined from a saturated paste extract from a soil sample and must be done by a laboratory

Table 3 Relative soil-water salt tolerance levels of agricultural crops

Tolerant 6 - 10 dS/m	Moderately Tolerant 3 - 6 dS/m	Moderately Sensitive 1 - 3 dS/m	Sensitive 0 - 1 dS/m
Barley	Wheat	Broadbean	Bean
Asparagus	Beet	Maize	Carrot
Date Palm	Squash	Sunflower	Okra
	Fig	Cabbage	Onion
	Olive	Cauliflower	Almond
	Pomegranate	Cucumber	Apple
		Eggplant	Apricot
		Lettuce	Avocado
		Sweet Melon	Grapefruit
		Pepper	Lemon
		Potato	Lime
		Pumpkin	Orange
		Radish	Peach
		Spinach	Pear
		Tomato	Plum
		Squash	Pommelo
		Turnip	Strawberry
		Watermelon	Tangerine
		Grape	

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Table 3 is ordered by increasing salinity tolerance i e, broadbean is more sensitive than grape The order of crops indicative of salinity tolerance in this table is relative only Different varieties of crops may be more or less tolerant than as shown in this table See Table 4 for more detailed information

2 2 Soil-Water Salinity and Yield Potential

Table 4 summarizes the effect of salinity on the yield potential of selected crops Soil salinity tolerances given in the table apply primarily to crops from late seedling to maturity that are exposed to fairly uniform salinities throughout the crop season Tolerance during the germination and early seedling stage may be different ***Actual response of plants to salinity varies with growing conditions (climate, irrigation and agronomic management) and crop variety*** Data in the table should be used to select a crop, relative to others, based on likelihood of salinity problems given soil and water quality information In addition, ***the data in Table 4 applies to surface-irrigated crops and conventional irrigation management assuming a leaching fraction equal to 0 15 to 0 20***

A leaching fraction larger than about 0 25 may not be practical because of the large volume of water required In such cases consideration must be given to the selection of a more salt tolerant crop that will require less leaching to control the soil-water salinity level Soil type, irrigation frequency, climate, and crop variety can significantly effect yield response under irrigation with a given water quality and thereby influence the leaching fraction

Rootstocks used for certain tree or vine crops absorb Cl and Na at different rates this can appreciably influence salinity tolerance With a reduction in the amount absorbed, accumulation is reduced There is also considerable differences between cultivars within a species

3 Practices to Control Rootzone Salinity

Because crops, and different cultivars of the same crop, vary considerably in their tolerance to salinity, crops should be selected that produce satisfactorily for the particular conditions of salinity expected to occur in the rootzone Plant density should also be increased to compensate for the smaller plant size that exists under saline conditions This increases the interception of the incoming energy of the sun, and hence crop yield, relative to normal densities It is especially important to consider the crop's salt tolerance during seedling development This is often the most sensitive growth stage, and high yields are impossible without satisfactory establishment of crop stand

Improvements in salinity control on irrigated lands generally come from improvements in irrigation management The key to effective irrigation (and hence salinity control) is to provide the proper amount of water at the proper time *The optimum irrigation scheme provides water nearly continuously to keep the soil water content in the rootzone within narrow limits* Carefully programmed periods of stress may be desirable to obtain maximum economic yield with some crops, cultural

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practices also may demand periods of 'dry' soil Thus careful control of timing and the amount of water applied is a prerequisite to high water use efficiency and to high crop yield especially when irrigating with saline waters

Table 4 Crop tolerance and yield potential as influenced by the saturated soil paste extract salinity (EC_e) [1]

Crop	Yield potential influenced by EC_e				
	100%	90%	75%	50%	0%
Vegetables					
Squash, zucchini	4 7	5 8	7 4	10	15
Beet, red[2]	4 0	5 1	6 8	9 6	15
Squash, scallop	3 2	3 8	4 8	6 3	9 4
Broccoli	2 8	3 9	5 5	8 2	14
Tomato	2 5	3 5	5 0	7 6	13
Cucumber	2 5	3 3	4 4	6 3	10
Spinach	2 0	3 3	5 3	8 6	15
Celery	1 8	3 4	5 8	9 9	18
Cabbage	1 8	2 8	4 4	7 0	12
Potato	1 7	2 5	3 8	5 9	10
Corn, sweet	1 7	2 5	3 8	5 9	10
Sweet potato	1 5	2 4	3 8	6 0	11
Pepper, sweet	1 5	2 2	3 3	5 1	8 6
Lettuce	1 3	2 1	3 2	5 1	9 0
Radish	1 2	2 0	3 1	5 0	8 9
Onion	1 2	1 8	2 8	4 3	7 4
Carrot	1 0	1 7	2 8	4 6	8 1
Bean	1 0	1 5	2 3	3 6	6 3
Turnip	0 9	2 0	3 7	6 5	12
Fruits[3]					
Date palm	4 0	6 8	11	18	32
Grapefruit	1 8	2 4	3 4	4 9	8 0
Orange	1 7	2 3	3 3	4 8	8 0
Peach	1 7	2 2	2 9	4 1	6 5
Apricot[4]	1 6	2 0	2 6	3 7	5 8
Grape[4]	1 5	2 5	4 1	6 7	12
Almond[4]	1 5	2 0	2 8	4 1	6 8
Plum, prune[4]	1 5	2 1	2 9	4 3	6 1
Blackberry	1 5	2 0	2 6	3 8	6 0
Strawberry	1 0	1 3	1 8	2 5	4 0

1 In gypsiferous soils plants will tolerate EC_e's about 2 dS/m higher than indicated

2 Sensitive during germination, EC_e should not exceed 3 dS/m

3 These data are applicable when rootstocks are used that do not accumulate Na or Cl rapidly or when those ions do not predominate in the soil

4 Values are for vegetative growth only, not yield

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Table 4 Continuation

Crop	Yield potential influenced by EC_e				
	100%	90%	75%	50%	0%
Field					
Barley[1]	8 0	10	13	18	28
Sorghum	6 8	7 4	8 4	9 9	13
Wheat[1]	6 0	7 4	9 5	13	20
Wheat, durum	5 7	7 6	10	15	24
Soybean	5 0	5 5	6 3	7 5	10
Cowpea	4 9	5 7	7 0	9 1	13
Sudan grass	2 8	5 1	8 6	14	26
Alfalfa	2 0	3 4	5 4	8 8	16
Corn	1 7	2 5	3 8	5 9	10
Broadbean	1 5	2 6	4 2	6 8	12
Clover	1 5	2 3	3 6	5 7	9 8
Bean	1 0	1 5	2 3	3 6	6 3

1 Less tolerant during emergence and seedling EC_e should not exceed 4 to 5 dS/m

This calls for water delivery to the field on demand which in turn requires close coordination between the farmer and the organization that distributes the water It calls for measurement of water flow (rates and volumes) measurement of the water and salt content of the soil, ways to predict or measure the rate of water use by the crop, and ways to detect or predict the onset of plant stress It also calls for an accurate control of the volume delivered to each field and its uniform areal distribution within the field

The prime requirements of irrigation management for salinity control are timely irrigations, adequate leaching, adequate drainage, and water table depth control Other significant contributing and interacting factors should also be considered These include the delivery system and the method and manner of the irrigation

3 1 The Delivery and Drainage Systems

For efficient control of a supply system, the water volume passing critical points, including the outlets to individual fields, needs to be controlled and metered This demands installation of effective flow controlling and measuring devices, without which seepage losses are difficult to identify and oversupply to fields is likely to occur Additionally, many delivery systems encourage over-irrigation because the water is supplied for fixed periods, or in fixed amounts, irrespective of seasonal variations in on-farm needs Such systems make the use of some types of irrigation, such as trickle exceedingly difficult Ideally, water delivery should be on-demand and to accomplish this there needs to be, in addition to appropriate delivery facilities, close coordination between the management of water delivery and the users

The maintenance of the drainage system is important and the tile lines or open ditches should be kept clean and on grade Over-irrigation also contributes to the water table and salinity problems as well as increasing the amount of water that the drainage system must accommodate Therefore a proper relation between irrigation management and drainage must be maintained to prevent irrigated lands from becoming salt affected The amount of water applied should be sufficient to supply the crop and satisfy the leaching requirement but not enough to overload the drainage system *It is important to recognize that inefficient irrigation is a major cause of salinity and shallow water tables* in many irrigation projects of the world and that *the need for drainage can usually be reduced through improvements in irrigation management* Ways to improve irrigation efficiency should be sought ***first*** before the drainage capacity is increased

3 2 On-Farm Irrigation Practices

In general, improvements in salinity control occur by providing the appropriate amount of water at the appropriate time with high uniformity of application The ideal irrigation scheme would provide water more or less continuously to the plant to match evapotranspiration losses and to keep the water content in the rootzone within narrow limits commensurate with adequate aeration and would minimize loss in deep percolation for leaching By this means the salinity of the soil water in the major part of the rootzone is prevented from increasing significantly between irrigation events as evapotranspiration proceeds The availability of the water to the crop is thus facilitated and stress is avoided Sometimes 'stress' is desired to increase the proportion of reproductive versus vegetative growth and to speed maturity For such cases, proper stress periods should be 'programmed' into the management To achieve such an ideal system requires delivery of the water to the field on demand at appropriate flow rates and volumes To know what volume of replenishment water is needed for irrigation, evapotranspiration rates need to be very accurately known

Additional water (over that required to replenish losses by plant transpiration and evaporation) must be applied, at least occasionally, to leach out the salt that has accumulated since the previous leaching This leaching requirement depends on the salt content of the irrigation water and on the maximum salt concentration permissible in the soil-water solution, which depends in turn on the salt tolerance of the crop

Fortunately, much of the needed leaching can be achieved during pre-irrigations between crops or during early season irrigations when soil permeability is generally at its maximum and crop use at its minimum If rainfall is significant, less leaching from irrigation is needed The control of salinity by leaching is accomplished most easily in permeable coarse-textured soils Medium- and fine-textured soils have the agronomic advantage of a greater water-holding capacity and ordinarily present no major problem from the stand-point of salinity control, particularly if they have good structure and are underlain by a sand or gravel

aquifer which facilitates the removal of drainage water Prevention of salt accumulation is most difficult in fine textured, slowly permeable soil

The method of irrigation is important in the control of salinity Trickle irrigation, if properly designed, minimizes salinity and crop stresses because the soil water content is maintained at a high level and the salts are leached to the periphery of the wetted volume where rooting activity is minimal As explained below, higher salinity in the irrigation water can be tolerated using trickle compared to other methods of irrigation

The frequency of irrigation affects the response of crops to saline waters Salts reduce availability of water for plant use in almost direct proportion to their total concentration in the soil solution Irrigation frequency (irrespective of irrigation method) should be increased, all else being equal, so that the moisture content of saline soils is maintained as high as practicable without creating aeration or disease problems Especially critical are seedling establishment and the early stages of vegetative growth Reasons for this recommendation follow

Time-averaged rootzone salinity is affected by the degree to which the soil water is depleted between irrigations and the leaching fraction Crop stress is increased as the time between irrigations is increased because the force with which water is held by soil particles increases approximately exponentially as the soil dries As the salts progressively concentrate in the reduced volume of soil-water, the remaining fresh water is held tighter by the salt ions The total force that must be overcome by a crop extracting water is the sum of the two attraction forces that due to soil particles and that due to salt ions

Crop yield is closely related to the time and depth averaged total soil-water potential As water is removed from a soil of non-uniform salinity distribution in the rootzone, the total stress (attraction forces) of the water being absorbed by the plant tends to approach uniformity in all depths of the rootzone, even though the components of the total force vary inversely among these 'strata' Thus, following an irrigation, plant roots are less active in absorbing water in soil depths of high salt concentration than in those of low salt concentration With the normally observed [illegible] distributions in soils (increasing salinity with depth), this means that most of the water uptake is from the upper, less saline soil depths until sufficient water is removed to increase the soil particle water attraction force to a point where, when combined with the increasing salt ion attraction force, the total water stress (salt plus soil particle forces) at some lower depth becomes less inhibitive At this time salinity effects on crop growth will magnify These observations allow one to conclude that (1) plants can tolerate higher levels of salinity under conditions of low total water stress (such as is achieved with high-frequency forms of irrigation, like micro), and (2) high soil-water salinities occurring in deeper regions of the rootzone can be significantly offset, if sufficient low-salinity water is added to the upper profile depths at a rate to satisfy the crop's evapotranspiration requirement

Thus, the level of salinity that can be tolerated in the soil depends in part, on the distribution of salinity in the soil profile, on the frequency and extent to which the soil water is depleted between irrigations, and on the water content of the soil Irrigation management has an important effect on permissible levels of salinity of irrigation waters

A frequent constraint to improving on-farm water use is the lack of information on when an irrigation is needed and what capacity for replenishment is available within the rootzone Ideally, irrigation management should have the soil water near maximum capacity at planting time but depleted by 50% or more, at harvest And, it should maintain water within the rootzone during the major period of vegetative growth at a level which produces no deleterious plant water stress through successive, properly-timed irrigations Under saline conditions, this requires some 'extra' water for leaching - a minimum commensurate with the salt tolerance of the crop being grown Irrigation scheduling requires some method of assessing the water availability to the crop with sufficient lead time to provide for a water application before significant stress occurs In addition the amounts of water needed for refilling the depleted rootzone reservoir and for leaching must be determined

Scheduling methods can be used which are based on irrigating when depletion of soil water per se or soil water potential or some associated soil or water property reaches some predetermined level (set-point) The attainment of this level can be determined either by direct measurement of some appropriate soil property or estimated from meteorological data With the latter method, daily reference evapotranspiration of full ground-cover crop (usually a well-watered healthy grass) is calculated from measurements of air temperature humidity, solar radiation and wind The actual evapotranspiration (ET) of the crop is then estimated from empirically determined crop coefficients [1] The summation of these daily ET values is a measure of accumulative soil water depletion A plot of depletion versus time gives a way to project the need for irrigation when the degree of allowable depletion is known

The same approach can be used based on direct measurements of soil water content, or a related parameter, using neutron meters, resistance blocks, or capacitance soil probes Some of these methods can provide information on the amount of water storage available in the soil for replenishment Most of the methods suffer the limitation of needing an empirical determination of the set-point value for irrigation which varies with crop rooting characteristics, stage of plant growth, soil properties and climatic stress Furthermore, measurements of soil water content or soil particle attraction forces can not be used (at least not conveniently) to assess or control the leaching fraction (the fraction of infiltrated water that passes the rootzone) as is required to prevent an excessive build-up of soil salinity For saline water, irrigations should be scheduled before the total soil-water attraction forces increase to the level that prohibits the crop from

[1] See Module 2-3, *Crop Water Requirements*

extracting sufficient water to sustain its physiologic processes without loss in yield

Typically, the crop's root system normally extracts progressively less water with increasing soil depth because rooting density decreases with depth and available soil-water decreases with depth as salt concentration increases Therefore, the frequency of irrigations would ideally be determined by the total soil water potential in the upper rootzone where the rate of water depletion is greatest The amount of water to apply also depends on the stage of plant development and the salt tolerance of the crop and, consequently, should be based on the status of the soil-water at deeper depths In early stages of plant development it is often desirable to irrigate to bring the soil to 'field capacity' to the depth of present rooting or just beyond Eventually, however, excess water must be applied to leach out salts accumulated in the profile to prevent salt concentrations from exceeding tolerable levels Thus, the amount of water required is dictated by volume of soil reservoir in need of replenishment and the level of soil salinity in the lower rootzone

3 3 Drainage and Its Reuse for Irrigation

For any irrigation area to remain viable in the long term drainage (either natural or artificial) must be able to cope with the waters percolating beneath the irrigated land Without such drainage, ground waters eventually rise to levels that cause the rootzone to become water logged or salinized In addition to excess rainfall, contributions to deep percolation come from leaching water, leakage in the distribution system, and waters invading the irrigated area from elsewhere Management practices which reduce these contributions also usually reduce the degradation of the waters that receive it Such practices include increasing irrigation efficiency, adoption of the concept of 'minimized leaching', and interception and reuse of sub-surface drainage flows for irrigation or diversion to appropriate waste sites

With the minimized leaching approach, the aim is to make the maximum use of each volume of the applied irrigation water in evapotranspiration, thus producing minimum drainage and salt return Where the drainage water can be intercepted such as by groundwater pumping or tile-drainage, it is often of a quality which permits reuse on irrigated crops of higher salt tolerance It is often feasible to substitute saline drainage water for some of the conventional irrigation water in a 'cyclic' reuse strategy which also involves the rotation of salt tolerant crops and salt sensitive crops

The cyclic reuse strategy succeeds because (i) preplant and initial irrigations of the tolerant crops are made with the lower salinity water, thereby leaching salts out of the soil in the vicinity of the emerging seedling, the drainage water being substituted after seedling establishment, (ii) the maximum salinity in the rootzone possible with long-continued use of the more saline drainage water does not result since it is used for only part of the rotation, and (iii) the salt accumulated in the soil profile from irrigation with the drainage water is leached

out during the subsequent period of irrigation of a sensitive crop with lower salinity water In situations where the normal water is of particularly low salinity, crusting and permeability problems may develop, if its electrolyte concentration is too low for the level of soil sodicity developed during the period of irrigation with drainage water

An alternate strategy often advocated, is to dilute the drainage waters with better quality waters and to use the blend for irrigation In fact this is the process operative when drainage waters move by diffuse flow back to river or groundwater systems Whether by intentional blending or by diffuse flow, this process of blending generally reduces the supply of water suitable for irrigation, especially when the drainage water salinity is high In attempting to meet transpiration, a plant can only extract soil-water up to its tolerance of salt concentration (this determines the usable portion of the blend), the remaining water is unusable and must pass once again out of and beyond the rootzone, often displacing or dissolving more salt in the process Thus, any addition of salt to a water supply reduces the degree to which it can be consumed in crop growth In terms of crop production, greater flexibility and use of the total water supply can be achieved by intercepting and keeping drainage waters isolated from surface or groundwater supplies of better quality

Reuse of a drainage water for irrigation eventually increases its salinity to the point that further reuse is no longer possible and it must be disposed of by some means

3 4 Monitoring for salinity control

The proper operation of a viable, permanent irrigated agriculture, especially when using saline waters, requires periodic information on the levels and distribution of soil salinity within the rootzones and fields of the irrigation project The salt level within the rootzone must be kept below harmful levels Direct monitoring of rootzone salinity is recommended to evaluate the effectiveness of various management programs The shape of the salinity-depth relation of the soil profile and information on water table depth provide direct information on the adequacy of the irrigation/drainage system

Changes in soil salinity can be determined from periodic measurements made (i) on extracts of soil samples, (ii) on soil water samples collected *in situ,* usually with vacuum extractors, (iii) in soil, using buried porous salinity sensors which imbibe and equilibrate with the soil water, and (iv) in soil, using four-electrode probes, or (v) remotely by electromagnetic induction techniques

Especially useful is measurement of the soil-water solution electrical conductivity (EC_{ss}) since it is a measure of both soil-water content and soil-water salinity Soil salinity in irrigated agriculture is normally low at shallow soil depths and increases through the rootzone Thus measurements of EC_{ss} in shallow depths of the soil profile, made over an irrigation cycle, are indicative of changing soil water content there, while measurements of EC_{ss} deeper in the

profile, where little water uptake occurs are more indicative of salinity accumulation

Depletion of soil-water to a set-point level, depth of water penetration from an irrigation or rainfall, and leaching fraction can all be determined from EC_{ss} measurements made within the rootzone over time However, measurements of both volumetric soil-water content and soil-water salinity, from which the total water potential can be estimated, are more ideally suited for these needs

4 Leaching of Accumulated Salts

4 1 Leaching Practices

Leaching has to be carried out to maintain a favorable salt balance in the soil To increase the efficiency of leaching the following practices are suggested

- Leaching should be carried out intermittently and not continuously Experience has shown that unsaturated flow of water through the soil profile is more effective in leaching salts than is saturated flow
- There is no need to apply the leaching requirement during each irrigation Leach when soil salinity levels indicate it is needed, particularly at critical growth stages
- To benefit from the local rainfall carry out leaching during the cool winter season Applying leaching water immediately prior to the arrival of a low pressure wave and rain fills the rootzone and allows all of the rainfall to be used for leaching
- For heavy soils with low infiltration rates, it is best to carry out the leaching process after soil plowing and seedbed preparation in the fall season
- Use salt tolerant crops, which require a small percentage of irrigation water for leaching purposes
- Use sprinkler or micro-spray irrigation for leaching Sprinkler or micro-spray irrigation applications can be adjusted to ensure unsaturated flow of water in the soil profile Sprinkler or micro-spray is also suitable for occasional leaching of salts from areas irrigated by trickle irrigation
- Avoid long periods of fallow to minimize salt accumulation in the root zone by capillary movement of salts upward from lower, more saline soil moisture zones If a long fallow period is necessary, periodically till the soil to break up capillaries, which reduces evaporation and salt movement
- Cultivate soil to minimize surface cracks and to improve the water infiltration rate This will increase the efficiency of leaching

4 2 Leaching Fractions

With every irrigation a certain amount of salts is brought to the soil Crops absorb water added by irrigation and/or rainfall leaving behind the salts that were in the irrigation water Soluble salts move with irrigation water and there should be an additional amount of water, more than that needed by the crops, to

carrying the salts out of the root zone The proportion of excess water needed as related to the total depth of irrigation water applied, is termed the Leaching Fraction (LF)

In order to maintain a constant salt balance in the soil, the total volume of salt carried out with the drainage water must equal the total volume of salt added to the soil-water solution from all sources the irrigation water, additives such as fertilizers, and salts dissolved from native soil material Leaching fractions vary according to the crop, total quantity of salts added to the soil-water solution, and the frequency of irrigation

The LF is determined from Figure 1 The curve labeled "conventional irrigation' is used where the soil is allowed to dry out between irrigation, i e, where significant total attraction forces (soil particle and salt) occurs Most surface and sprinkler irrigation methods are considered conventional irrigation Micro irrigation managed such that the rootzone dries significantly between irrigations should also be considered conventional irrigation

The curve labeled high frequency irrigation is used where the rootzone soil does not dry out significantly between irrigations

It is not unusual for salts entering the soil-water solution from sources other than irrigation water to be significant For this reason it is best to determine leaching fractions and leaching schedules by periodically monitoring the salinity levels of the soil-water solution at different depths of the crop rootzone

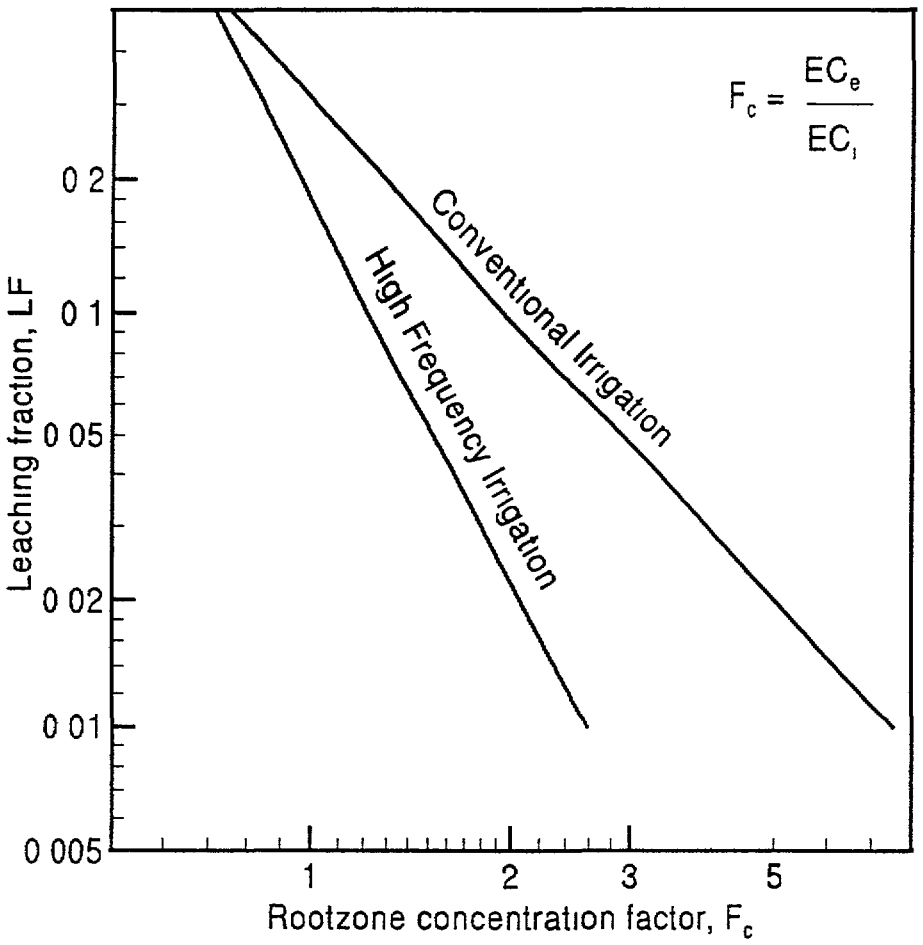

Figure 1 Leaching fraction based on irrigation frequency and rootzone concentration factor

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USE OF SALINE IRRIGATION WATER

CASE STUDY, LEACHING FRACTION

Known Data

- Salinity of available irrigation water = EC = 1 2 dS/m
- Maximum desired salinity of soil-water solution = EC_e = 2 5 dS/m
- Crop water requirement per season per dunum = 900 mm

Determine

- Compare leaching fractions and the total seasonal water requirements IR_S, for high frequency and conventional, low frequency irrigations

Solution

The LF is determined from Figure 2 For this example,

$$F_c = \frac{EC_e}{EC_i} = \frac{2\ 5}{1\ 2} = 2\ 08$$

From the figure, LF = 0 02, and LF = 0 09 for high frequency and conventional irrigations, respectively

The total seasonal irrigation requirement the crop demand plus the leaching requirement is

$$IR_S = \frac{\text{Crop water requirement}}{1 - LF}$$

High Frequency Irrigations

$$IR_S = \frac{900}{1 - 0\ 02} = 918\ 4 \text{ mm}$$

Conventional Irrigations

$$IR_S = \frac{900}{1 - 0\ 09} = 989\ 0 \text{ mm}$$

Note that for a seasonal crop requirement of 900 mm, irrigated with water of 1 2 dS/m, 18 4 mm of water for high frequency irrigations and 89 mm of water for conventional irrigations are needed for leaching purposes each season to maintain a soil-water solution salt balance having a salinity level of 2 5 dS/m

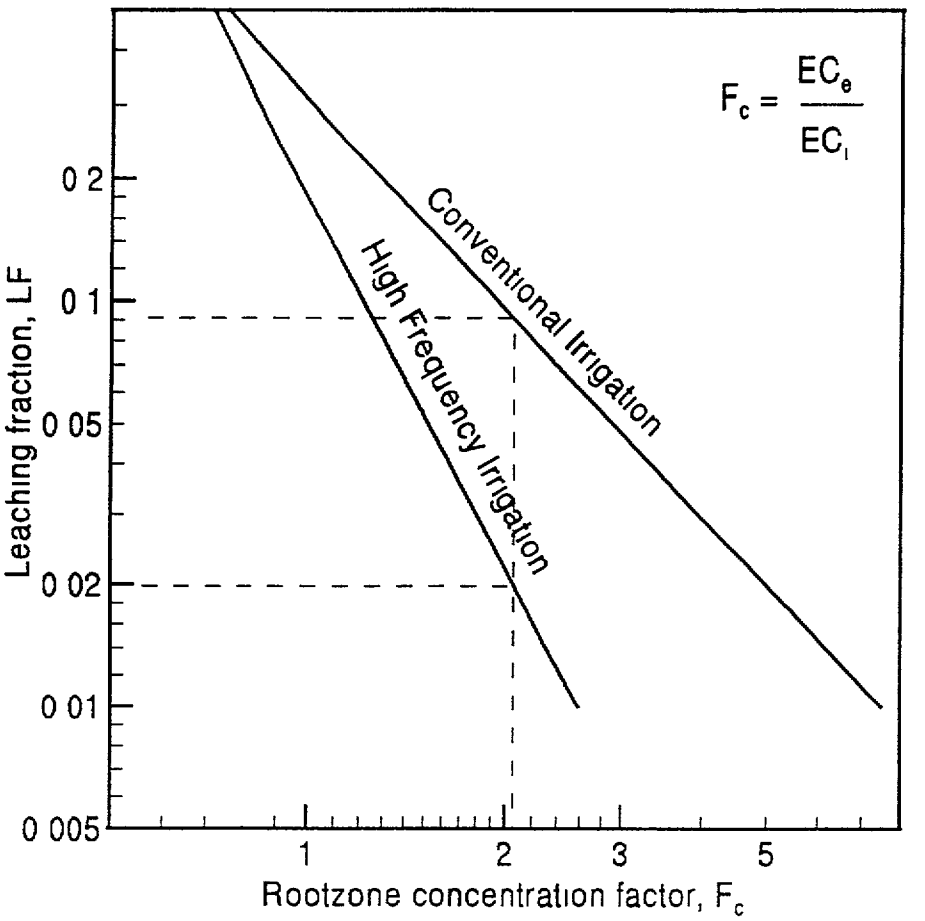

Figure 2 Leaching fraction based on irrigation frequency and rootzor concentration factor

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MICRO IRRIGATION SYSTEMS
CROP WATER REQUIREMENTS

[Supplemental]

1 INTRODUCTION

Crop water use results in the transfer of **salt-free** water to the atmosphere, thereby concentrating the remaining salts in the soil solution Maintenance of a favorable root environment requires the replenishment of soil moisture as it is used Thus, crop water use is the basic factor determining irrigation water requirements

An estimation of a crop's water use rate is needed to

- Maintain the proper level of moisture in the soil
- Size irrigation system components (pipes, valves, pumps, etc), and
- Operate and manage the irrigation system

2 DEFINITIONS

Evapotranspiration (ET, mm/day) Water is transferred to the atmosphere by direct evaporation of solid and liquid water from soil and plant surfaces as well as by transpiration Since these processes each involve evaporation and are not easily separated they are combined and called evapotranspiration

Transpiration (T, mm/day) The evaporation of water from a plant surface that goes directly into the atmosphere or into intercellular spaces and then by diffusion through the stomata to the atmosphere

Reference Evapotranspiration (ET_o, mm/day) Reference ET is defined in terms of two crops, alfalfa and grass For both reference crops the estimated ET_o assumes the plants are disease free, actively growing, completely shading the ground, and not short of water

Crop Coefficients (KC, decimal) The relationship between the ET of a specific crop at a specific time in its growth and the ET_o leads to crop coefficients

$$KC = \frac{ET}{ET_o}$$

Consumptive Use (CU, mm/day) Includes water used in all of the plant processes (digestion, photosynthesis, transport of mineral and photosynthates structure support, and growth) as well as direct evaporation from soil and plant surfaces CU exceeds ET by the amount of water used for plant processes Since this difference is usually less than one percent, ET and CU are normally assumed to be equal

Effective Precipitation (P_e, mm/day) Rainfall that is useful or usable in any phase of crop production In arid zones, soils tend to accumulate salts in the root zone Where salt accumulations occur, P_e should not be considered in determining crop water requirements Often the irrigation system must be operated during rainfall events to keep salts away from plant roots

Leaching Fraction (LF, decimal or mm/day) The amount of water that must flow through the root zone to remove accumulating salts Leaching water is in excess of ET requirements LF is usually expressed as a decimal portion of ET

3 FACTORS AFFECTING PLANT WATER REQUIREMENTS

The ET rate is affected by many factors, the most important are the leaf area stage of crop growth, climate, and soil

- Transpiration rates vary during the season and with the stage of crop growth, even though the evaporative demand may be nearly constant The leaf area increases as the plant grows, offering a larger transpiring surface As the plant ages, older leaves transpire less and there are fewer new leaves, the ET rate decreases for most annual crops

  With some annual crops, grain for example, the transpiration rate increases from the sprouting of the seed through the dough stage then decreases as the grain ripens Other annual crops, green onion for example do not show a decrease in transpiration rate near harvest if the evaporative demand remains constant

- The most important climatic factor affecting evapotranspiration is solar radiation it is the source of energy necessary to transform water from a liquid to a vapor in both plants and soil Air temperature humidity rainfall and wind also influence evapotranspiration for a given crop

- Soil factors affecting evapotranspiration include the water holding capacity in the root zone soil temperature, and salt concentration in the soil water When the soil is near field capacity, plants can obtain water with relative ease, but as soils approach the wilting point, it become more difficult for the roots to obtain water for transpiration Evaporation from the soil is greater when the surface is wet and only a partial crop cover exists than when the surface begins to dry Soil temperature affects the viscosity of the water in the soil, the vapor pressure and the ability of the roots to absorb water Lack of adequate soil aeration will slow root and top growth and thus indirectly limit the transpiration rate

- High concentrations of salt in the soil can kill the plant and stop transpiration entirely In lesser amounts, it makes the plant roots do more work obtaining water and reduces the evapotranspiration and growth rates of the plant It increases the irrigation requirement of a field because additional irrigation water, in excess of that needed for evapotranspiration, must be applied to leach or remove salts from the root zone

4. DIRECT MEASUREMENT OF EVAPOTRANSPIRATION

Direct measurement techniques involve isolating a portion of the crop from its surroundings and determining ET by measurement The manager of a trickle irrigation system seldom can justify the time or funds required to determine the rate of evapotranspiration that occurs in his area for various crops Instead he must rely on the results of local studies, published results from studies in other areas of similar

climatic, and theoretical estimates However he should be aware of the problems techniques, and reliability of various methods used to determine or measure evapotranspiration in order to evaluate the reliability and applicability of published ET data to his area

4 1 Conservation of Mass Technique

The most widely used direct measurement techniques are based on the conservation of mass principle The equation defining the conservation of mass principle for the control volume in Figure 1 is

$$\text{Inflow} - \text{Outflow} = \Delta S = D_{rz}(\theta_{vf} - \theta_{vi})$$

Where Inflow and Outflow = total flow into and out of the control volume respectively, during the time interval being considered, cm, ΔS = change in soil moisture within the control volume during the time interval being considered cm, D_{rz} = depth of root zone (below soil surface), cm, and θ_{vf}, θ_{vi} = soil moisture contents by volume at end (final) and beginning (initial) of the time interval being considered, respectively decimal

$$\text{Inflow} = I + P - SFI + LI + GW$$

$$\text{Outflow} = ET + RO + LO + LF + DP$$

Where I = depth of irrigation cm, P = precipitation or rainfall, cm, SFI = surface flow into the control volume cm, LI = subsurface lateral flow into the control volume, cm, GW = ground water seepage into the control volume, cm, ET = evapotranspiration, cm, RO = surface flow out of the control volume, cm, LO = subsurface lateral flow out of the control volume, cm, LF = leaching fraction cm, and DP = deep percolation (i e , downward movement of water from the control volume in excess of that needed for leaching), cm

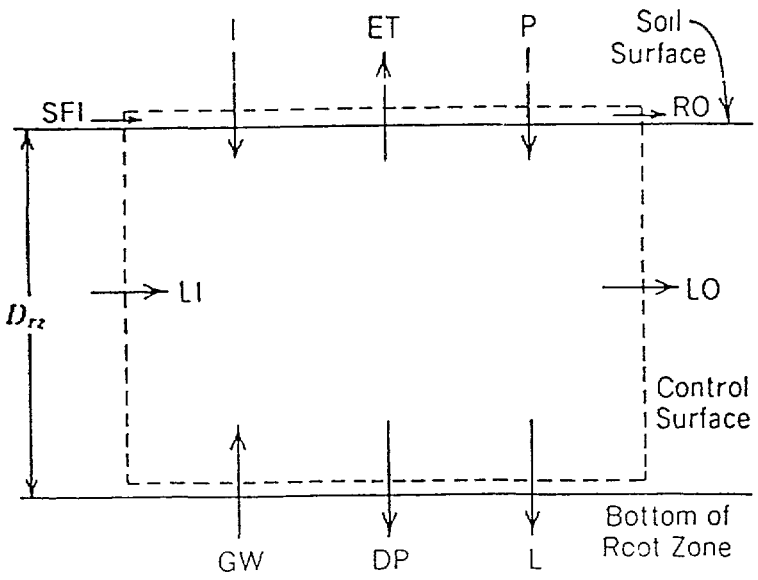

Figure 1 Sketch defining the conservation of mass principle for a control volume

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Combining the inflow and outflow equations gives the final equation

$$ET = I + P + SFI + LI + GW - RO - LO - LF - DP - Drz\,(\theta vf - \theta vi)$$

The accuracy of ET estimates obtained with this equation is usually low because it is generally difficult to control and/or measure one or more of the terms in the equation

4 2 Soil Moisture Sampling

Soil samples taken at two different dates and dried in an oven at 105 °C are used to determine the decrease in soil moisture This is called gravimetric soil moisture sampling A temperature of 105 °C is used for drying the soil to ensure that only soil water is evaporated At higher temperatures the soil organic matter starts to burn and there is more weight lost, causing a wrong measure of soil water More recently neutron and other types of soil moisture probes have been used extensively and generally result in more reliable data The rate of evapotranspiration is calculate using the following equation

$$ET = \frac{W_{ET}}{\Delta T} = \frac{\sum_{i=1}^{n} \Delta\theta_{Vi} \times \Delta S_i}{\Delta T}$$

Where $\Delta T = (T_2 - T_1)$ time interval between sampling dates (usually days) W_{ET} = water used in evapotranspiration mm i = an index n = number of soil layers under consideration, ΔS_i = thickness of the i-th layer mm and $\Delta\theta_{Vi} = (\theta_1 - \theta_2)$ volumetric change in soil moisture θ_1 and θ_2 are volumetric water contents on sampling days 1 and 2 respectively decimal

When using gravimetric sampling procedures the soil moisture is usually expressed as a percentage on a dry-weight basis θ_D and must be converted to a volumetric basis by multiplying by the bulk density ρ_s of the soil

$$\theta_V = \rho_s \frac{\theta_D}{100}$$

The first set of samples is usually taken 2 to 4 days after an irrigation, and the second set 5 to 10 days later, or just before the next irrigation

Evapotranspiration rates can be reliably determined by soil sampling if adequate precautions are taken

- At least 6 sample sites representative of general field conditions are used, a minimum of 4 may be adequate when using a neutron meter
- The depth to the water table should be much greater than the root zone depth
- Only take soil samples when rainfall is absent If there is rainfall after the first sample is obtained, sampling must be redone or the ET calculation will be in error, the calculated ET value will be low
- Over irrigation and drainage are minimized by
  - giving the preplant irrigation at least 10 days before planting,

- applying less water at each irrigation than the amount that could be stored in the soil,
- taking the first soil sample at least 2 days after a normal or light irrigation when ET is small, wait longer than 2 days if a heavy irrigation is used, and
- considering only the active root zone depth in ET computations

5 ESTIMATING EVAPOTRANSPIRATION

Estimates of ET are required in areas where measured ET data are not available Several theoretical and empirical equations have been developed for computing crop ET These estimating procedures are based on the correlation of measured ET with one or more climatic factors

The estimating methods commonly used in Jordan (listed alphabetical and not in order of preference) are

- Blaney-Criddle
- Hargreaves
- Pan Evaporation method
- Penman-Monteith
- Radiation

These five methods consider the effect of climate on crop water requirement and use mean daily climatic data for 30 day or smaller periods ET_0 is expressed in mm per day and represents the mean value over the period chosen for use The selection of method to use must be based on the type and accuracy of climatic data availab. and on the accuracy required in determining water needs Climatic data needed for the different methods are

Method	T °C	Humidity	Wind	Sunshine	Radiation	Evap	Envir
Blaney-Criddle	*	+	+	+			+
Hargreaves	*				+		
Pan Evaporation		+	+			*	*
Penman-Monteith	*	*	*	*	x		
Radiation	*	+	+	*	x		+

(*) measured data, (+) estimated data, (x) used if available but not essential

5 1 Blaney-Criddle Method

The Blaney-Criddle method is based on the principle that ET_{crop} is proportional to the product of day length percentage and mean monthly air temperature It is useful where **only** temperature data are available and other parameters can be general estimates Estimates should be made on a monthly basis

$$Et_o = a_b + b_b \times f \text{ (mm/day)}$$

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$$a_b = 0.0043 \times RH_{mn} - \frac{n}{N} - 1.41$$

$$b_b = 0.82 - 0.0041 \times RH_{mn} + 1.07\frac{n}{N} + 0.006 \times \left[1.1 \times U_{da} - RH_{mn}\left(\frac{n}{N} + 0.1 \times U_{day}\right)\right]$$

$$f = p_f(0.46\,T_a + 8.13)$$

$$n/N = 2.0\,(RS/RA) - 0.5$$

$$RH_{mn} = [e^o(T_{dew})/e^o(T_{max})] \times 100$$

Where p_f = mean **daily** percentage of total annual day time hours for the given time period, usually 1 month, n = sun shine hours during the day, N = potential sun shine hours during the day, RH_{mn} = minimum daily relative humidity, T_a = average daily air temperature, °C, U_{day} = daytime wind speed, m/sec, RS = short wave (global) radiation measured at the soil surface, cal/cm²/day, RA = extraterrestrial radiation (outside the atmosphere), cal/cm²/day, and e^o = saturation vapor pressure at the temperatures given, mbar

The Blaney-Criddle method should only be applied for periods of one month or longer, in humid, windy, and mid-latitude winter conditions an over and under estimation of up to 25% has been noted The Blaney-Criddle method has proven to be very accurate for the Jordan Valley, however it must be calibrated Given its complexity it is not suitable for use by those without access to the required weather data It will not be discussed further

5.2 Hargreaves Method

The Hargreaves method uses the maximum and minimum temperature and latitude It is accurate in locations where solar energy is the primary factor determining ET, such as the Jordan Valley

$$ET_o = 0.0023 \times RA(T + 17.8) \times TD^{0.5}$$

Where ET_o = average daily reference crop evapotranspiration, mm/day, RA = extraterrestrial radiation in equivalent water evaporation per day at 20 °C, mm/day, T = mean daily temperature, °C,

$$T = \frac{T_{mx} + T_{mn}}{2}$$

T_{mx} and T_{mn} = mean daily maximum and minimum temperatures, °C, and TD = average daily temperature range for the period considered

$$TD = T_{mx} - T_{mn}$$

Extraterrestrial radiation can be calculated for any period throughout the year

RA = 15.67 DR [OM*Sin(Lat)*Sin(Dec) + Cos(Lat)*Cos(Dec)*Sin(OM)]

where Lat = latitude in radians (1 radian = 57 2958 degrees) Dec = declination in radians, J = Julian day (January 1 = 1), DR = relative distance of the sun from the earth and OM = the sunset hour angle in radians for Lat < 55°

$$Dec = 0\ 40876 * Cos\{0\ 0172142 * (J + 192)\}$$

$$DR = 1\ 0 + 0\ 033 * Cos(0\ 0172142 * J)$$

$$OM = Acos\ \{-Tan(Lat) * Tan(Dec)\}$$

The Hargreaves equation is a good method for areas with air temperature data only There is little need for local calibration It can under-estimate in very humid climates because T_{mx} and T_{mn} may differ little so that ET_o goes toward zero The method is not very accurate for the days of major weather changes but usually provides satisfactory results when T °C and TD are averaged over periods of five or more days

The Hargreaves method is appropriate for use in the Jordan Valley For easier use of the ET_o equation Table 1 gives the square root of TD values expected in the Jordan Valley Figure 2 presents annual RA values for the Middle Jordan Valley average weekly or monthly values can be read from the figure The error in using RA values from the Middle Valley for the entire valley is less than 2%

Table 1 Square roots of numbers

No	Square root	No	Square root	No	Square root	No	Square root
5	2 236	5 25	2 291	5 5	2 345	5 75	2 398
6	2 450	6 25	2 500	6 5	2 550	6 75	2 598
7	2 646	7 25	2 693	7 5	2 739	7 75	2 784
8	2 828	8 25	2 872	8 5	2 916	8 75	2 958
9	3 000	9 25	3 041	9 5	3 082	9 75	3 123
10	3 162	10 25	3 202	10 5	3 240	10 75	3 279
11	3 317	11 25	3 354	11 5	3 391	11 75	3 428
12	3 464	12 25	3 500	12 5	3 536	12 75	3 571
13	3 606	13 25	3 640	13 5	3 674	13 75	3 708
14	3 742	14 25	3 775	14 5	3 808	14 75	3 841
15	3 873	15 25	3 905	15 5	3 937	15 75	3 969
16	4 000	16 25	4 031	16 5	4 062	16 75	4 093
17	4 123	17 25	4 153	17 5	4 183	17 75	4 213
18	4 243	18 25	4 272	18 5	4 301	18 75	4 330
19	4 359	19 25	4 388	19 5	4 416	19 75	4 444
20	4 472	20 25	4 500	20 5	4 528	20 75	4 555
21	4 583	21 25	4 610	21 5	4 637	21 75	4 664
22	4 690	22 25	4 717	22 5	4 743	22 75	4 770
23	4 796	23 25	4 822	23 5	4 848	23 75	4 873
24	4 899	24 25	4 924	24 5	4 950	24 75	4 975
25	5 000	25 25	5 025	25 5	5 050	25 75	5 074

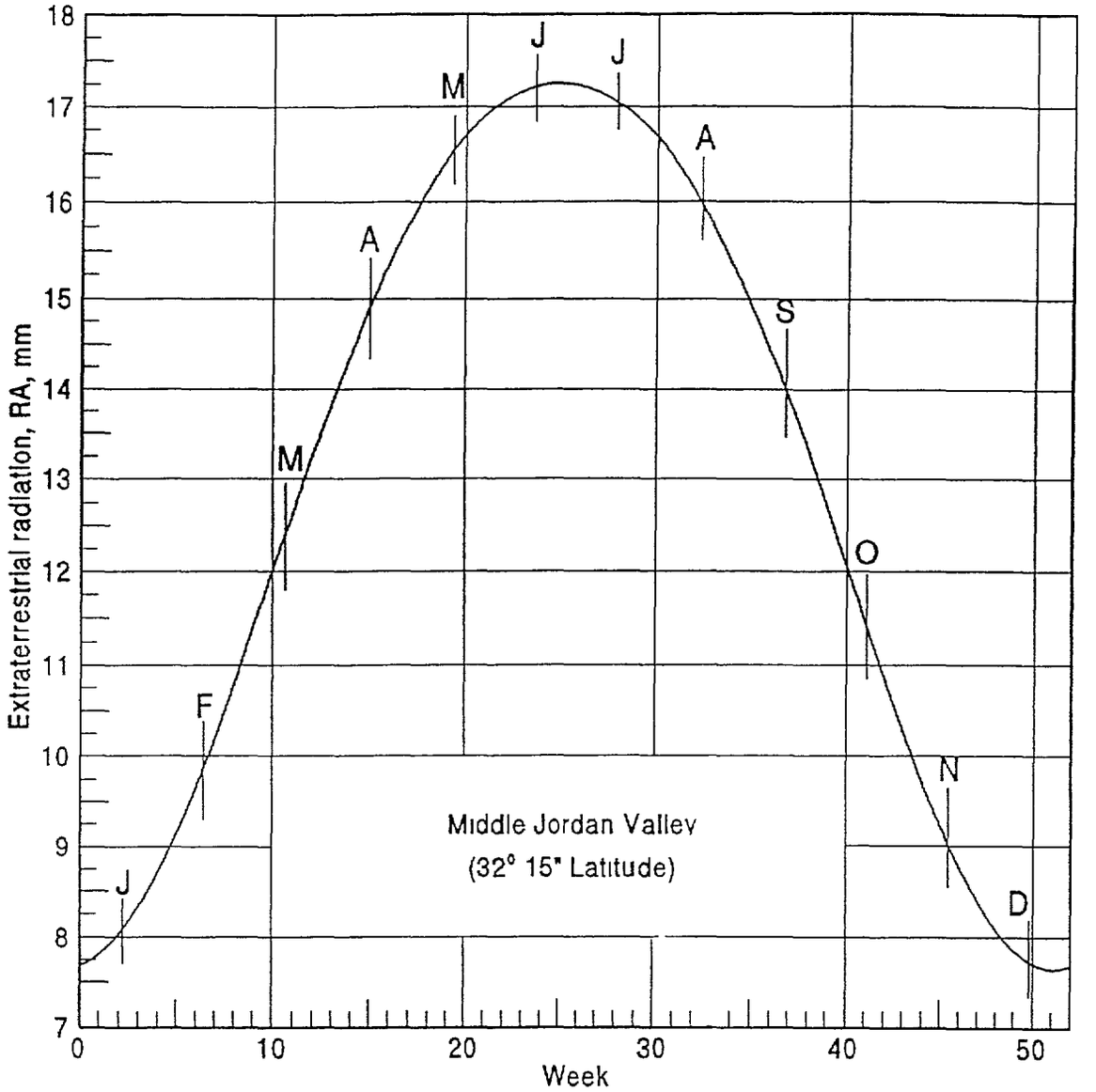

Figure 2 Annual extraterrestrial radiation values for the Middle Jordan Valley

5 3 Pan Evaporation Method

Evaporation pans provide a measurement of the effects of radiation, wind, temperature and humidity on evaporation from a specific open water surface In a similar fashion the plant responds to the same climatic variables but several factors may produce significant differences in loss of water Reflection of solar radiation from a water surface is only 5-8 percent, from most plant surfaces reflection is 20-25 percent Storage of heat within the pan can be appreciable and may cause almost equal evaporation during night and day, most crops transpire only during daytime Also, differences in water losses from pans and crops can be caused by differences in turbulence, temperature, and humidity of the air immediately above the surfaces Heat transfer through the sides of the pan can occur Also, the color of the pan influences measured results, especially when the pan is placed in fallow rather than cropped fields

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Not withstanding these deficiencies with proper siting the use of pans to predict crop water requirements for periods of 10 days or longer is still warranted From the many different types of pans, the US Class A pan is commonly used in Jordan and is presented here [1]

To relate pan evaporation to ET_o, empirically derived coefficients are given that take into account climate and pan environment ET_o can be obtained from

$$ET_o = C_{pan} \times E_{pan}$$

where E_{pan} = pan evapotranspiration representing the mean daily value for the period considered, mm/day, and C_{pan} = pan coefficient for the Jordan Valley C_{pan} ranges between 0 73 and 0 75

C_{pan} values relate to unscreened pans located in an open agricultural area/field with no plants or structures taller than one meter within 50 m of the pan The immediate surrounding soil surface, within 10 m of the pan, is covered by green frequently mowed grass cover or is left bare

- Where pans are placed in a small enclosure but surrounded by tall crops for example 2 5 m high maize, the coefficient will need to be increased by 0 04 to 0 08
- The C_{pan} values of 0 73 to 0 75 apply to galvanized pans annually painted with aluminum Little difference in E_{pan} will show when inside and outside surfaces of the pan are painted white An increase in E_{pan} of up to 10 percent may occur when they are painted black The material from which the pan is made may account for variations of only a few percent
- The level at which water is maintained in the pan is very important errors may be up to 15 percent when the water level in the pan falls 10 cm below the accepted standard of between 5 cm and 7 5 cm below the rim
- A screen mounted over the pan will reduce E_{pan} by up to 10 percent In an endeavor to avoid pans being used by birds for drinking, a pan filled to the rim with water can be placed near the Class A pan birds may prefer to use the fully filled pan
- Turbidity of the water in the pan does not affect E_{pan} data by more than 5 percent
- Overall variation in E_{pan} is not constant with time because of aging, deterioration, and repainting

[1] The Class A evaporation pan is circular, 121 cm in diameter and 25 5 cm deep It is made of galvanized iron (22 gauge) or monel metal (0 8 mm) The pan is mounted on a wooden open frame platform with its bottom 15 cm above ground level The soil is built up to within 5 cm of the bottom of the pan The pan must be level It is filled with water 5 cm below the rim, and the water level should not drop to more than 7 5 cm below the rim Water is regularly renewed to eliminate extreme turbidity A galvanized pan is painted annually with aluminum paint

The Pan method can offer results with a possible error of 15% depending on the location of the Pan, its condition, and the care with which measurements are taken When locally calibrated, ET_o values calculated from Pan readings are accurate enough for ET_{crop} estimations

5 4 Penman-Monteith Method

The Penman-Monteith method is suggested for areas where measured data on temperature, wind and sunshine duration or radiation are available and accurate Compared to the other methods, it has the potential to be the most accurate

The Penman-Monteith equation consists of two terms an energy (radiation) term and an aerodynamic (wind and humidity) term The relative importance of each term varies with climatic conditions Under windy conditions particularly in the more arid regions, the aerodynamic term becomes relatively more important

The procedures to calculate ET_o using the Penman-Monteith equation are complicated This is because the formula contains components which need to be calculated from other measured climatic data when there are no direct measurements of a needed variable For instance for places where no direct measurements of net radiation are available, there may be measured solar radiation, sunshine duration, or cloudiness observations from which net radiation can be estimated The sub-equations are lengthy and are not included in this module

The Penman-Monteith equation is written

$$ETo = c\left[\underbrace{W \times R_n}_{\text{radiation term}} + \underbrace{(1 - W) \times f(u) \times (ea - ed)}_{\text{aerodynamic term}}\right]$$

where ET_o = reference crop evapotranspiration mm/day W = temperature related weighting factor, R_n = net radiation in equivalent evaporation, mm/day, f(u) = wind related function, (ea-ed) = difference between the saturation vapor pressure at the mean air temperature and the mean actual vapor pressure of the air, both in mbar, and c = an adjustment factor to compensate for the effect of day and night weather conditions

When accurate data is available and local calibration is obtained, the Penman-Monteith method offers the best results with a maximum possible of error of plus or minus 10% in summer and up to 20% under low evaporative conditions This equation is not practical for use by farmers and calculation of ET_o by this method will not be discussed

5 5 Radiation Method

This method is suggested for areas where available climatic data include measured air temperature and sunshine, cloudiness or radiation, but not

measured wind and humidity Knowledge of general levels of humidity and wind is required and these are to be estimated using published weather descriptions extrapolation from nearly weather stations or from local sources

The relationship representing the mean ET_o value over a given period is expressed as

$$ET_o = c(W \times R_s)$$

where ET_o = reference crop evapotranspiration for the period considered, mm/day, R_s = solar radiation in equivalent evaporation mm/day, W = weighting factor which depends on temperature and latitude, and c = adjustment factor that depends on mean humidity and daytime wind conditions R_s is given by the equation

$$R_s = \left(0\ 25 + 0.50\frac{n}{N}\right)RA$$

where n/N = the ratio between actual measured bright sunshine hours and maximum possible sunshine hours, RA = the amount of radiation received at the top of atmosphere expressed as unit equivalent evaporation, mm/day

The Radiation method should be more reliable than the Blaney-Criddle approach In extreme conditions, the method involves a possible error up to 20% in summer This method also requires access to data not commonly available to farmers, calculation of ET_o by this method will not be discussed

6 SELECTION OF CROP COEFFICIENT

The five methods discussed in the previous section estimate the effect of climate on ET_o To account for the effect of crop characteristics on water requirements, crop coefficients, KC are used to relate ET_o to crop evapotranspiration, ET_{crop} The KC value 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 ET_{crop} can be found by

$$ET_{crop} = KC \times ET_o$$

Each of the five methods predicts ET_o and only one set of crop coefficients is required

Figure 3 illustrates where in the growth cycle the KC values apply Table 2 discusses determining the beginning and ending of growth stages

Table 3 gives KC values for crops commonly grown in the Jordan Valley Approximate ranges of seasonal ET_{crop} for different crops are given in Table 4 The magnitudes shown will vary within these ranges according to the factors discussed in the next section

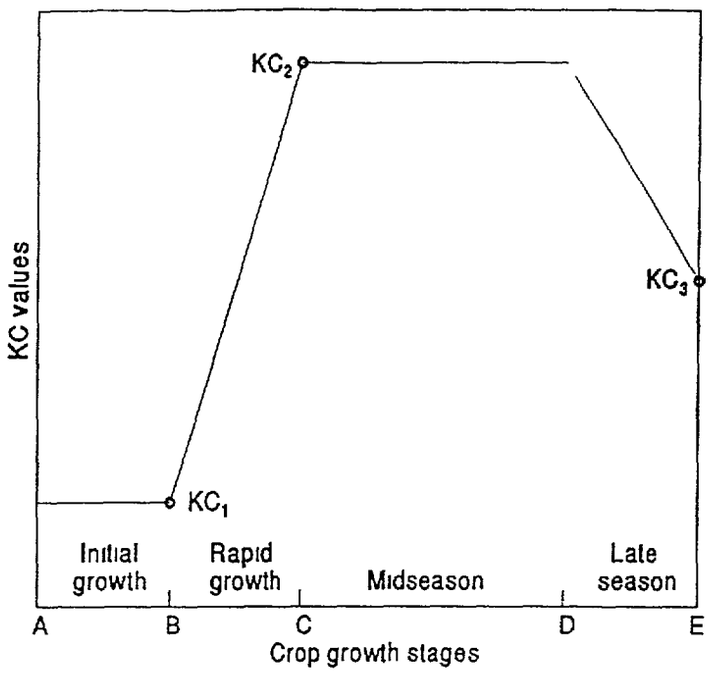

Figure 3 Generalized crop coefficients and crop growth stages

Table 2 Stages of crop development and KC values

KC values	Growth stage	Description
KC_1	Initial (A to B)	Germination and early growth when the soil surface is exposed (ground cover ≤ 10%)
KC_1 to KC_2	Rapid growth (B to C)	From 10% ground cover to attainment of 70-80% ground cover or peak water use
KC_2	Mid season (C to D)	From attainment of 70-80% ground cover to start of maturing, normally well past the flowering stage of annual crops
KC_2 to KC_3	Late season (D to E)	From when water use begins to decline until full [illegible] and water use ceases
KC_3	Harvest (E)	The end of the water use season

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Table 3 Crop coefficients, KC, for use with ET_0 estimates

Crop	KC_1	KC_2	KC_3
Alfalfa	0 40 - 0 50	1 00 - 1 40	0 95 - 1 35
Artichoke	0 90 - 1 00	0 95 - 1 05	0 90 - 1 00
Asparagus	0 25 - 0 30	0 95	0 25
Banana	0 40 - 0 65	1 00 - 1 20	0 75 - 1 15
Barley	0 25 - 0 30	1 00 - 1 10	0 10 - 0 20
Beans (green)	0 30 - 0 40	0 95 - 1 05	0 85 - 0 95
Beans (dry)	0 30 - 0 40	1 05 - 1 20	0 25 - 0 30
Beets (table)	0 25 - 0 40	1 05 - 1 20	0 25 - 0 30
Cabbage*	0 30 - 0 50	0 95 - 1 10	0 80 - 0 95
Cantaloupe	0 15 - 0 40	1 00 - 1 10	0 30 - 0 90
Carrots	0 40 - 0 50	1 05	0 75
Citrus**	0 65	0 65 - 0 75	0 65
Corn (sweet)	0 20 - 0 50	1 05 - 1 20	0 95 - 1 10
Cucumber	0 20 - 0 40	0 90 - 1 00	0 70 - 0 80
Deciduous orchard, clean	0 5	0 85 - 1 20	0 50 - 0 85
Deciduous orchard, with cover crop	0 75 - 0 85	1 10 - 1 25	0 70 - 1 10
Egg plant	0 25 - 0 50	0 95 - 1 10	0 80 - 0 90
Grape	0 20 - 0 50	0 74 - 0 85	0 20 - 0 45
Lettuce	0 20 - 0 30	0 85 - 1 05	0 45
Olives	0 60	0 80	0 80
Onions (dry)	0 40 - 0 60	0 95 - 1 10	0 75 - 0 85
Onions (green)	0 40 -0 60	0 95 - 1 05	0 95 - 1 05
Pea (fresh)	0 40 - 0 50	1 05 - 1 20	0 95 - 1 10
Pepper (fresh)	0 30 - 0 40	0 95 - 1 10	0 80 - 0 90
Pistachio	0 10	1 10	0 35
Potato	0 40 - 0 55	1 10 - 1 20	0 40 - 0 75
Radish	0 20 - 0 30	0 80 - 0 90	0 75 - 0 85
Spinach	0 20 - 0 30	0 95 - 1 05	0 90 - 1 00
Squash	0 20 - 0 40	0 90 - 1 00	0 70 - 0 80
Tobacco	0 30 - 0 40	1 00 - 1 20	0 75 - 0 85
Tomato	0 25 - 0 50	1 05 - 1 25	0 60 - 0 85
Watermelon	0 25 - 0 50	1 00 - 1 10	0 20 - 0 70
Wheat	0 20 - 0 40	1 05 - 1 25	0 20 - 0 30

* Includes other crucifers such as cauliflower, broccoli, and Brussels sprouts
** Add 0 20 to 0 25 for cover crop or if no weed control

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Table 4 Approximate range of seasonal ET_{crop}

Crop	ET_{crop} (mm)	Crop	ET_{crop} (mm)
Alfalfa	600 -1500	Onion	350 - 600
Avocado	650 - 1000	Orange	600 - 950
Banana	700 - 1700	Potato	350 - 625
Bean	250 - 500	Sweet potato	400 - 675
Date	900 - 1300	Tobacco	300 - 500
Deciduous tree	700 - 1050	Tomato	300 - 600
Grains (small)	300 - 450	Vegetable	250 - 500
Grapefruit	650 - 1000	Vineyard	450 - 900
Maize	400 - 750	Walnut	700 - 1000

6 1 Factors influencing KC and yET_{crop} values

The factors fall into the broad categories of plant characteristics, climate time of planting, and frequency of water applications

- The effect of crop characteristics on the relationship between yET_{crop} and ET_o can be significant Wide variations between major groups of crops are largely due to the resistance to transpiration of different plants such as waxy leaves (citrus)

- Differences in crop variety can cause differences in crop height, roughness, reflection, and ground cover, which produces variations in ET_{crop}

- For high evaporative conditions (i e , hot, strong winds and low humidity) ET_o values up to 14 mm/day and ET_{crop} values up to 17 mm/day may be realistic, particularly for small fields in arid areas that are strongly affected by dry wind conditions However, wilting of crops may occur under such conditions and may result in ET_{crop} values well below ET_o

- Particularly following sowing and during the early growth stage, the frequency of rain or irrigation is important

- General climatic conditions, especially wind and humidity, are to be considered, compared with a smooth grass cover, wind will affect the rate of transpiration of taller crops more due to air turbulence above the rougher crop surface The effect is more pronounced in dry than in humid climates and KC values for rougher crop surface are therefore greater in dry climates

- ET_{crop} is the sum of transpiration by the crop and evaporation from the soil surface, E_{soil} During full ground cover evaporation is negligible, just following sowing and during the early growing period E_{soil} may be considerable, particularly when the soil surface is wet for most of the time from irrigation and rain

- Transpiration and evaporation are governed by different physical processes However, for the crop growing season E_{soil} forms part of ET_{crop} and the

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coefficient relating ET_o and E_{soil} is part of the appropriate crop coefficient, KC

- The values of KC largely depend on the level of ET_o and the frequency with which the soil is wetted by rain and/or irrigation KC values have rather sharp increases following rain and irrigations, with a less sharp but marked decline afterwards until the next rain or irrigation To simplify application average KC values are used Some compromise in accuracy by not differentiating between various soil types has been accepted

CROP WATER REQUIREMENTS

CASE STUDY

CALCULATION DATA

Tomato planted September 11 at Deir Alla total season 180 days (about 26 weeks)

Growth stage	Stage length (days)	KC
Initial	35	0 25
Rapid growth	45	0 25 - 1 05
Mid season	70	1 05
Late season	30	1 05 - 0 60

WEEKLY ET_0 DETERMINATION

Table 6 presents the calculation results The Table is completed as follows

- The annual and crop weeks are taken from the calendar for the entire crop season
- Column 1 is filled in by estimating RA values from Figure 2 Use the center of each week as an average value for that week Figure 4 shows how the RA value for the first week is estimated from the graph
- Columns 2 and 3 are taken from local weather data a farmer may have his own maximum and minimum thermometers
- Column 4 is calculated using

$$T = \frac{T_{mx} + T_{mn}}{2}$$

- Column 5 = Column 4 + 17 8
- Column 6 = T_{mx} - T_{mn}
- Column 7 is filled using Table 1 to estimate the square roots of the values in Column 6 Table 5 shows how the square root of the TD value for the first week is estimated from the Table
- Column 8 is filled using values from Columns 1, 5, and 7 in

$$ET_o = 0\,0023 \times RA(T + 17\,8) \times \sqrt{TD}$$

or

$$ET_o = 0\,0023 \times \text{Column } 1 \times \text{Column } 5 \times \text{Column } 7$$

- Column 9 is filled by estimating values from Figure 5, which is drawn using values given in the calculation data, which come from Table 3
- Column 10 = Column 8 × Column 9
- Column 11 = Column 10 × 7 days/week

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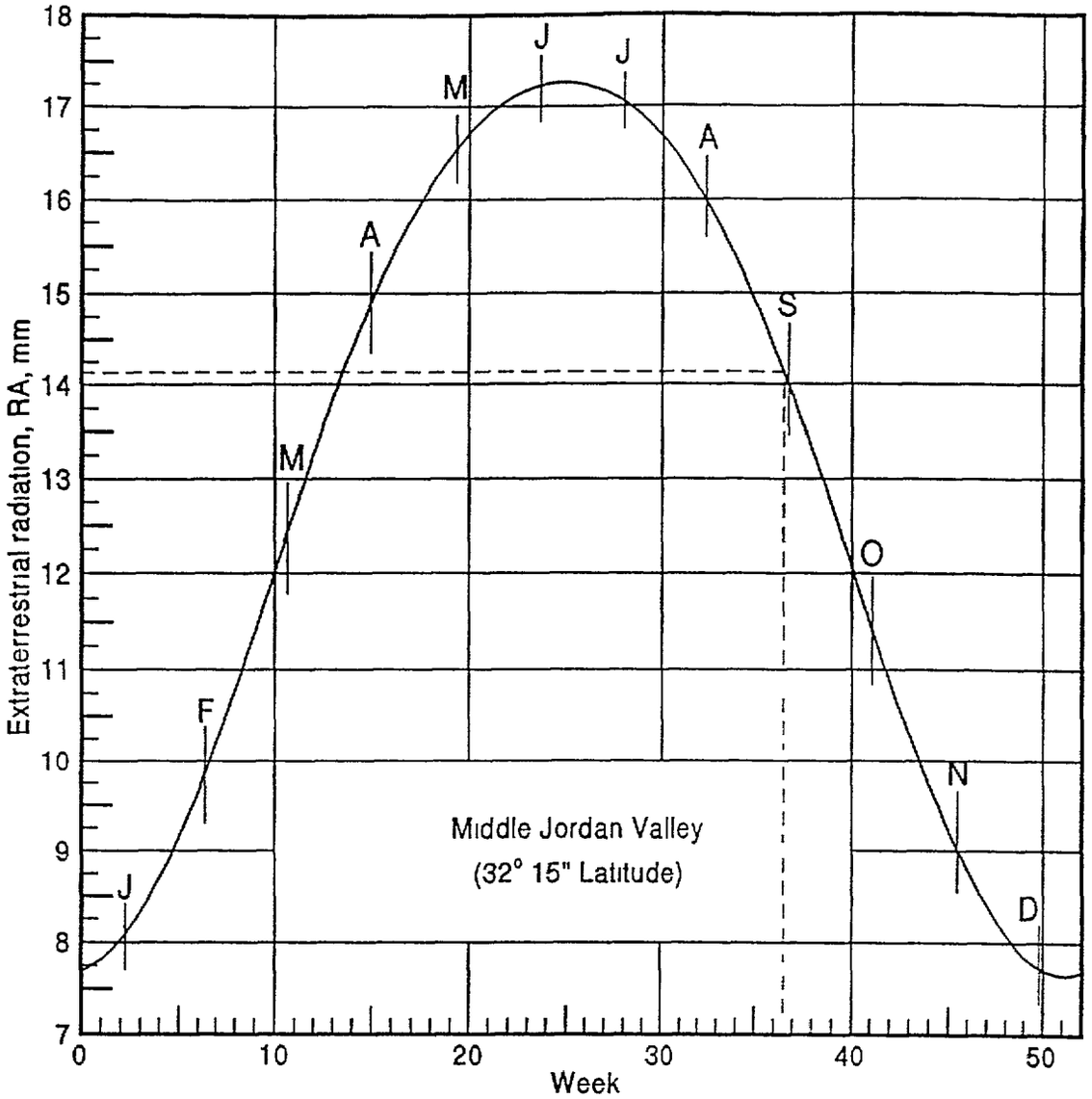

Figure 4 Annual extraterrestrial radiation values for the Middle Jordan Valley

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Table 5 Square roots of numbers

No	Square root	No	Square root	No	Square root	No	Square root
5	2 236	5 25	2 291	5 5	2 345	5 75	2 398
6	2 450	6 25	2 500	6 5	2 550	6 75	2 598
7	2 646	7 25	2 693	7 5	2 739	7 75	2 784
8	2 828	8 25	2 872	8 5	2 916	8 75	2 958
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11	3 317	11 25	3 354	11 5	3 391	11 75	3 428
12	3 464	12 25	3 500	12 5	3 536	12 75	3 571
13	3 606	13 25	3 640	13 5	3 674	13 75	3 708
14	3 742	**14 25**	**3 775**	**14 5**	**3 808**	14 75	3 841
15	3 873	15 25	3 905	15 5	3 937	15 75	3 969
16	4 000	16 25	4 031	16 5	4 062	16 75	4 093
17	4 123	17 25	4 153	17 5	4 183	17 75	4 213
18	4 243	18 25	4 272	18 5	4 301	18 75	4 330
19	4 359	19 25	4 388	19 5	4 416	19 75	4 444
20	4 472	20 25	4 500	20 5	4 528	20 75	4 555
21	4 583	21 25	4 610	21 5	4 637	21 75	4 664
22	4 690	22 25	4 717	22 5	4 743	22 75	4 770
23	4 796	23 25	4 822	23 5	4 848	23 75	4 873
24	4 899	24 25	4 924	24 5	4 950	24 75	4 975
25	5 000	25 25	5 025	25 5	5 050	25 75	5 074

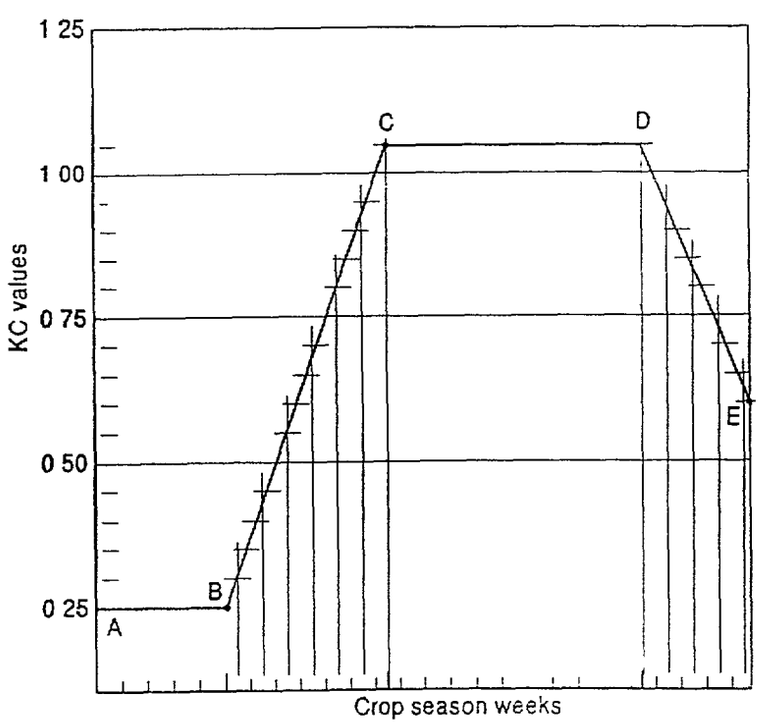

Figure 5 Crop coefficient curve for fall planted tomato at Deir Alla

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Table 6 Weekly ET_{crop} values for fall planted tomatoes at Deir Alla Jordan, estimated using the Hargreaves equation

Column		1	2	3	4	5	6	7	8	9	10	11
Annual week	Crop week	RA mm/day	T_{mx} °C	T_{mn} °C	T °C	T+17.8	TD °C	$TD^{0.5}$	ET_o mm/day	KC	ET_{crop} mm/day	ET_{crop} mm/wk
37	1	14.1	36.5	22.1	29.3	47.1	14.4	3.79	5.8	0.25	1.5	10.5
38	2	13.5	40.4	24.1	32.3	50.1	16.3	4.04	6.3	0.25	1.6	11.2
39	3	13.0	35.5	23.1	29.3	47.1	12.4	3.52	5.0	0.25	1.3	9.1
40	4	12.3	33.1	20.4	26.8	44.6	12.7	3.56	4.5	0.25	1.1	7.7
41	5	11.7	32.3	18.7	25.5	43.3	13.6	3.68	4.3	0.25	1.1	7.7
42	6	11.2	31.6	19.9	25.8	43.6	11.7	3.41	3.8	0.31	1.2	8.4
43	7	10.5	31.2	19.2	25.2	43.0	12.0	3.46	3.6	0.43	1.5	10.5
44	8	10.0	27.9	15.5	21.7	39.5	12.4	3.52	3.2	0.56	1.8	12.6
45	9	9.5	25.2	15.8	20.5	38.3	9.4	3.07	2.6	0.68	1.8	12.6
46	10	9.0	21.6	8.8	15.2	33.0	12.8	3.58	2.4	0.80	1.9	13.3
47	11	8.5	25.0	11.1	18.1	35.9	13.9	3.73	2.6	0.93	2.4	16.8
48	12	8.2	24.1	11.7	17.9	35.7	12.4	3.52	2.4	1.05	2.5	17.5
49	13	7.9	23.7	12.1	17.9	35.7	11.6	3.40	2.2	1.05	2.3	16.1
50	14	7.7	20.8	10.9	15.9	33.7	9.9	3.15	1.9	1.05	2.0	14.0
51	15	7.6	17.4	9.0	13.2	31.0	8.4	2.90	1.6	1.05	1.7	11.9
52	16	7.6	16.3	8.5	12.4	30.2	7.8	2.79	1.5	1.05	1.6	11.2
1	17	7.7	17.1	11.1	14.1	31.9	6.0	2.45	1.4	1.05	1.5	10.5
2	18	7.8	19.7	11.1	15.4	33.2	8.6	2.93	1.7	1.05	1.8	12.6
3	19	8.1	16.6	8.9	12.8	30.6	7.7	2.77	1.6	1.05	1.7	11.9
4	20	8.5	19.5	11.4	15.5	33.3	8.1	2.84	1.8	1.05	1.9	13.3
5	21	8.8	19.2	10.3	14.8	32.6	8.9	2.98	2.0	1.05	2.1	14.7
6	22	9.4	20.5	9.5	15.0	32.8	11.0	3.32	2.4	1.00	2.4	16.8
7	23	10.0	18.4	11.5	15.0	32.8	6.9	2.63	2.0	0.94	1.9	13.3
8	24	10.5	17.7	8.4	13.1	30.9	9.3	3.05	2.3	0.84	1.9	13.3
9	25	11.0	22.1	13.0	17.6	35.4	9.1	3.02	2.7	0.73	2.0	14.0
10	26	11.7	19.7	11.7	15.7	33.5	8.0	2.83	2.6	0.63	1.6	11.2

MICRO IRRIGATION SYSTEMS

IRRIGATION SCHEDULING

[Supplemental]

1 Introduction

Irrigation scheduling is the accurate forecasting of water application (in timing and amount) for optimal crop production A good irrigation schedule consists of three basic elements correct timing of applications, supplying the proper amount of water, and distributing water uniformly To obtain the best response, irrigation water should be applied to the individual field or section of a field according to the needs of the crop growing thereon, desired soil moisture levels, soil-water salinity levels, and rainfall events The irrigation water requirement is usually expressed in mm/day or mm/month

When for example the irrigation water need of a certain crop grown in a hot dry climate such as the Jordan Valley is 8 mm/day, this means that each day the crop uses water equivalent to a layer 8 mm deep over the area covering the crop rootzone An irrigation water need of 8 mm/day however does not mean that this 8 mm has to be supplied by irrigation every day although with micro irrigation systems water could be given daily The irrigation interval has to be chosen such that the crop will not suffer from water shortage between irrigations As will be explained later this depends on crop and soil characteristics

Replenishment of the soil moisture used in crop evapotranspiration (ET) is the largest component of the water requirement Evapotranspiration results in the transfer of salt-free water to the atmosphere thereby concentrating the remaining salts in the soil solution Another source of salts in irrigated soils is the irrigation water itself all irrigation waters contain some salts The amount of water required for leaching is directly proportional to ET and the concentration of salt in the irrigation water and inversely proportional to the salinity tolerance of the crop Maintenance of a favorable root environment requires the periodic removal or leaching of accumulated salts

Irrigation Water Requirement (IR, mm/day) Is defined as the depth of water needed to meet the water loss through ET of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility, and achieving full production potential under the growing environment

$$IR = \frac{ET - P_e + LF}{E_a}$$

Evapotranspiration (ET, mm/day) Water is transferred to the atmosphere by direct evaporation of solid and liquid water from soil and plant surface as well as by transpiration of the plant Since these processes each involve evaporation and are not easily separated, they are combined and call evapotranspiration

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Effective Precipitation (P_e, mm/day) Rainfall that is useful or usable in any phase of crop production In arid zones, soils tend to accumulate salts in the root zone Where salt accumulations occur, P_e should not be considered in determining crop water requirements Often the irrigation system must be operated during rainfall events to keep salts away from plant roots

Leaching Fraction (LF, decimal or mm/day) The amount of water that must flow through the root zone to remove accumulating salts Leaching water is in excess of ET requirements and flows downward through the root zone carrying away accumulating salts LF is usually expressed as a decimal portion of ET

Irrigation Water Application Efficiency (E_a, decimal) It is not practical to apply irrigation water perfectly, without losses or misapplications E_a is a measure of the degree of inefficiency in the irrigation water application system and must be included in the calculation of irrigation water requirements The E_a can be determined from a system evaluation

2 FACTORS EFFECTING IRRIGATION SCHEDULING AND APPLICATION AMOUNTS

In principle the amount of irrigation water given in one irrigation application (irrigation depth) is the amount of water used by the plants since the previous irrigation for some irrigations a leaching requirement may be added The maximum amount that should be given has to be determined and is influenced by the factors

- soil textures and depths
- soil moisture content
- crop growth stage and rooting depth
- soil-water solution salinity, and
- irrigation method

2 1 Soil Texture

The soil texture influences the maximum amount of water that can be stored in the soil per meter depth Table 1 gives the ranges in water holding capacity for different soil textures Sandy soils have a low available water content, it will be necessary to irrigate frequently with a small amount of water Clay has a high available water content, a larger amount can be given but less frequently

The depth of each soil layer also effects the quantity of water that can be stored in the root zone For example, loam and sandy soils can hold 167 mm and 83 mm of water per meter of depth, respectively If the loam is 0 25 m deep and underlain by 0 75 m of coarse sand, the total water holding capacity for 1 meter of soil profile is 104 mm

$$(0\,25 \times 167)_{loam} + (0\,75 \times 83)_{sand} = 104\text{mm}$$

2 2 Soil Moisture Content

When scheduling an irrigation, one must consider the quantity of water remaining in the soil that is available to the plant Remember that a knowledge of the quantity of water in a soil reveals nothing about its relationship to plant

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performance until it is calibrated in terms of the water-retention properties of the particular soil involved [1] Since all soils differ in water-retention characteristics, this calibration is required for every soil of a different type existing on a farm

Table 1 Range in available water-holding capacity of soils of different texture

Soil Texture	Water-holding Capacity Range mm/m	Average mm/m
Very coarse - very coarse sands	33 to 62	42
Coarse - coarse sands, fine sands, and loamy sands	62 to 104	83
Moderately coarse - sandy loams	104 to 145	125
Medium - very fine sandy loams, loams, and silt loams	125 to 192	167
Moderately fine - clay loams, silty clay loams, and sandy clay loams	145 to 208	183
Fine - sandy clays, silty clays and clays	133 to 208	192
Peats and mucks	167 to 250	208

If the storage capacity of a soil, at a given level of depletion can retain an irrigation of about 25 millimeters in the root zone and an irrigation of 50 millimeters of water is applied the inefficiency in irrigation and waste of water is apparent

Information is needed about the rate at which water is used from the soil by evapotranspiration and the amount of water that can be usefully stored in the soil root zone The difference in water content of the soil between two successive measurements represents the evapotranspiration in a known time interval A succession of soil-water quantity measurements made over an extended period of time provides information on the water-use rate in the area studied

2 3 Rooting Depth

The rooting depth of a crop also influences the maximum amount of water that can be stored in the rootzone If the root system of a crop is shallow little water can be stored in the rootzone and frequent, but small, irrigation applications are needed With deep rooting crops more water can be taken up and more water can be applied less frequently Young plants have shallow roots compared to fully grown plants Thus just after planting or sowing, the crop needs smaller and more frequent water applications than when it is fully developed Table 2 gives the effective rooting depths for most crops Figure 1 is a general root growth curve that can be used to estimate the crop root depth at different times in the season

When there is a water shortage, drought sensitive crops of high economic value should be given priority Table 3 shows selected crops with their sensitivity to water shortages In general, the mid-season stage is the most sensitive to water

[1] For more information see Module 2-1, *Soil-Water System*

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Table 2 Effective crop rooting depths *

Crop	Root depth (m)	Crop	Root depth (m)
Vegetables		**Field Crops**	
Artichoke	0 6 to 0 9	Alfalfa	1 2 to 1 8
Asparagus	1 2 to 1 8	Barley	0 9 to 1 1
Bean (dry)	0 6 to 1 2	Beet (sugar)	0 6 to 1 2
Bean (green)	0 5 to 0 9	Corn (field)	0 6 to 1 2
Beet (table)	0 4 to 0 6	Pastures	0 3 to 0 8
Broccoli	0 6	Peanut	0 4 to 0 8
Brussels sprout	0 6	Safflower	0 9 to 1 5
Cabbage	0 6	Sorghum	0 6 to 0 9
Cantaloupe	0 6 to 1 2	Soybean	0 6 to 0 9
Carrot	0 4 to 0 6	Tobacco	0 6 to 1 2
Cauliflower	0 6	Wheat	0 8 to 1 1
Celery	0 6		
Chard	0 6 to 0 9	**Permanent**	
Corn (sweet)	0 4 to 0 6	Almond	0 6 to 1 2
Cucumber	0 4 to 0 6	Apple	0 8 to 1 2
Egg plant	0 8	Apricot	0 6 to 1 4
Lettuce	0 2 to 0 5	Avocado	0 6 to 0 9
Onion	0 3 to 0 6	Banana	0 3 to 0 6
Parsnip	0 6 to 0 9	Berries	0 6 to 1 2
Pea	0 4 to 0 8	Cherry	0 8 to 1 2
Pepper	0 6 to 0 9	Citrus	0 9 to 1 5
Potato (Irish)	0 6 to 0 9	Date	>2 1
Potato (sweet)	0 6 to 0 9	Fig	0 9
Pumpkin	0 9 to 1 2	Grape	0 5 to 1 2
Radish	0 3	Olive	0 9 to 1 5
Spinach	0 4 to 0 6	Passion fruit	0 3 to 0 5
Squash	0 6 to 0 9	Peach	0 6 to 1 2
Strawberry	0 3 to 0 5	Pear	0 6 to 1 2
Tomato	0 6 to 1 2	Plum	0 8 to 1 2
Turnip	0 5 to 0 8	Walnut	1 7 to 2 4
Watermelon	0 6 to 0 9		

* Approximately 80% of the feeder roots are in the top 60% of the root zone in a deep, uniform, well-drained soil profile Soil and plant environmental factors often offset normal root development therefore, soil density, pore shapes and sizes, soil-moisture status, aeration nutrition, texture and structure modification soluble salts, and plant root damage by organisms should all be taken into account

shortages and the late-season stage is the least sensitive To plan water applications under these conditions some crop specific information is needed

Annual crops have four growth stages

- Initial — from sowing to 10% ground cover,
- Crop development — from 10% to 70% ground cover,

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- Mid-season — flowering and fruit setting and
- Late-season — ripening and harvest

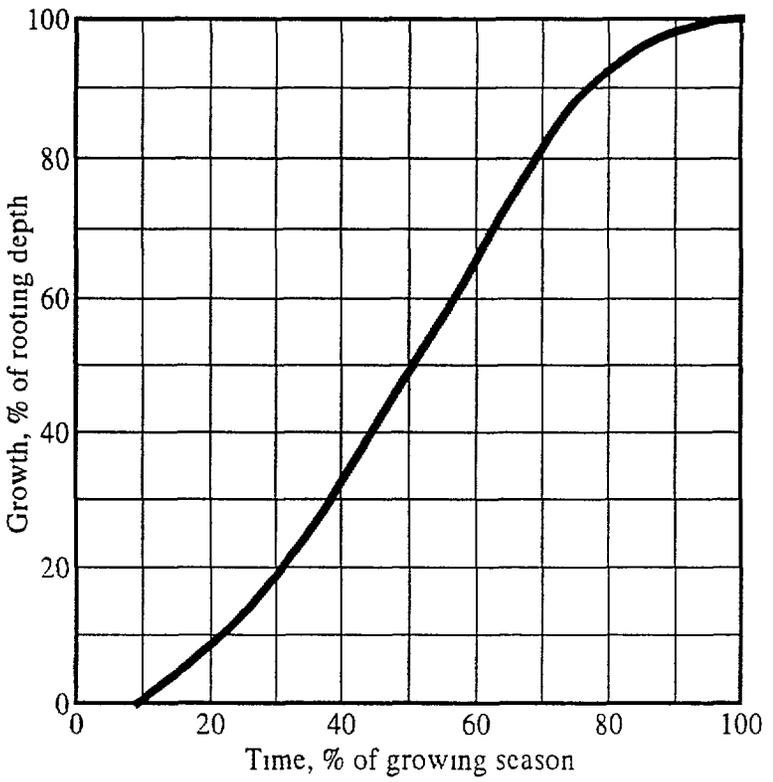

Figure 1 General seasonal root growth curve

2-4 Soil-Water Solution Salinity[2]

The sum of the force with which water is held by soil particles and the force of attraction by salt ions in the soil-water solution is the total force moisture stress plants must exceed to obtain water These are the factors that decrease the availability of soil moisture to plants below the level of availability of pure water under normal atmospheric conditions In scheduling irrigations with saline water, the total moisture stress must be kept in mind

With every irrigation a certain amount of salts is brought to the soil Crops absorb water added by irrigation and/or rainfall, leaving behind the salts that were in the irrigation water Soluble salts move with irrigation water and there should be an additional amount of water, more than that needed by the crops, to carrying the salts out of the root zone The proportion of the excess water needed, as related to the total depth of irrigation water applied, is termed the Leaching Fraction (LF) Leaching fractions based on the quality of the irrigation water, the allowable soil-water solution salinity level, and the frequency of irrigations are found using Figure 2 The quantity of salts in the irrigation water and soil-water solution is measured by the electrical conductivity of the liquids and expressed as deci-Siemens per meter (dS/m)

[2] For more information see Module 2-2, *Use of Saline Irrigation Water*

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In order to maintain a constant salt balance in the soil, the total volume of salt carried out with the drainage water must equal the total volume of salt added to the soil-water solution by the irrigation water additives such as fertilizers, and salts dissolved from native soil material It is not unusual for the quantity of salts entering the soil-water solution from non irrigation sources to be significant Leaching fractions vary according to the crop total quantity of salts added to the soil-water solution, and the frequency of irrigation It is best to determine leaching fractions and leaching schedules by periodically monitoring soil-water solution salinity levels at different depths of the crop rootzone

Table 3 Critical growth periods where moisture stress adversely affects yield

Crop	Critical growth period for moisture stress
Alfalfa	After cutting
Banana	Throughout
Barley	Shooting and earing
Maize	Flowering and early grain formation
Wheat	Flowering through dough stage
Citrus	Flowering period and fruit filling
Olive	Flowering and yield formation
Vegetables	
Asparagus	Brush
Bean Lima	Pollination and pod development
Bean Green	Pod enlargement
Broccoli	Head development
Cabbage	Head development
Carrot	Root enlargement
Cauliflower	Head development
Corn	Silking and tasseling ear development
Cucumber	Flowering and fruit development
Eggplant	Flowering and fruit development
Lettuce	Head development
Melon	Flowering and fruit development
Onion, dry	Bulb enlargement
Pea	Flowering and pod filling
Pepper	Flowering and fruit development
Potato, white	Tuber set and tuber enlargement
Potato, sweet	Root enlargement
Radish	Root enlargement
Squash, summer	Bud development and flowering
Tomato	Early flowering, fruit set, and enlargement
Turnip	Root enlargement

2 5 Irrigation Method

Irrigation method can be a limiting factor when determining the maximum amount of water that can be applied during one irrigation This is particularly true for surface irrigation on a small-scale (small water flows and small fields) For micro irrigation systems small flows are not problematic but large flows can be Micro systems are designed for frequent applications of small flows but cannot supply the large flows needed for infrequent long-interval irrigation schedules

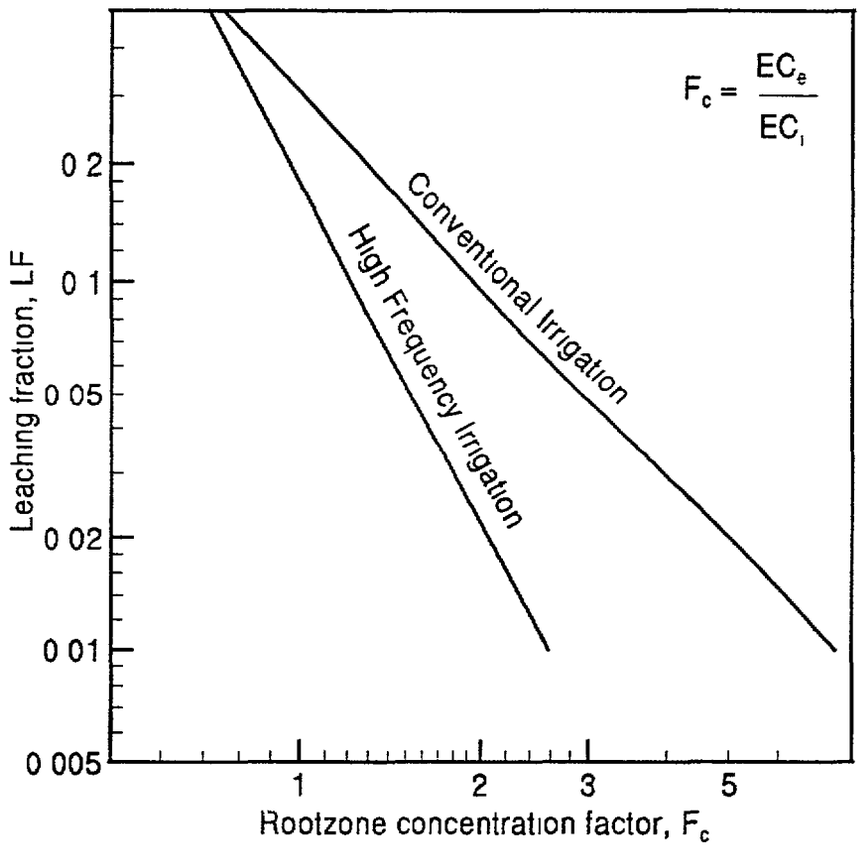

Figure 2 Leaching fraction based on irrigation frequency and rootzone concentration factor

Research shows that full coverage of the rooting zone with irrigation water is not necessary for optimum production Thirty to 50% root zone wetting has been recommended for trickle irrigation, higher values are used for some tree crops The proportion of the crop root zone wetted (P_w), is used to adjust the schedule for trickle irrigation, which wets only a portion of the root zone

3 DETERMINING IRRIGATION SCHEDULES

Irrigation depth and/or the irrigation interval vary with crop development At the beginning of the growing season, the amount of water per irrigation is small and given frequently This is due to the low evapotranspiration rate of young plants and

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their shallow root depth During the mid-season the irrigation depth should be larger and given less frequently because the evapotranspiration demand is higher and the root depth is at maximum

When micro irrigation methods are used it is possible and practical to vary both the irrigation depth and interval during the irrigation season With micro irrigation it is just a matter of turning on the tap longer/shorter or less/more frequently This flexibility is available to those farmers in the Jordan Valley who use pools to store water between deliveries For farmers depending upon pressure from the water delivery pipeline, no pools the irrigation depth and interval are kept nearly constant over the growing season because of the JVA rotation delivery schedule

Developing the basic irrigation schedule is a systematic process that need not be complex Information needed in addition to the physical parameters are

- Daily evapotranspiration rate (ET_d) — calculated or estimated based on climatic factors Module 2-3 *Crop Water Requirements* presents a discussion of this topic In place of ET_d soil moisture levels may be measured and used to estimated soil moisture depletion rates
- Management allowed deficit (MAD) — the proportion of the available water held in the root zone that is allowed to be depleted before irrigation water is applied MAD is a function of crop value and sensitivity to water deficit Table 4 is a guide for selecting MAD values

Table 4 Guide for selecting management-allowed deficit (MAD) values

Crop and rooting depth	MAD %
Shallow-rooted high value fruit and vegetable crops	25 - 40
Orchards [1] vineyards berries and medium-rooted row crops	40 - 50
Forage crops grain crops and deep-rooted row crops	50

1 Some fresh fruit orchards require lower MAD values during fruit finishing for sizing

3 1 System Application Rate

Farmers can use information obtained from a **System Evaluation** (Module Series 3-1 to 3-4) to accurately determine the rate at which their system applies water The net application rate of the system, N_R (cm/hr) is found by

$$N_R = EU \times A$$

where A = application rate of the system, cm/hr, and EU = emission uniformity based on the low quarter, expressed as a decimal

The system application rate is the amount of moisture that will be applied to the soil surface per hour of system operation This parameter is determined by the type of emitters used and the pressure in the lateral lines it should not change during the crop season The system should not be designed to apply water at a rate faster than it can infiltrate into the soil Table 5 gives average intake rates

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for various soil textures At these intake rates water will not pond on the soil surface

3 2 Irrigation Application Depth

The irrigation application depth I_d (cm) can be estimated from the relation

$$I_d = \frac{AWC \times MAD \times z \times P_w}{100}$$

where I_d = depth of irrigation, cm, AWC = available water capacity, cm m (Table 1) MAD = proportion of AWC to be depleted before irrigation, % (Table 4), z = crop rooting depth m (Table 2 and Figure 1), and P_w = percentage of the crop area wetted expressed as a decimal fraction of 0 01 to 1, see Figure 3 As the crop rooting depth changes through the season the I_d would also change

Table 5 Moisture intake rates for various soil textures

Soil Texture	Intake Rate (IR) Range (cm hr)	Average (cm/hr)
Loamy sand sand	1 25 < IR	-
Sandy loam	1 to 1 8	1 3
Loam silty loam	0 8 to 1 25	1 1
Clay loam sandy clay loam	0 5 to 0 8	7 5
Clay	IR <0 1 to 0 5	0 3

3 3 Irrigation Interval

The irrigation interval, I_I (days), is calculated using

$$I_I = \frac{I_d}{T_d \times (1 - LF)}$$

$$T_d = 0\ 1 \times ET_d \times (P_d)^0$$

where T_d = average daily transpiration rate during the peak-use month, cm/day LF = the leaching fraction, expressed as a decimal fraction, ET_d = conventionally estimated evapotranspiration rate during the peak-use month, cm/day, and P_d = percentage of the soil surface area shaded by crop canopy at midday (solar noon), %

The P_d can be estimated by inspection Simply mark off the area allocated to a tree or plant and observe the percentage of the area that is directly under the plant canopy, see Figure 3 A mature orchard usually has a maximum $P_d \approx 80\%$

The irrigation interval will change throughout the crop season as the rooting depth which effects I_d and the T_d requirements change I_I would be rounded down to the nearest day, e g , I_I = 7 4 days would become 7 days If I_I is rounded

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up the MAD is increased i e the soil moisture depletion is greater For sensitive crops a higher MAD may negatively effect the yield

Effective rainfall is not considered for production systems using plastic houses tunnels, or mulch because little or no benefit is received from rainfall Where soil salts must be considered open field irrigation must continue during rainfall events to keep the salts from being washed into the root zone

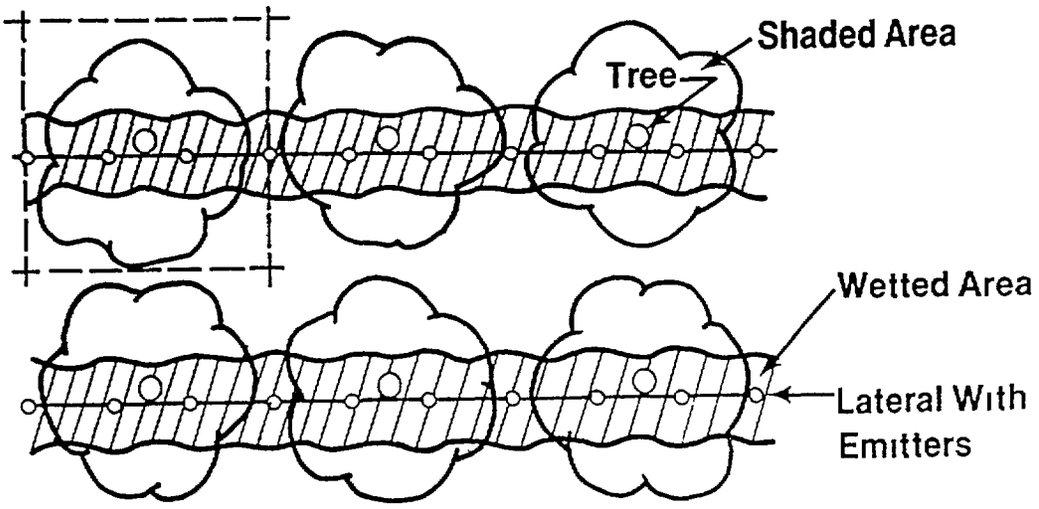

Figure 3 Percentages of wetted and shaded areas,
$P_w \approx 30\%$ and $P_d \approx 55\%$

3 4 Irrigation Set Time

The irrigation set time T_{set} (hr), is the time period the irrigation system must be operated to apply the required quantity of water Following on from the above, the irrigation set time is

$$T_{set} = \frac{I_i \times ET \times (1 + LF)}{N_R}$$

when I_d is known T_{set} is

$$T_{set} = \frac{I_d}{N_R}$$

4 Total Marketable Yield vs Total Water Application

A considerable amount of research has been done on the yield of a crop versus the quantity of water applied Results from research done on two vegetables, which are grown in the Jordan Valley, is shown in Figure 4 and illustrates the following points

- Different crops respond differently to additional quantities of irrigation water
- The deficit irrigation range is that part of the curve to the left of the peak yield This region is characterized by an increase in marketable yield per additional unit of water applied

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- The irrigation optimum range is where high yields are achieved, yields are within 10% of the maximum achievable
- 25% and 35% deficit irrigations will give 90% yields for lettuce and Chinese cabbage respectively
- The over-irrigation range is to the right of the peak yield value and is characterized by a reduction in marketable yield per additional unit of water applied
- Rates of yield decrease caused by over-irrigation differ by crop
- For maximum monetary return per unit of water irrigation water applications should be in the deficit range, near the irrigation application required for peak yields

It is apparent from the figures that more water does not necessarily mean more yield

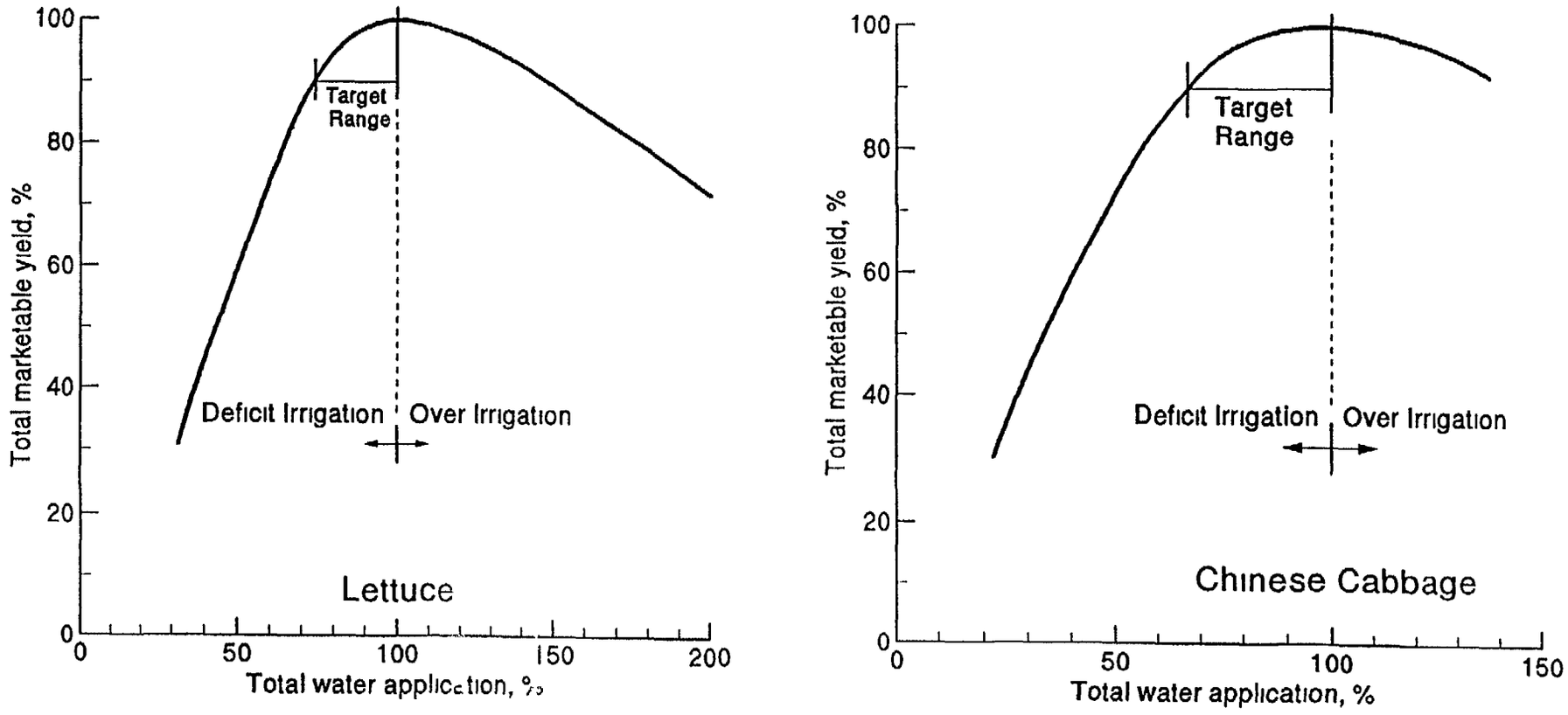

Figure 4 Marketable yield as a function of total seasonal water applications for lettuce and Chinese cabbage

IRRIGATION SCHEDULING

CASE STUDY I

1 GIVEN DATA

Crop	Tomato
Crop age	70 % of season, peak production
Maximum rooting depth	1 2 m
Rooting depth,[3] z	0 82 x 1 2 = 0 98 m
Soil type	loam
Available water capacity, AWC	16 7 cm/m
Distribution uniformity, DU	70%
Irrigation method, high frequency	GR drip line 40 cm emitter spacing
Application rate, A	2 lph = 1 25 cm/hr
Management allowed deficit MAD	25 %
Proportion of the root zone wetted, P_w	40 %
Evapotranspiration, ET_d	7 mm/day
Percentage of the soil surface shaded P_d	80%
Maximum EC_e allowed	2 5 dS/m
Salinity of irrigation water EC_i	2 35 dS m
$L_c = LC_e/EC_i$	1 06
Leaching fraction LF from Figure 5	0 15

2 CALCULATION STEPS

2 1 System application rate

To prevent surface runoff the system application rate should not exceed the infiltration rate of the soil From Table 5 the average infiltration rate of a loam soil is 1 1 cm/hr

$$N_R = DU \times A = 0\ 70 \times 1\ 25 = 0\ 875 \text{ cm/hr}$$

The system application is within the allowance for the soil intake rate N_R would be calculated early in the season and assumed constant for the remainder of the season During design the system application rate should be specified to not exceed the soil intake rate

2 2 Irrigation application depth

$$I_d = \frac{AWC \times MAD \times z \times P_w}{100} = \frac{16\ 7 \times 25 \times 0\ 98 \times 0\ 4}{100} = 1\ 64 \text{ cm}$$

If irrigation occurs at the desired MAD, an application of 1 64 cm is required to replenish the water used from the root zone Application of water in excess of 1 64 cm will refill a larger portion of the root zone than the 40 % desired and could result in losses to deep percolation

[3] For 70% of the growth season the rooting depth is about 82% (Figure 1), the maximum rooting depth is taken from Table 2

2 3 Irrigation interval

$$T_d = 0\ 1 \times ET_d \times (P_d)^{0.5} = 0\ 1 \times 0\ 7 \times (80)^{0.5} = 0\ 63 \text{ cm/day}$$

$$I_1 = \frac{I_d}{T_d \times (1 + LF)} = \frac{1\ 64}{0\ 63 \times (1 + 0\ 15)} = 2\ 3 \text{ days}$$

A 2 day irrigation interval should be used during this stage of the crop season This is the time of peak water use and fruit filling, the crop is in a critical period and water shortage could adversely affect both quality and quantity of yield

2 4 Irrigation set time

$$T_{set} = \frac{I_1 \times T_d \times (1 + LF)}{N_R} = \frac{2 \times 0\ 63 \times (1 + 0\ 15)}{0\ 875} = 1\ 66 \text{ hrs}$$

The irrigation system should be operated for 1 66 hours or 100 minutes

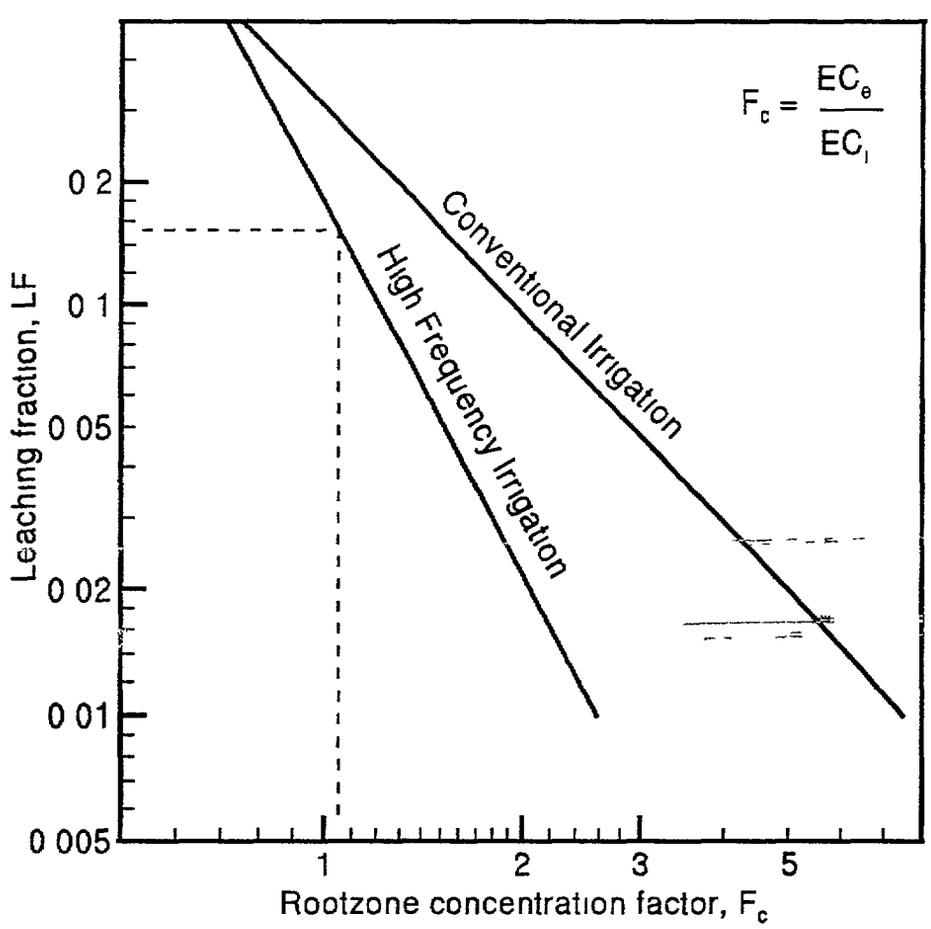

Figure 5 Leaching fraction based on irrigation frequency and rootzone concentration factor

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SYSTEM PERFORMANCE EVALUATION EFFECTIVENESS, FOLLOW-UP SURVEY

This form is to be completed by the farmer 2 – 3 weeks after the Evaluation Report has been delivered and discussed with the farmer

We want to evaluate the effectiveness of the technical services provided by the IAS staff The purpose is to improve the quality of our services Farmers, please respond to the following questions with frankness and honesty Your responses are confidential

IAS did an irrigation system performance evaluation on your farm The results of this field work were reported to you The following questions refer to this technical work

1	Yes	No	In your opinion did the IAS adequately measure" and evaluate the various components of irrigation system performance
2	Yes	No	Was the technical information presented to you in such a way that you could easily understand it?
3	Yes	No	In your opinion did the IAS team have the technical skills to help you?
4	Yes	No	Were the suggestions to improve irrigation performance practical?
5	Yes	No	Did you put into practice any of the system operation, maintenance and management suggestions offered by the IAS team?

As a result of the field work, do you have a better understanding of

6	Yes	No	the surface topography of the field evaluated and its relation to irrigation water management?
7	Yes	No	crop rooting depths and plant water needs thru the season?
8	Yes	No	soil moisture levels and ability of the soil to hold water?
9	Yes	No	how much water was applied and its relation to irrigation needs?
10	Yes	No	the penetration of the water into the soil profile by the irrigation?
11	Yes	No	the timing of this irrigation and/or knowing when to irrigate next?
12	Yes	No	the costs associated with the irrigation event?
13	Yes	No	how to improve system performance in upcoming irrigations?
14	Yes	No	Were IAS staff courteous and respectful of you. your staff and your farm?

Please feel free to offer additional comments _____

_____

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MICRO IRRIGATION SYSTEMS
EVALUATION OVERVIEW

[Supplemental]

1 INTRODUCTION

The purpose of evaluating irrigation systems is twofold (a) To determine the efficiency of the system as it is being used and (b) To determine how effectively the system can be operated and whether it can be improved Essential parts of any evaluation are the identification of areas for improvement and development of a program to improve system operation Always keep in mind that system operation is composed of two parts (a) Delivery of water through the physical infrastructure (head unit pipes, fittings, and emitters) and (b) Management of the system, when and how long water is run through the system at each irrigation

System evaluation involves measuring conditions at one or more points in a field selected to be typical or representative Value judgments or additional measurements must be made to correlate these data to an overall field

> *The accuracy of most measurements will seldom justify calculating efficiencies to more than ± 5 percent*

A fundamental difference exists in evaluating micro-irrigation systems as compared to surface irrigation systems The concept of applying a uniform depth of water over the entire area is in conflict with the advantages of micro-irrigation A distinct advantage for micro-irrigation is to decrease the area of surface wetting to minimize the evaporation from the soil surface The water is applied to the area near the plant roots and helps to minimize weed growth in areas between the plants in the nonproductive area by keeping this area dry This is particularly important in tree crops where the water can be applied near the tree, concentrating plant roots in the irrigated area while not inhibiting growth and production

Trickle irrigation systems deliver water slowly, usually at the soil surface, from tubing with many closely spaced very small outlets to create an essentially continuous wetted line, or from more widely spaced emitters to create intermittent wetted spots In practice, at the peak water use design period they are operated frequently and so keep the central portion of the wetted soil bulb well above field capacity on medium and fine textured soils

2 SYSTEM EVALUATION DEFINITIONS

Application Efficiency (AE) is the ratio of the average depth of the irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied, expressed as a percent This term indicates the percentage of water applied that is stored in the root zone for crop use *It is not useful in evaluating irrigation system operation* in the field because high efficiencies can be obtained by under-irrigation even when water is distributed very non-uniformly

Contaminant Removal Efficiency (E_R) is a measure of the suspended solids removal ability of the filtration system, measures for both media and screen filters should be made Filtration is an important factor in the uniformity of water distribution,

> *The most important cause of emitter plugging is suspended solids passing the filtration units*

Percentage Emitter Plugging (EP) is an indirect measure for assessing the effectiveness of a microirrigation filtration system The possible sources of emitter plugging are physical, chemical, and biological in nature In addition, the degree of emitter plugging can be used as a measure of the effectiveness of preventative practices such as chemical water treatment

> *The maximum allowable plugging percentage is 20% for row crops if the emitter spacing is designed for 0 5 of the diameter of the wetted area*

Statistical Uniformity (U_S) is an estimate of the uniformity of emitter discharge rates throughout an existing microirrigation system U_{SP} measures the uniformity of emitter discharge when emitter plugging is included

> *A statistical uniformity of 80% or greater is required before fertilizer injection through the irrigation system is recommended*

Emission Uniformity (EU) is a ratio of average irrigation water deliveries, average delivery to the lowest one-quarter of emission points divided by average delivery to the entire field, expressed as a percent The EU is a useful indicator of the magnitude of distribution problems A low EU value indicates that losses due to deep percolation are excessive if adequate irrigation is applied to all areas

Although the concept of low EU is relative, values less that 67 percent are generally considered as unacceptable For example, if the desired depth of infiltrated water is 4 inches and the EU is 67 percent, the average depth infiltrated must be 6 inches and the deep percolation loss will be 2 inches However if deep percolation is limited by reducing the applied depth and the EU value is low, the area receiving the low quarter depth of irrigation will be seriously under irrigated

The EU of new installations may be close to 90 percent, but EU and the application efficiency (AE) usually decline appreciably with continued use, a more typical value of about 80 percent should be considered

Scheduling Ratio (SR) is a measure of the adequacy of irrigation scheduling for trickle irrigated fields The localized above field capacity condition that is usually maintained by frequent applications imply that there may be continuous deep percolation

Irrigation Efficiency (IE) is the ratio of the volume of water that is beneficially used to the volume of irrigation water applied Table 1 lists examples of beneficial and non-beneficial uses of irrigation water

Table 1 Beneficial and non-beneficial uses of on-farm irrigation water

Beneficial Uses	Non-Beneficial Uses
Crop transpiration	Weed transpiration
Leaching requirements	Evaporation from a wet soil surface
Climate control	Leakage from pipes and fittings
Weed germination	Surface runoff from over irrigation
Packing the soil for harvest	Deep percolation exceeding leaching requirements
Pesticide applications	
Fertilizer applications	

MICRO IRRIGATION SYSTEMS
DATA COLLECTION

[Trainee Guide]

1 INTRODUCTION

This module will walk you step-by-step through collection of the data necessary to evaluate a trickle irrigation system For the results to be meaningful, reasonable care must be taken in the data collection process Make sure the equipment is working correctly and you are comfortable in its use At all times think about the data you are collecting, if the data looks unreasonable recheck or redo the test If you determine some data is wrong during the analysis phase it is not easy to return to the field to collect good data

In cases where the system walk-through identifies substantial deficiencies (major leaks in main or sub-main pipelines, damaged or non-functional equipment), it may be best to end the evaluation at this phase Identified major deficiencies may need to be corrected before a useful system evaluation can be made

Throughout the data collection process be observant of the system record descriptions of deficiencies and parts that are working well Look at the crops and soils being irrigated, clues on water application uniformity, application quantity, and water quality can be obtained These clues can be explored in more detail during data collection and analysis

> ***As improvements are made to the irrigation system, additional sampling of the system will be needed to further refine operation and maintenance practices Maintaining high efficiency is an ongoing effort that requires constant monitoring and improvements***

2 MATERIAL REQUIREMENTS

2 1 Needed forms

- 2 1 1 Data collection forms
- 2 1 2 Schematic diagrams showing data collection points see following Figures

2 2 Equipment needed

- 2 2 1 Pressure gauge (0-50 psi range) with "T" adapters for temporary installation at either end of the lateral hoses
- 2 2 2 Pressure gauge (0-50 psi range) with pitot tube for temporary insertion into the manifold or lateral hose
- 2 2 3 A stopwatch or watch with easily visible second hand
- 2 2 4 Graduated cylinder with 250 ml capacity
- 2 2 5 Measuring tape 3 to 6 m long
- 2 2 6 Funnel with 8 cm to 16 cm diameter

2 2 7 Ladies knee high nylon stockings, or equivalent

2 2 8 Containers to hold water samples taken from filter inlets and outlets

2 2 9 Level instrument and rod

2 2 10 Tape measure, about 30 meter

3 DATA COLLECTION, SYSTEM OFF

3 1 General farm inventory

3 1 1 Fill in the Farming Practice Inventory, **Data Sheet 1**
Conduct a walk-through to get an overview of the system, Weaknesses to look for include the absence of pressure regulators and pressure gauges, incorrect piping, capacity to flush mains, submains, and laterals, insert emitter placement on laterals, leaks at joints or valves, emitter plugging damaged emitters, and other obvious system defects, look at the condition of the crop (uniformity in size, maturity, and color)

At this point decide whether to proceed with the evaluation or to delay until major deficiencies have been corrected

3 1 2 Complete the Trickle Irrigation System Inventory **Data Sheets 2** and **3**

3 2 Media filter, **Data Sheet 4**

3 2 1 Open the drain valve at the bottom of the tank

3 2 2 Open the port on the media filter tank

3 2 3 Record the observed status of the media filter bed (flat, cones & valle , sediment and trash laden)

3 2 4 Record the estimated size of the filter media

3 2 5 Collect a sample of the filter media [Label the sample date and place collected, person taking the sample]

3 2 6 Reseal the filter tank

3 3 Screen filter, **Data Sheet 4**

3 3 1 Open the drain valve at the bottom of the tank

3 3 2 Open the filter tank

3 3 3 Remove the filter element

3 3 4 Record the observed status of the filter mesh screen (mesh size, holes, tears, degree of screen plugging)

3 3 5 Clean and reinstall the element

3 3 6 Reseal the filter tank

3 4 Equipment installation, Figure 1 shows the points for equipment installation

3 4 1 If necessary, install missing pressure gauges

3 4 2 If necessary, install flow meter

3 4 3 If necessary install tee sections and valves in the filter inlet and outlet lines

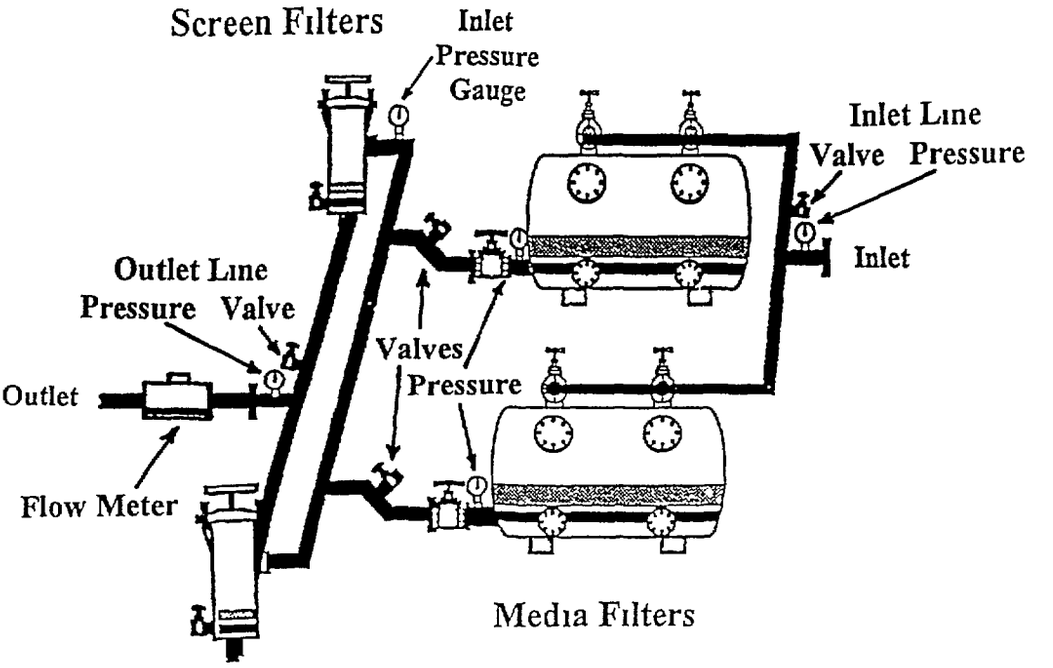

Figure 1 Locations of pressure gauges, valves, and flow meter for data collection at the head unit

3 5 Locate the **four** submains to be evaluated, Figure 2 shows an example

3 5 1 **One**, submain hydraulically closest to the water source (number 1)

3 5 2 **Two and three**, submains in the middle of the system (numbers 3 & 4)

3 5 3 **Four**, submain hydraulically farthest from the water source (number 6)

Mark on the system sketch the location of the submains used in the evaluation

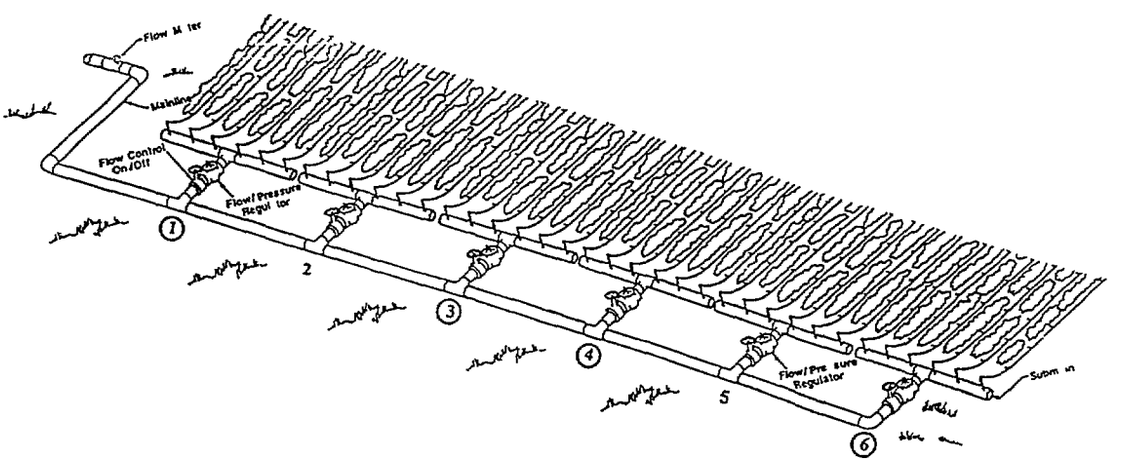

Figure 2 Selection of the submain to test

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3 6 Submains, **Data Sheet 5** and **Data Sheet 6** for survey information

3 6 1 Measure the length of each test submain

3 6 2 Measure the slope of each test submain The level and rod are used to take elevation readings at the **inlet** and **end** of the submain The difference in the readings divided by the length between measuring points is the slope If the inlet to the submain is in the center elevation measurements should be made at both ends From the inlet, a portion of the submain may be sloping downward and the other portion may be sloping upward

3 7 Selection of **four** laterals to evaluate

The approach to lateral selection varies according to the number of laterals on a submain ***The goal is to select laterals that are representative of the area to be evaluated*** As evaluations become more detailed, the number of submains or manifolds and laterals used increases but representation should still be obtained

3 7 1 Submains with a large number of laterals, Figure 3

- **One**, lateral closest to the point where water enters the submain
- **Two**, lateral about one third the distance to the end of the submain There are 9 laterals on each side of the entry point, 1/3 of 9 = 3
- **Three** lateral about two thirds the distance to the end of the submain, 2/3 of nine = 6
- **Four**, lateral at the end of the submain

When laterals are on both sides of the point where water enters a submain, it is best to choose two test laterals on each side

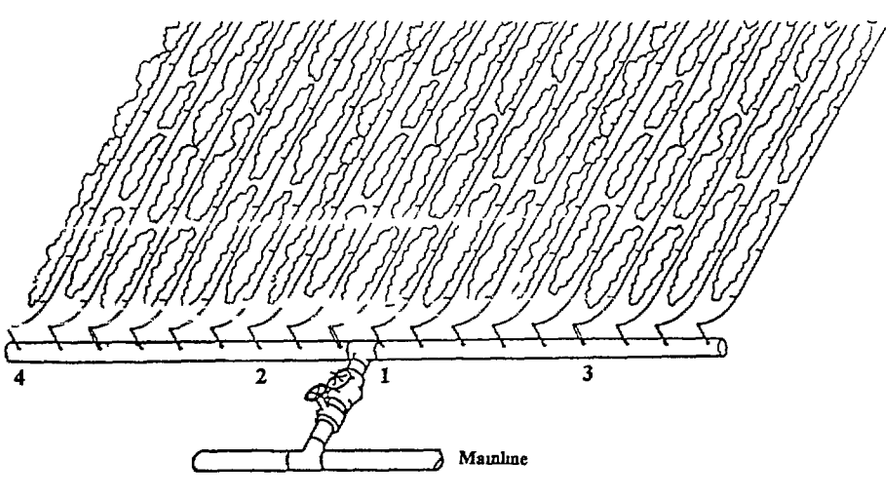

Figure 3 Selection of laterals to test, submain with many laterals

3 7 2 Submains with few laterals, Figure 4

- **One**, lateral hydraulically closest to the water source
- **Two**, lateral about one third the hydraulic distance from the water source
- **Three**, lateral about two thirds of the hydraulic distance from the water source

- **Three,** lateral about two thirds of the hydraulic distance from the water source
- **Four,** lateral hydraulically farthest from the water source

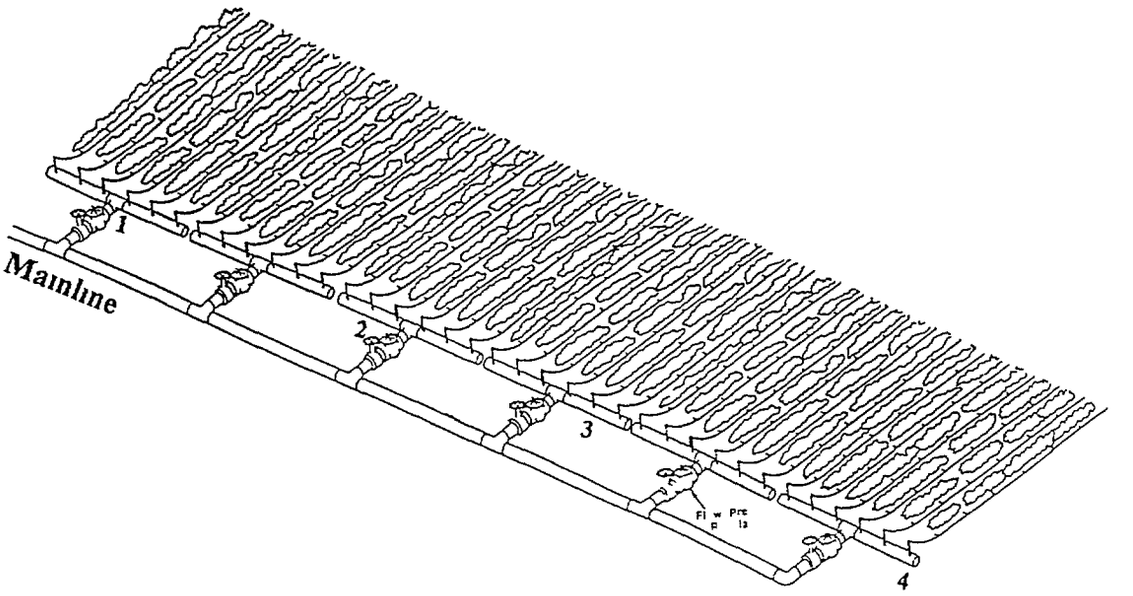

Figure 4 Selection of laterals to test submain with few laterals

3 8 Lateral information, **Data Sheet 5** and **Data Sheet 6** for survey information

3 8 1 Measure the length of each test lateral

3 8 2 Measure the slope of each test lateral The level and rod are used to take elevation readings at the inlet and end of each lateral The reading at the inlet minus the reading at the end divided by the length between measuring points is the slope If the slope is negative, the lateral is sloping upwards

3 8 3 Record the other basic information on the test laterals

3 9 Number of emitters, **Data Sheet 8** [This data can be collected while walking to the end of the lateral to measure its length]

Count the number of emitters on each lateral tested [for GR tubing, measure the emitter spacing and calculate the number of emitters in the line]

4 DATA COLLECTION PROCEDURES, SYSTEM ON

Bring the system up to full operation and allow time for it to stabilize

4 1 Flow rate and pressure differences, **Data Sheet 4**

4 1 1 Record the flow rate through the filtration units

4 1 2 Record the pressures at the inlet and outlet of the media filter

4 1 3 Record the pressures at the inlet and outlet of the screen filter

4 2 Contaminant removal samples **[Label sample collection bottles]**

4 2 1 Collect at least a 1 5 liter sample from the pipe **entering** the media filter

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4 2 2 Collect at least a 1 5 liter sample from the pipe **exiting** the media filter

4 2 3 Collect at least a 1 5 liter sample from the pipe **exiting** the screen filter

4 2 4 Record the flow rate at the time of data collection **Data Sheet 7**

4 3 Submains **Data Sheet 5**

4 3 1 Measure the water pressure at the inlet of each test submain disconnect the first lateral hose and insert the pressure gauge using the pitot tube If the inlet is at the center of the submain, as shown in Figures 3 and 4, take the pressure reading at the lateral closest to the inlet

4 3 2 Measure the water pressure at the end of each test submain disconnect the last lateral hose and insert the pressure gauge using the pitot tube

If the inlet is at the center of the submain, as shown in Figures 3 and 4, take a pressure reading at **both** ends Record the readings as right and left as seen when standing at the inlet facing the laterals, the pressure and slope readings should be on the same line for the section and each section would have the same inlet pressure Each submain of this type will use two lines on the data sheet

4 4 Emitter plugging **Data Sheet 8** [This data can be collected while walking to the end of the lateral to measure its end pressure]

Count the number of emitters on each lateral tested that are fully plugged or emitting less than 10% of the design flow

4 5 Measure and record the water pressure at the inlet and downstream ends of each lateral to be tested, **Data Sheet 8**

4 5 1 At the inlet end disconnect the lateral hose and insert the pressure gauge using the "T" If the lateral cannot be disconnected, remove the first inserted emitter on the line, insert the pressure gauge using the pitot tube

4 5 2 At the downstream end open the end of the lateral and collect the material being flushed from the line with a ladies nylon stocking and record values on **Data Sheet 8**

4 5 3 Insert the pressure gauge using the "T" Plug the open end of the "T" with a thumb or finger and read the pressure

4 6 Measure the discharge at two adjacent emission points, denoted as A and B on **Data Sheet 9**, at each of **four different** locations on each lateral, See Figure 5

4 6 1 Two adjacent emission points should be near the inlet to the lateral,

4 6 2 Two adjacent emission points should be at the 1/3 distance location,

4 6 3 Two adjacent emission points should be at the 2/3 distance location, and

4 6 4 Two adjacent emission points should be at the end of the lateral

Record on the data sheet the time required to collect a volume of 100 ml at each emission point

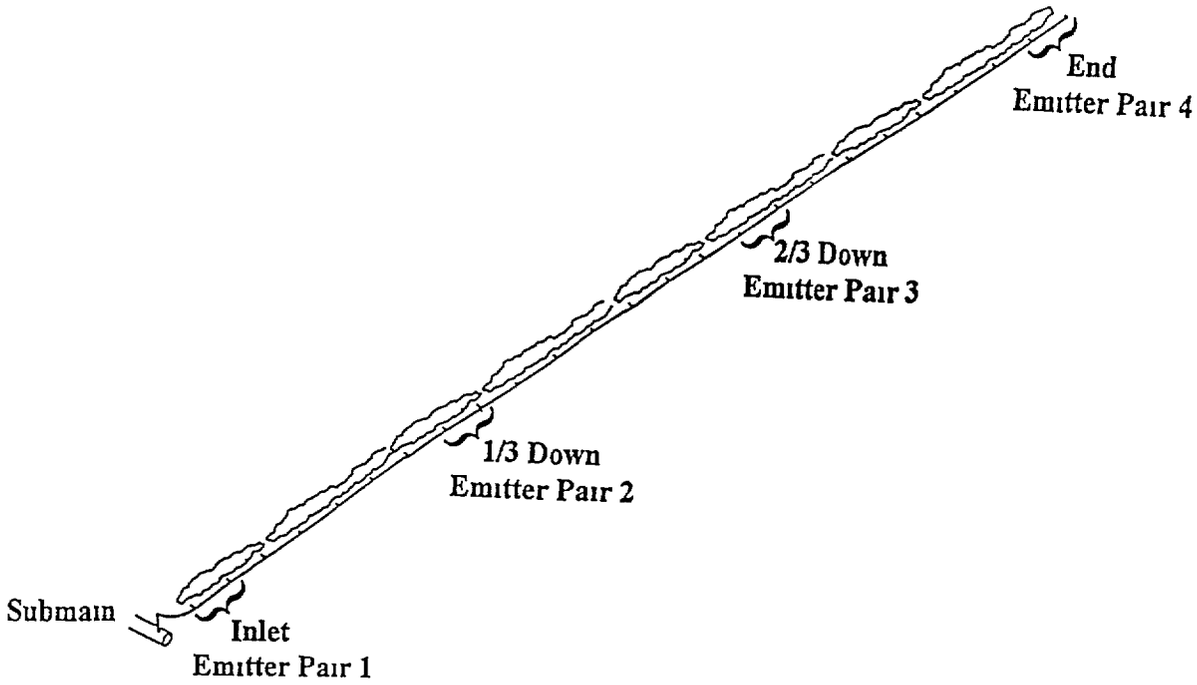

Figure 5 Selection of emitter pairs to sample

5 Analyses of Samples Collected

Take media and water samples to the Jordan Valley Authority Laboratory for analyses [During the training exercise, give the samples to the instructor]

6 System Management

Use **Data Sheet 10** to log water delivery and application data Completion of this data sheet should be a part of each irrigation event Use the recorded data to evaluate management of the irrigation system, scheduling ratio, and to help identify system deficiencies

FARMING PRACTICE INVENTORY, DATA SHEET 1

Farm **DA**–_____ Farm Unit No _____ Date ____/____/199____

Farm Name _____

Evaluators _____

Crop _____ Planting Date _____ Spacing _____

Crop Age _____ Estimated Root Depth _____

Soil Type _____ Description _____

Irrigated Area _____ Infiltration Rate _____

Water Holding Capacity _____

Irrigation practices

Irrigation frequency _____

Length of irrigation, for how much time does each lateral get water _____

Number of laterals irrigating at the same time _____

Maximum number of emitters per lateral _____
(Lateral length/Emitter spacing)

Emitter design flow rate _____

Walk-Through Observations

_____

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TRICKLE IRRIGATION SYSTEM INVENTORY, DATA SHEET 2

Farm **DA–**_____ Farm Unit _____ Date ___/___/199___

Farm Name _____

Evaluators _____

Pressure Source JVA ____ Pump ____ **System Age** _____

Pump

Age _____ Make _____ Model _____

Output Pressure _____ psi Discharge rate _____ lps

Screen Filter

Age _____ Type _____ Model _____

Manufacturer _____

Design Inlet Pressure _____ psi Outlet Pressure _____ psi

Flow rate _____ l/s

Media Filter

Age _____ Type _____ Model _____

Manufacturer _____

Design Inlet Pressure _____ kPa/psi Outlet Pressure _____ kPa/psi

Flow rate _____ l/s

Fertilizer Injector

Age _____ Type _____ Model _____

Manufacturer _____

Reservoir/Pool Yes _____ No _____ Lined Yes _____ No _____

Capacity _____ Liters, M^3 Lining Material _____

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TRICKLE IRRIGATION SYSTEM INVENTORY, DATA SHEET 3

Regulators/Valves

Pressure reducing Yes ___ No ___ Age _____

Type _____ Model _____

Manufacturer _____

Flow control Yes ___ No ___ Age _____

Type _____ Model _____

Manufacturer _____

Vacuum relief Yes ___ No ___ Age _____

Type _____ Model _____

Manufacturer _____

Sketch of System Layout

FILTER PRESSURE LOSS-FLOW TEST, DATA SHEET 4

Farm _____ Date _____ Evaluators _____

Age of media filter unit _____ Age of screen filter unit _____

Electrical conductivity of water _____ dS/m

What is the average backflushing/cleaning interval during operation

Media filter _____ Screen filter _____

Results of media inspection _____

_____

Results of screen inspection _____

_____

Size of media _____ Size of screen mesh _____

Data Collection

- Pressure taps shall be located a minimum of five pipe diameters downstream of any tees, elbows, valves, flow measuring instruments etc
- Measurements shall be made upstream and downstream of the filter unit being tested
- Taps shall not protrude inside the pipes The edge of each hole shall be clean and sharp or slightly rounded
- All taps shall be identical in design

Filter type	Flow rate l/s	Pressure Upstream	Pressure Downstream
Media 1			
Screen 1			

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SUBMAINS AND LATERALS, DATA SHEET 5

Farm _____ Date _____ System Age _____ years / months

Submains

Submain Number	Age Years/ Months	Material PVC/PE	Number of Laterals	Length M	Slope M/M	Pressure inlet	Pressure end	Diameter mm

Laterals

ID Number	Age Yr/Mn	Length M	Slope M/M	Dia mm	Number Emitters	Emitter Spacing	Emitter Type

SURVEY NOTES, DATA SHEET 6

Notes	Elevation	Fore Sight	Instrument Height	Back Sight	Station

REMOVAL EFFICIENCY OF FILTRATION UNIT, DATA SHEET 7

Farm _____ Date _____ Evaluators _____

Water Sample Collection

Use valves on the side of the inlet and outlet pipes for collection of water samples during a test for compositional and particle size analyses The sampling valves shall be located on the horizontal centerline of the inlet and outlet pipes and above any downstream throttling device or filtration

- Collect samples 30 minutes or more after last backwash cycle
- Use a sample bottle that has been thoroughly cleaned and allowed to dry before the test
- Sample size should be at least 1 5 liter (common mineral water bottle)

Analysis of water samples

Location	Particle Size Distribution, mg/l					Flow
	Total	Organic	> 400 µm	200-400 µm	0-200 µm	l/s
Inlet (M)[1]						
Outlet (M)						
Outlet (S)						
Inlet (M)						
Outlet (M)						
Outlet (S)						
Inlet (M)						
Outlet (M)						
Outlet (S)						
Inlet (M)						
Outlet (M)						
Outlet (S)						

1 M = media filter, S = screen filter

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LATERAL LINES AND EMITTERS, DATA SHEET 8

Farm _____ Date _____ Evaluators _____

Lateral ID	Lateral Pressure, kPa (psi)			Contaminants[1]	Emitters		
	Inlet	End	Δ = I - E		Number	Plugged	% Plugged

1 Qualitative measure of lateral hose contamination, rating of quantity of material caught in a ladies nylon stocking

0 = none 2 = medium 1 = slight 3 = major

Comments

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EMITTER DISCHARGES, DATA SHEET 9

Farm _____ Date _____ Evaluators _____

Location of emitters on lateral		Location of lateral on submain, Submain ID _____							
		Inlet Lateral ID ___		**1/3 Down** Lateral ID ___		**2/3 Down** Lateral ID ___		**End** Lateral ID ___	
		sec/100 ml	mlps	sec/100 ml	mlps	sec/100 ml	mlps	sec/100 ml	mlps
Inlet	A								
	B								
	Avg								
1/3 down	A								
	B								
	Avg								
2/3 down	A								
	B								
	Avg								
End	A								
	B								
	Avg								

IRRIGATION SCHEDULE, DATA SHEET 10

Submain ID	Date	Time Begin	Meter Start	Meter End	Time End	Delivery liters

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MICRO IRRIGATION SYSTEMS

DATA ANALYSES

[Supplemental]

1 INTRODUCTION

This module details the analyses procedures used for the data collected in the field Example data sets are used to shows the procedures Evaluation of the numerical results obtained is discussed in Module 3-4, Recommendations The trainee should note that not all of the data collected is used in these analyses procedures The unanalyzed data is used in making recommendations for improvement in the operation and maintenance of the irrigation system Given the accuracy of the data collection and irrigation processes, it is advisable to report results to the nearest 5%

2 ANALYSES

2 1 Filtration Unit(s)

2 1 1 Contaminant Removal Efficiency (E_R)

Testing sampling of inflow and outflow, for contaminant removal should be conducted for all filtration units individually E_R is a measure of the suspended solids removal ability of the filtration unit

$$E_R = \left(1 - \frac{S_{out}}{S_{in}}\right) \times 100$$

where E_R = the removal efficiency, %, S_{out} = the outlet concentration of suspended solids, mg/l, and S_{in} = the inlet concentration of suspended solids, mg/l Water samples should be collected and the suspended solids identified by the JVA Laboratory Table 1 presents the analysis of a set of water samples

Table 1 Concentration of suspended solids in water entering and exiting a water filtration unit

Particle size µm	Inlet concentration mg/l	Outlet concentration mg/l
0 - 200	60	20
200 - 400	30	5
> 400	10	2
Organic	5	1 5
Totals	105	28 5

$$E_R = \left(1 - \frac{28\ 5}{105}\right) \times 100 = 72\ 9\% \approx \mathbf{70\ \%}$$

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If particle size ranges are not desired the samples can be oven-dried at 105 °C and the solid matter weighed, all sizes are included in the total weights

2 1 2 Percentage Emitter Plugging (EP)

EP is an indirect measure for assessing the effectiveness of a micro irrigation filtration system

$$EP = \frac{E_p}{E_o} \times 100$$

Where E_o = the number of emitters in the sample and E_p = the number of plugged or closed emitters The maximum allowable plugging percentage is 20% for row crops if the emitter spacing is designed for 0 5 of the diameter of the wetted area

A sample lateral in a field has 125 emitters four of the emitters are completely plugged

$$EP = \frac{E_p}{E_o} \times 100 = \frac{4}{125} \times 100 = \mathbf{3\ \%}$$

2 2 Distribution System

The distribution system is comprised of the main line, submains or manifolds and emitters The evaluation of the tubing is limited to pressure readings, to evaluate pressure losses through the system, and leaks Identified leaks should be measured, to quantify water losses, and their impact on the system efficiency assessed

2 2 1 Statistical Uniformity (U_S)

U_S is an estimate of the uniformity of emitter discharge rates throughout an existing micro irrigation system

$$\bar{q} = \frac{1}{n}\sum_{i=1}^{n} q_i$$

$$S_q = \left\{ \frac{1}{n-1}\left[\sum_{i=1}^{n} q_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} q_i \right)^2 \right] \right\}^{1/2}$$

$$U_s = 100\left(1 - \frac{S_q}{\bar{q}}\right)$$

Where q_i = the emitter discharge rate, lph, n = the number of randomly selected emitters, i = a subscript identifying individual emitters, S_q = the standard deviation, and $\bar{q}$ = the mean emitter discharge, lph

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The 95% confidence limits for a specific statistical uniformity U_S, and a given random sample size, n, is selected from Table 2 In some cases interpolation of values in the table is required For example, given U_S = 90% as determined from a sample size of 36 observations would result in a confidence limit of ± 2 4% This indicates that for this example the true statistical uniformity is between 87 6% and 92 4%

Table 2 95% confidence limits, ±%

	Number of observations, n			
U_S	18	***36***	72	144
90	3 5	***2 4***	1 7	1 2
80	7 3	5 0	3 4	2 4
70	11 5	7 8	5 4	3 8
60	16 2	10 9	7 6	5 4

Example Time in seconds to fill a 100 ml container from individual emitters is given in column 2 of Table 3 for n = 18 samples

Step 1 Calculate the flow rates, q_i, (mlps) using the above data The calculation results are shown in column 3 of Table 3

$$q_1 = 100 \text{ ml per } 64 \text{ s} = 100/64 = 1\ 56 \text{ mlps, etc}$$

Table 3 Collected and calculated data for example

Sample	Time to fill 100 ml, s	Flow rate, mlps	Flow rate, squared
1	64	1 56	2 43
2	79	1 27	1 61
3	67	1 49	2 22
4	71	1 41	1 99
5	75	1 33	1 77
6	81	1 23	1 51
7	68	1 47	2 16
8	85	1 18*	1 39
9	75	1 33	1 77
10	69	1 45	2 10
11	85	1 18*	1 39
12	77	1 30	1 69
13	89	1 12*	1 25
14	68	1 47	2 16
15	81	1 23	1 51
16	90	1 11*	1 23
17	65	1 54	2 37
18	61	1 64	2 69
Totals		24 31	33 24

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Step 2 Calculate the mean and standard deviation for the measured flows

$$\bar{q} = \frac{24\ 31}{18} = 1\ 35 \text{ mlps}$$

$$S_q = \left\{\frac{1}{17}\left[33\ 24 - \frac{24\ 31^2}{18}\right]\right\}^{1/2} = 0\ 15 \text{ mlps}$$

Step 3 Calculate the statistical uniformity and determine the confidence limit from Table 2

$$U_s = 100\left(1 - \frac{0\ 15}{1\ 35}\right) = 88\ 9 \approx \mathbf{90\%}$$

From Table 2 with n = 18, for U_s = 90% the confidence limit = 3 5 and for U_s = 80% the confidence limit = 7 3 then

$$\frac{(7\ 3 - 3\ 5)_{\text{Confidence Limit Difference}}}{10_{\text{Range in } U_S \text{ Values}}} = 0\ 38_{\text{Unit Change}}$$

$$3\ 5_{\text{confidence at 90\%}} + \left\{(90 - 89)_{\text{difference in } U_S} \times 0\ 38_{\text{unit change}}\right\} = 3\ 88\%$$

the confidence limit is ± **4%** The true Statistical Uniformity for this example is between 85% and 95% (rounded to the nearest 5%)

2 2 2 Statistical Uniformity considering Emitter Plugging (U_{SP})

U_{SP} is an estimate of the uniformity of emitter discharge rates throughout an existing micro irrigation system when emitter plugging is considered

$$U_{SP} = 100\left\{1 - \left[\frac{1}{1-C}\left(\left(\frac{S_q}{\bar{q}}\right)^2 + 1\right) - 1\right]^{1/2}\right\}$$

Where C = the decimal proportion of emitters that are completely plugged

For the example used above, 3% of the emitters are completely plugged

$$U_{SP} = 100\left\{1 - \left[\frac{1}{1-0\ 03}\left(\left(\frac{0\ 16}{1\ 35}\right)^2 + 1\right) - 1\right]^{1/2}\right\} = 78\ 7 \approx \mathbf{80\%}$$

2 2 3 Emission Uniformity (EU)

EU is a measure of the uniformity of water delivery to all emitters in the system Again using the data from Table 3, the four low quarter flows are marked with asterisks

$$EU = \frac{\text{average LQ delivery of irrigation water}}{\text{average delivery of irrigation water}} \times 100$$

$$EU = \frac{1\ 15}{1\ 35} \times 100 = \mathbf{85\%}$$

2 3 Irrigation Management

2 3 1 Scheduling Ratio (SR)

SR is a measure of the adequacy of irrigation scheduling for trickle irrigated fields

$$SR = \frac{A \times EU \times H}{T_d \times (1 + LF)} \times 100$$

$$T_d = 0\ 1 \times ET_d \times (P_d)^{0.5}$$

Where A = system application rate, cm/hr, EU = emission uniformity based on the low quarter, expressed as a decimal, H = irrigation duration hrs, T_d = average daily transpiration rate during the peak-use month, cm/day, LF = leaching fraction, expressed as a decimal fraction, ET_d = conventionally estimated evapotranspiration rate during the peak-use month, cm/day, and P_d = percentage of the soil surface area shaded by crop canopy at midday (solar noon), %

The known data is Crop = tomatoes, A = 1 25 cm/hr, EU = 0 85, H = 1 hr, ET_d = 0 7 cm/day, P_d = 80%, and LF = 0 15

$$T_d = 0\ 1 \times ET_d \times (P_d)^{0.5} = 0\ 1 \times 0\ 7 \times (80)^{0.5} = 0\ 63 \text{ cm/day}$$

$$SR = \frac{A \times EU \times H}{T_d \times (1 + LF)} \times 100 = \frac{1\ 25 \times 0\ 85 \times 1\ 0}{0\ 63 \times (1 + 0\ 15)} \times 100 = 147\ \% \approx \mathbf{150\ \%}$$

2 3 2 Irrigation Efficiency (IE)

IE is the ratio of the quantity of water that is beneficially used to the quantity of irrigation water applied

$$IE = \frac{Q_b}{Q_i} \times 100 = \frac{T_d \times (1 + LF) + Other}{A \times H} \times 100$$

Where Q_b = the quantity of the delivered water beneficially used and Q_i = the quantity of water delivered to the field Beneficial use is for multiple purposes including crop water use, salt-leaching, and pesticide or fertilizer applications Use data from the above examples, assume no additional water is used for pesticide or fertilizer applications

$$IE = \frac{T_d \times (1 + LF) + Other}{A \times H} \times 100 = \frac{0\ 63 \times (1 + 0\ 15) + 0}{1\ 25 \times 1\ 0} \times 100 = 58\ \% \approx \mathbf{60\ \%}$$

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MICRO IRRIGATION SYSTEMS
RECOMMENDATIONS

[Supplemental]

1 INTRODUCTION

For an irrigation system evaluation to be of value to the farmer, the results must be presented in a form usable by the farmer This presentation should have two parts

- A description of the tests completed, including a copy of the data collected and an analysis of the data
- A list of recommendations that give the farmer a detailed description of what needs to be done to improve the efficiency of his infrastructure and operational practices

The following sections contain discussions of some of the most common defects in trickle irrigation systems, pumping plant evaluations and recommendations are covered in Module 3-5 The evaluator is expected to use his experience in drawing from this material to prepare recommendations for the farmer Not all situations are covered in this module and the user is expected to search other sources of information as the need arises

> ***The evaluator must exercise common sense in his evaluations and not trust only the numbers calculated Remember the walk-through and what you saw Keep in mind the capabilities of the farmer when you make recommendations, it is not useful to recommend actions he cannot carry out***

2 INTERPRETATION OF DATA ANALYSES

Analyses of the data collected in the field can give indications of the current performance of an irrigation system's operation and maintenance Analyses results can also be used to pinpoint weaknesses in system operation, maintenance, and design that can lead to improvements

2 1 Contaminant Removal Efficiency (E_R)

A properly operated filter system should remove close to 100% of the particulate material for which it is designed E_R values below 95% indicate serious problems with the filter system A large volume of water, and the contamination it carries, flows through the filters at each irrigation Flow passages in emitters are small and a few milligrams of particulate matter can clog several emitters Emitters clogged by mineral particulate material are difficult, if not impossible, to clean and return to service Keeping particulate material out of the system is the most effective and economical means for preventing clogging and extending the life of trickle laterals

2 2 Statistical Uniformity (U_S) and Emission Uniformity (EU)

The statistical uniformity and emission uniformity are used to characterize the design, operation, and maintenance of the physical system Table 1 gives the acceptability of system management, which is constrained by design and maintenance, based on the values obtained for EU and U_S

Table 1 Acceptability of the system as currently managed

	Uniformity	
Acceptability	Emission EU, %	Statistical U_S, %
Excellent	100 - 94	100 - 95
Good	87 - 81	90 - 85
Fair	75 - 68	80 - 75
Poor	62 - 56	70 - 65
Unacceptable	< 50	< 60

100% U_s or EU means the entire field receives an equal depth of water Less than 100% implies that some areas of a field receive more water than others This may result in over irrigation in one part of the field and under irrigation in another part

The EU should be greater that 80% before fertigation is practiced The uniformity of fertilizer application is approximately equal to the uniformity of the water application At low EU values, fertilizer is applied unevenly and large quantities are lost to deep percolation

Poor emission uniformity, poor in-field water distribution, Figure 1, results in some plants receiving too much water and other receiving not enough water The variation can result in significant yield differences

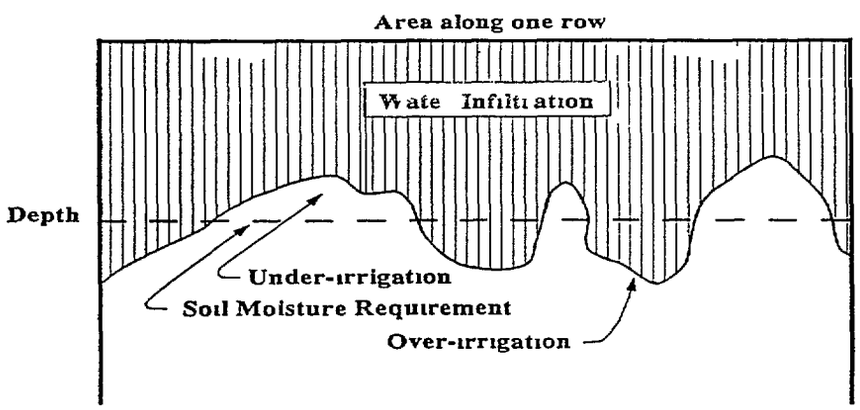

Figure 1 Low emission uniformity, poor in-field water distribution

High emission uniformity and good in-field water distribution, Figure 2, results in all plants receiving about the same quantity of water However, if the

irrigation application time is too long, irrigation efficiency will be low and water wastage can be high

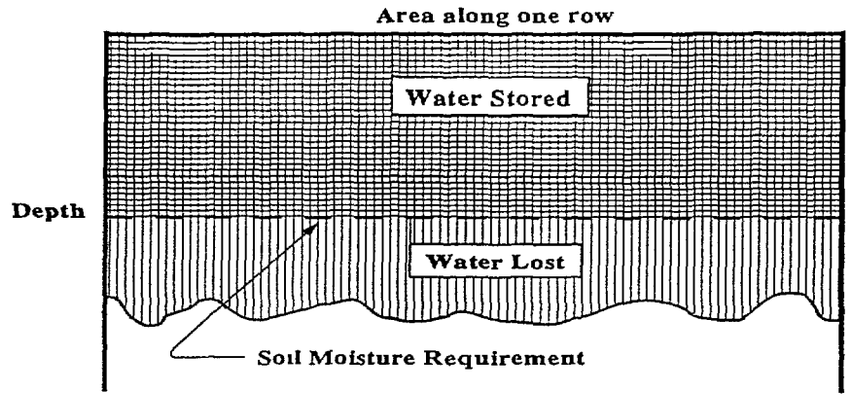

Figure 2 High emission uniformity, good in-field water distribution, but irrigation time too long, low irrigation efficiency and water wastage

High emission uniformity and the proper irrigation application time results in good in-field water distribution and high irrigation efficiency, Figure 3

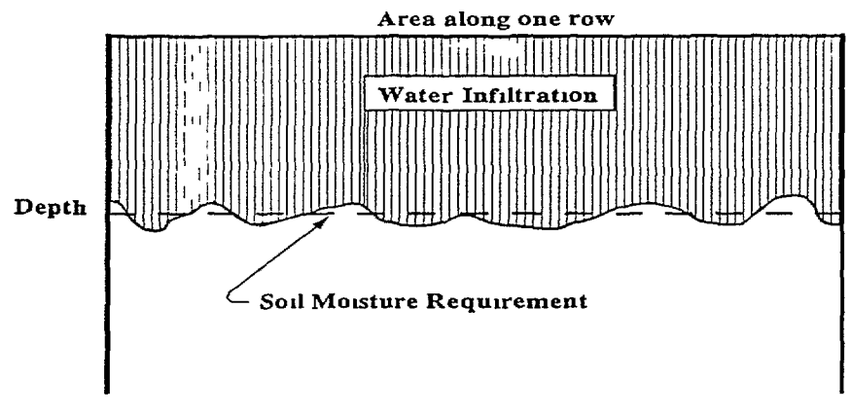

Figure 3 High emission uniformity, good in-field water distribution, and proper irrigation time, high irrigation efficiency

2 3 Percentage Emitter Plugging (EP) and Statistical Uniformity considering Emitter Plugging (U_{SP})

Even a small percentage of emitter clogging can drastically effect the uniformity of water application Figure 4 can be used to estimate the effects of clogging on uniformity, U_{SP} With U_S = 90% and 5% plugging the true uniformity, U_{SP}, is about 75%, to low a value to recommend fertigation

The impact of emitter clogging on fertilizer distribution and fertilizer loss to deep percolation, because of uneven water distribution, is an often unappreciated problem

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2 4 Scheduling Ratio (SR)

High values of SR, more than 100%, indicate that water in excess of that required is being applied SR values greater than 120% indicate that irrigation water application quantities should be re-evaluated The excess water leaches fertilizers and is lost to deep percolation

SR values of 90% to 110% are acceptable, values of 80% to 90% indicate that some under irrigation is occurring but not enough to seriously damage yields, SR values below 80% are cause for concern and should be addressed

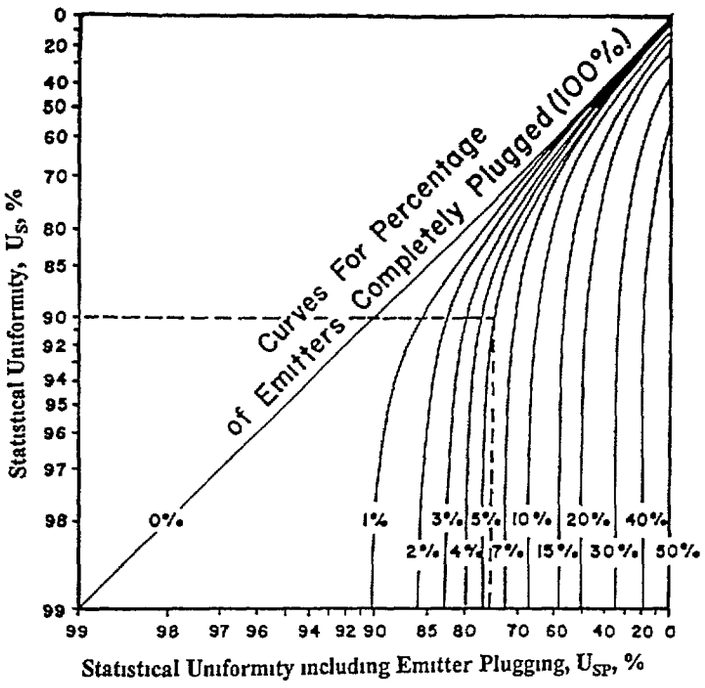

Figure 4 Relation between the degree of emitter plugging and statistical uniformity

2 5 Irrigation Efficiency (IE)

Irrigation efficiency cannot exceed 100% IE values of 100% can mean that system management is very good or, more likely, that under-irrigation is occurring IE values less than 80% indicate that water significantly in excess of that required is being applied and irrigation water application quantities should be re-evaluated

3 CAUSES AND SOLUTIONS FOR NON-UNIFORMITY AND LOW EFFICIENCY

Trickle systems should be designed and operated to prevent any surface runoff If the application rates exceed the soil intake rate, nonuniformities and water wastage can result If the time allowed for irrigation is based on the delivery flow rate and not the soil intake rate, plants may be under watered at each irrigation application

Periodic maintenance and flushing of the system is recommended to assure continual satisfactory operation of the trickle system The flushing interval is dependent upon

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the quality of water delivered to the system tubing A system with a properly designed and operated filtration unit, both media and screen filters, will require less frequent flushing than a system without filtration or with improperly designed and operated filtration units

Emitter Irregularities

Variation in emitter discharges due to manufacturing differences, inconsistencies in emitter orifice and passage sizes, can significantly decrease the uniformity of the system Poorly performing emitters should be replaced with others that operate correctly

Uniformity is also significantly decreased when only 1% to 5% of the emitters are completely clogged, even with 2 to 8 emitters per plant Plugging of emitters can be caused by physical, chemical, or biological contaminants The causes for plugging are site specific and detailed studies of the water quality should precede the design Periodic testing of emitter variability is necessary to identify clogging and changes that may occur in individual emitters over time Where plugging cannot be eliminated, increasing the number of emitters per plant will reduce the impact of plugging on uniformity

Filtration systems should be flushed on a regular basis to prevent orifice clogging and an excessive pressure loss through the filters The use of the irrigation system to apply fertilizers and other chemicals should be considered in designing the filtration system for preventing emitter clogging Chemicals can precipitate even after filtration if proper precautions are not implemented Adequate filtration is a must for trickle irrigation installations

- The most common insert or on-line emitter uniformity problem is the mixing of
  - **Emitter output rates** — a replacement emitter is of different flow rate than the original
  - **Emitter brands** — the replacement emitter is of different manufacture or type than the original The replacement will have a different flow rate than the original
- **Incorrect emitter placement** — emitters are not placed in accordance with the soil properties and plant rooting pattern Emitters must be installed at intervals that correspond with the plant spacing to provide equal volumes of water for each plant
- **Incorrect emitter selected** — the wrong type or flow capacity emitter is used for the irrigated crop An example would be the use of inline emitters (GR type), which are designed for vegetables, for an orchard crop Much of the soil between the widely spaced plants, soil which should be unirrigated, is wetted by the unnecessary emitters

System Pressure

The discharge of water through any emitter is a function of the orifice size and operating pressure Therefore, any pressure variation in the system can cause variations in discharge unless corrected or compensated with pressure regulators or the use of pressure compensating emitters The operation of a system with the incorrect average pressure can bias the application either higher or lower than the desired depth by larger or smaller pressures, respectively

An incorrect average pressure may result from

- Clogging of the filtration system
- Problems with the pumping plant, refer to module 3 5 for a description of these problems
- Valves partially closed which should be fully open valves fully open that should be partially closed, or partial blockage of part of the delivery pipe line

System pressure variations can be of three types

- Along individual laterals
- From lateral to lateral within a block (a single manifold)
- From block to block

In some cases all three types of variation may exist simultaneously Variations in emitter input pressures are reflected in emitter output depending upon emitter design Design or construction errors which can contribute to undesirable trickle irrigation pressure variations include

- **No pressure regulation at all** — The system pressure is totally at the mercy of the friction loss characteristics of each individual irrigation block Friction losses vary with elevation, pipe size, and proximity to the water source This deficiency may cause nonuniformity in water deliveries between blocks
- **One pressure regulator at the water source, but no block pressure regulators** — Lack of pressure regulators in each irrigation block may cause irregular flows and pressures The delivery to laterals in each block may vary, which increases the nonuniformity of irrigation water deliveries
- **Improperly set pressure regulators** — Install a pressure gauge near each pressure regulator in order to properly set/regulate the system and block regulators
- **Improperly sized main lines, submains, or laterals** — The various friction losses associated with elevation differences, system pipeline length, diameter, fittings, and on-line-emitter barbs should be calculated and corrected for proper system operation
- **System expansion friction losses** — Caused by the addition of new system components (laterals, valves, filters, emitters, etc) without regard to the initial design The result of a system expansion may be low pressure and low flows to

parts of the delivery network Reevaluate the capacities of the pumping plant, mains and submains and make corrections where necessary

- **Inadequate source pressure for the block area irrigated** — The irrigation system is designed to irrigate blocks that are too large for the pump size selected Where the system is using JVA supplied pressure an additional problem may be fluctuation in the pressure supplied
- **Leaks or breaks in the fittings, lines, or emitters** — Each on-line emitter penetrating a lateral line is a breach of the system-atmosphere barrier and a pressure release point The designer distributes these pressure release points uniformly to release equal amounts of water to each plant Any break or leak in the system is a pressure release point affecting the performance of emitters in close proximity If the break is large enough or if the incidence of leakage is numerous more emitters are affected and each emitter experiences some reduction in flow rate All leaks and breaks should be promptly repaired
- **Improper system operation** — Varying the number of laterals or blocks operated simultaneously can cause incorrect pressures in the system This problem may be partially corrected by the proper placement and use of pressure regulators The best irrigation uniformity is obtained when the system is operated as designed

Flow Meter

A deficiency on most farm irrigation systems in Jordan is the absence of a flow meter A flow meter is a cost effective tool for the farmer because it can assist him in maximizing the benefit he receives for each cubic meter of water purchased Without a flow meter it is difficult for the farmer to monitor how effectively he is irrigating

> ***An irrigator can't meet plant water needs efficiently if the system application rate is unknown***

The actual flow rate through a newly calibrated propeller flow meter, Figure 5, operating within its normal flow range is 96% to 103% of the reading indicated by the meter Pressure loss as water flows through a properly sized meter is 14 kPa or less A four inch propeller flow meter has an operating range of 3 lps to 38 lps

Meter installation criteria

Figure 6 illustrates an optimum flow meter installation Propeller meters are the most common meter used for agriculture because they are accurate and relatively inexpensive

- For optimum life and best accuracy, there must be a swirl-free, uniform-flow-velocity profile in the pipe immediately upstream of the meter
- Meters are intended for use in the horizontal position of the meter with respect to the inlet and outlet flanges
- Piping should be arranged to ensure the meter remains full of water at all times

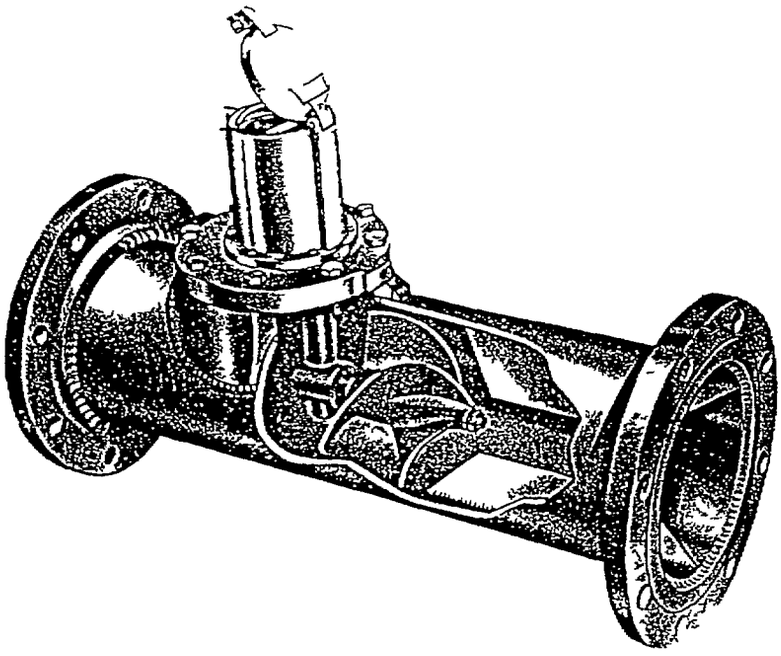

Figure 5 A typical propeller flow meter

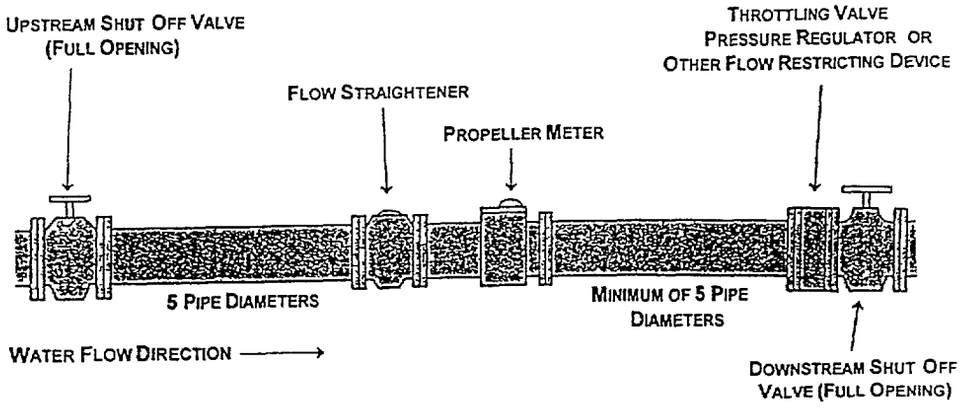

Figure 6 Optimum propeller meter installation

- Elbows, tees, and crosses should be no closer than 10 pipe diameters of straight pipe of the same nominal diameter on the meter upstream and five diameters downstream
- When pipe reducers are needed, only gradual or tapered concentric reducers should be used
- Pipe flange gaskets must be centered and not protruding into the main flow stream
- Install check valves, back flow prevention devices, throttling valves, and pressure-regulating devices a minimum of five pipe diameters downstream of the meter

- Use full-opening ball or gate valves for the meter set's isolation valves They must be installed a minimum of five pipe diameters upstream and downstream of the meter
- If a flow straightener is needed, nonuniform flow is present in the pipe immediately upstream of the meter, it should be installed immediately upstream of the meter
- If a flow straightener is not used, the run of straight of pipe immediately upstream of the meter should be a minimum of 10 pipe diameters

Use of Flow Meter in Problem Identification

A flow meter coupled with a pressure gauge at the pump can help zeroing in on the source of irrigation problems One of the easiest ways to monitor the irrigation system is to periodically note the irrigation flow rate The meter should be read at least two or three times a week Unplanned variations are an indication of developing problems

- Gradual slight decline in flow rate are often indicative of emitter clogging problems If the decline occurs during an irrigation, this may indicate that air is collecting at high points in the system and slowly blocking the passage of water
- A steady decline in pressure and/or flow rate over time may reflect pump wear
- A slight increase in flow rate may be the result of leakage
- A sudden increase of flow rate may be the result of a pipeline break
- A wide variation in indicator readings signals turbulence in the pipeline Turbulence at the meter may indicate that placement of the meter is incorrect, see Figure 6 for correct installation, or that air is entrained in the water
- If the rate indicator shows erratic, violent behavior, air or gas may be present in the water This may also indicate that the water level in the pool has fallen to the level where the pump suction intake periodically draws in air

A method of estimating emitter output is to measure the amount of water applied with a system flow meter over a period of time and divide by the number of emitters being supplied water This will give a good indication of the average amount of water flowing out of each emitter per unit time

Example A block of trees in an orchard has 56 trees served by two micro-sprayers per tree An irrigation lasted 2 hours and 6,720 liters of water was delivered Find the average sprayer flow rate

$$Q_{avg} = \frac{6{,}720 \text{ liter}}{56 \text{ trees} \times 2 \text{ sprays / tree} \times 2 \text{ hour}} = 30 \text{ liter / hour / spray} = 0\ 5 \text{ lpm / spray}$$

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PARTIAL EVALUATION OF MICRO-SPRAY IRRIGATION SYSTEM

CASE STUDY I

1 INTRODUCTION

A partial evaluation was made for a citrus orchard that uses two laterals per row of trees There are seven trees per lateral with one micro-spray emitter per tree per lateral line (two sprays per tree) The irrigation target is to apply 60 liters per tree per sprayer over a two hour period, 120 liters total for each tree Field evaluation data were collected for one row of trees near the head of the manifold

2 DATA COLLECTION

Initial

- All pressure compensating emitters were removed from the laterals and the holes plugged
- Each lateral was flushed until most sediment was removed As very large media is used in the filter tank and the irrigation water was not clear
- Pressure was measured at the lateral head (manifold off take) and end
- Flow from each micro-sprayer was collected for 20 seconds and measured in a 500 ml graduated cylinder

After Adjusting Micro-Spray Flows

- Each micro-sprayer was adjusted to a flow rate of about 250 ml per 30 seconds [1]
- Pressure was measured at the lateral head (manifold off take) and end
- Flow from each micro-sprayer was collected for 20 seconds and measured in a 500 ml graduated cylinder

The laterals are 35 meters long and sloping 0 00006 m/m Table 1 lists the data collected

3 DATA ANALYSES

Emission uniformity (EU) was calculated for initial and adjusted conditions Emission uniformity is defined as

$$EU = \frac{q_n}{q_a} \times 100$$

where q_n = the average flow from the lowest one-quarter of the micro-sprayers and q_a = the average flow from all the micro-sprayers There was wide variation in the initial EU values, 54% and 68% After adjustment the EU values were closer, 83% and 88%, and more in line with the potential EU offered by micro sprayer irrigation

[1] As each sprayer is adjusted the pressure and flow changes at every other sprayer on the line This is an iterative procedure that requires several passes down the lateral line to balance out the flows In the interest of time, only three adjustments were made per row

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Combining the flows from the two laterals shows an initial uniformity of 72%, Table 2 and Figure 3 This is a marginally acceptable uniformity The target irrigation water application volume was 840 liters for seven trees over two hours In the initial condition, the water delivery was 1,528 2 liters for the seven trees, 182% of the target volume This illustrates that an acceptable uniformity does not necessarily mean the system is operating at its highest potential Under the initial operating conditions there would be significant quantities of irrigation water lost to deep percolation

After adjustment, the EU increased to 90% and the irrigation application is 109% of the target These values are good and indicate that there is little wastage of irrigation water

Table 1 Field evaluation data collected for one row of trees

Lateral 1			Lateral 2		
Pressure	**Initial** (psi)	**Adjusted** (psi)	Pressure	**Initial** (psi)	**Adjusted** (psi)
Head	4 5	9 0	Head	5 5	9 0
End	2 0	8 2	End	2 0	7 9
Sprayer[2]	(ml/20 sec)	(ml/20 sec)	Sprayer	(ml/20 sec)	(ml/20 sec)
1	570	260	1	250	160
2	560	210	2	260	170
3	400	180	3	485	190
4	450	160	4	400	150
5	175	175	5	210	185
6	245	175	6	420	185
7	315	150	7	345	190
EU	**54%**	**83%**	**EU**	**68%**	**88%**

Table 2 Irrigation period delivery target equals 120 liters per tree per two hours

Lateral 1 + Lateral 2			Lateral 1 + Lateral 2		
	Initial			**Adjusted**	
Tree	(ml/20 sec)	(liters/2 hr)	Tree	(ml/20 sec)	(liters/2 hr)
1	820	295 2	1	420	151 2
2	820	295 2	2	380	136 8
3	885	318 6	3	370	133 2
4	850	306 0	4	310	111 6
5	385	138 6	5	360	129 6
6	665	239 4	6	360	129 6
7	660	237 6	7	340	122 4
Total		1,528 2	Total		914 4
EU		**72%**	**EU**		**90%**

[2] Sprayers are numbered starting from the inlet to the lateral (manifold end)

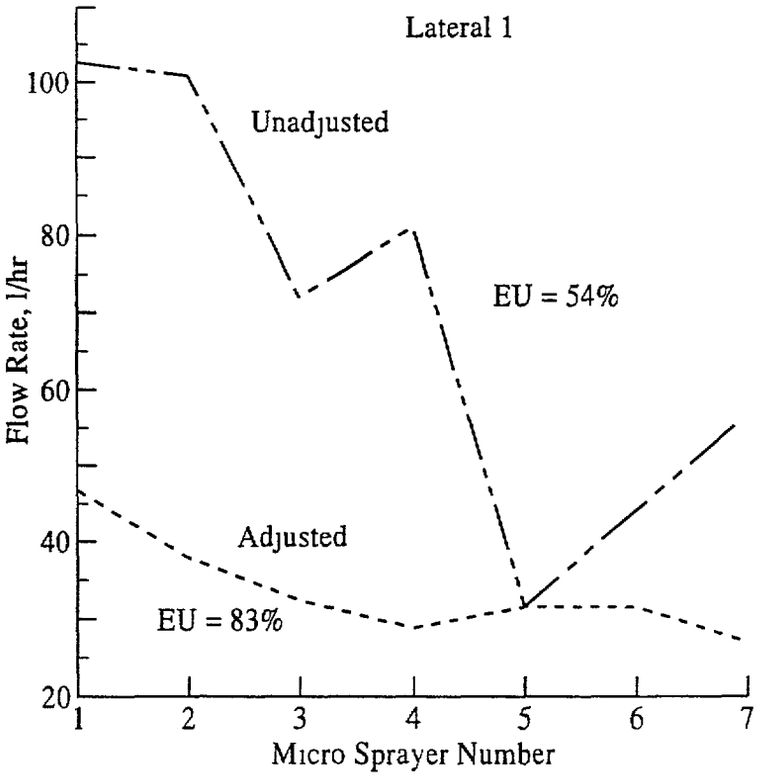

Figure 1 Uniformity for lateral 1, seven micro spray emitters

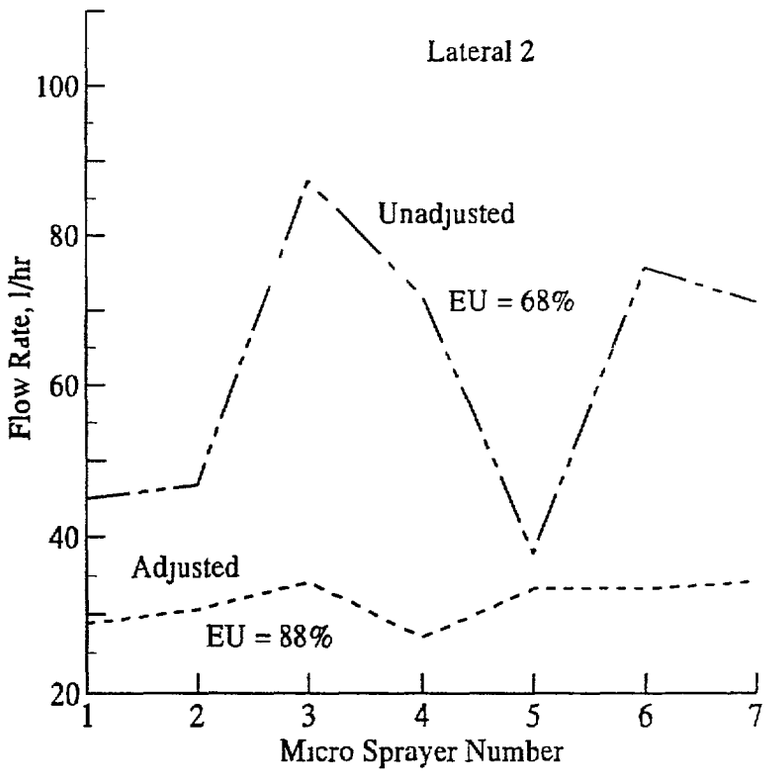

Figure 2 Uniformity for lateral 2, seven micro spray emitters

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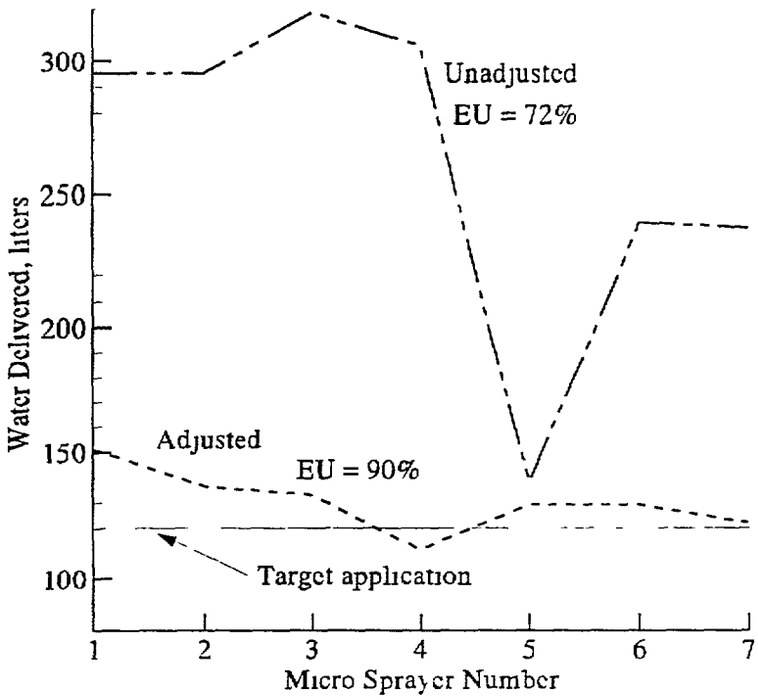

Figure 3 Results from combining flows from the two laterals serving one row of citrus trees

4 Observations and Recommendations

4 1 Observations

- The ends of several laterals were opened and allowed to drain Many had a large discharge of sediment indicating that a regular flushing program is not followed Those that were plugged had flow to the lower end after flushing Given the poor quality of irrigation water introduced into the lateral lines, each lateral should be flushed at the end of each irrigation period
- Lateral lines taking off in the second half of the manifold suffer from plugging and weak pressure in the ends As the above test shows adjustment of flows along the lateral can increase pressures at both ends of the lateral Increasing pressures at the inlets to the laterals will in turn increase the pressure in the manifold
- It was observed that when the micro sprayers were adjusted to decrease irrigation water applications and increase the uniformity of discharge down the line, they no longer sprayed but had a streamer discharge This indicates that pressure in the lateral line is excessive There are two ways to correct this problem, both will give the same flow rates for each sprayer (1) The pressure in the manifold can be decreased by partially closing the main valve to the manifold (2) The irrigation time can be decreased to one hour (or less), which would double the application rate, allowing the sprayers to function as designed The second approach would be preferred because of the difficulty in adjusting the manifold valve to set a given

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pressure For the farm evaluated basins are constructed around each tree and the infiltration rate appears to be sufficient to handle the higher application rate

- The slope of the manifold is 0 041 m/m This slope is steep enough to offer some pressure increase to compensate for friction losses

4 2 Recommendations Adjusting Micro Sprayers

Adjusting the micro sprayers on the laterals can reduce the pressure differential in the manifold Adjustment of lateral line flows need not be a time consuming operation By measuring a few sprayer discharges[3] the person doing the adjustment can develop an "eye" for the approximate flow rate that is desired The procedure is

- Flush each lateral line on the manifold, make sure all are free flowing out the open end (replace lateral lines if required)
- Remove and plug the holes for all non-operating or no longer used micro sprayers, bubblers, or other inserted emitters replace those desired but plugged (have all sprayers on a line in working order),
- Starting at the first lateral (closest to the head of the manifold) go down each lateral from the head (manifold end) to the end adjusting micro sprayer flow rates,
- After completing the adjustment of all the micro sprayers on each of the lateral lines the first time, repeat once more Two passes down each lateral line will significantly increase the emission uniformity

The following discussion assumes that the proper size of lateral lines are being used for the flow rate desired and the lines are not plugged (free flowing when the end is opened)

There is a reason for adjusting micro sprayer flows by starting from the lateral head and working to the tail As each sprayer is adjusted it changes the pressure and consequently the flow rate, in the line downstream It also causes the same changes upstream but to a lesser extent When the end pressure is significantly lower than the head pressure, which implies high flows if the lateral lines are of the proper size, on the first pass down the lateral each sprayer should be adjusted to slightly less than the desired flow rate As the flow rates per sprayer on down the line are decreased and the two end pressures are equalized the flow rates per sprayer up the line will increase

When micro sprayer flow rates are low and need to be increased, the pressure in the lateral line will drop with adjustment In this case, as one moves down the lateral adjust the flow rates to slightly higher than desired

[3] Needed would be an empty oil can with the top removed, to catch the sprayer discharge, a graduated cylinder to measure the water caught, and a stop watch or watch with a second hand to time the discharge capture

The same principle applies to the laterals on the submain Adjusting each micro sprayer on a lateral will cause the pressures at the head of the lateral, manifold end, to change All micro sprayers on all laterals on the manifold should be adjusted once before any second adjustment is made This will ensure that pressure changes in the manifold are influencing all laterals

PUMPING PLANT EFFICIENCY
DATA COLLECTION & ANALYSIS

[Supplemental]

1 INTRODUCTION

The aim of a pumping plant efficiency test is to compare the actual prevailing performance conditions of the pumping plant against standards Pumping plant efficiency is a product of the efficiencies of the power unit, pump, and if used, a transmission and gearhead The efficiency of the pumping plant affects the amount of energy consumed Inefficient systems can increase energy consumption and irrigation costs considerably To measure the efficiency of pumping plants an energy standard is used The standards for pumping plants are given in Table 1

Table 1 Pumping plant performance standards

		Direct Drive	Gearhead or V-Belt Drive
Energy Source	Fuel Unit	wkWh*/fuel unit	
Diesel	liter	2 38	2 27
Electric	kWh	0 66	0 627

* water kilowatt-hour per fuel unit

The procedure for running an irrigation pumping plant efficiency test is based on measuring the energy into the system and the energy that leaves The energy into a system is the fuel used per hour and the energy leaving the system is the water power To determine water power, the following formula is used

$$P = \frac{Q \times TDH}{K}$$

where P = water power in kWh or water horsepower, Q = flow rate in m^3 s, TDH = total dynamic head in meters, and K = 0 102

Once the water power is determined and the fuel use per hour is measured then the actual pump performance can be determined with the formula

$$\text{Actual Pump Performance} = \frac{P}{\text{Fuel Use per Hour}}$$

and the results from this equation can be substituted into the following formula to determine the comparative pumping plant efficiency, not the true pumping plant efficiency

$$\text{Comparative Efficiency} = \frac{\text{Actual Pump Performance}}{\text{Pump Performance Standard}}$$

The important values that must be measured accurately are the flow rate, total dynamic head, and the fuel use per hour

2 DATA COLLECTION

Overall accuracy of the tests can be enhanced if certain measurements are taken during a specific time interval For example water output and energy use measurements should be taken at the same time interval when using a propeller water meter A small change in water output during the test would reflect a corresponding change in energy consumption If the measurements are taken during the same time interval the *average flow rate* and the *average energy consumption* during the test time interval would correspond This same idea applies to the discharge pressure and lift head measurements They should be taken at the same time as indicated previously

2 1 Flow rate

Flow rate can be measured with a calibrated propeller type flow meter The meter must be installed in the pump discharge pipe before any branches this may require cutting the discharge pipe and repairing it when the test is finished

2 1 1 Location and installation of the meter

1 The meter should be placed a minimum of one meter downstream of any obstruction, such as an elbow tee or valve The meter must be placed ahead of any points where water is lost from the pipe line

2 The meter must be installed with the flow passing through the meter in the direction of the arrow cast into the meter housing

2 1 2 Finding the flow rate

1 The pump should be running long enough for the irrigation system to stabilize before taking any readings The flow rate should equal that normally used during irrigation

2 The meter must have full water flow through it If not flowing full, you must elevate a pipe section downstream from the meter to cause it to flow full

3 Watch the small dial on the meter You will notice that when it is at the "0" position, all the numbers in the totalizer are centered

4 Start the stopwatch when this hand reaches the "0" position and immediately record the number from the totalizer on the data worksheet, see Fig 1

5 Wait at least 5 minutes, it is best to use the same time period as that used for the energy use determination

6 Stop the stopwatch when the hand reaches the "0" position and immediately record the numbers from the totalizer on the data worksheet, see Fig 1

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7 Record the time on the data worksheet

8 Calculate the flow rate in m^3/sec using the worksheet

A more accurate instrument would be an ultrasonic flow meter This meter does not require shutting off the pump or irrigation system No disturbance is made to the piping system consequently the tests can be made quicker

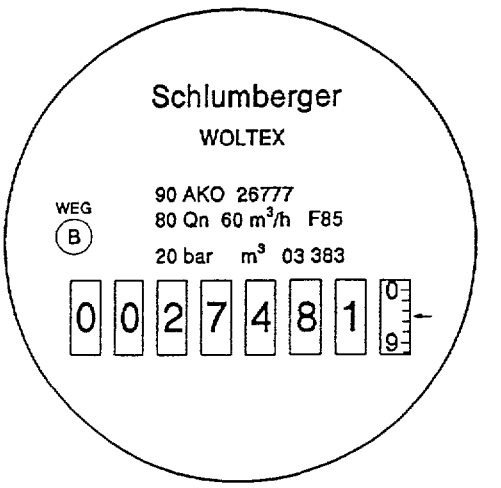

Figure 1 Face of a typical propeller flow meter

2 2 Total Dynamic Head

The total dynamic head is the sum of the lift from the water surface to the point where the discharge pressure is measured and the discharge pressure converted into head

2 2 1 Suction Head

A vacuum gauge can be used to determine the suction head The vacuum gauge reading will account for the elevation of the pump from the water surface (lift) and also the friction, suction, and velocity losses due to the suction pipe The resulting suction head can indicate whether the suction conditions are exceeding the required NPSH of the pump

2 2 1 1 Procedure

1 Install a vacuum gauge (see gauge installation below) as near as possible to the suction entrance of the pump

Note There is no correction for elevation of the gauge above or below the suction entrance The true reading is at the point of attachment to the pipe

2 When the system is operating and stabilized, take the reading

3 Convert the vacuum reading to meters of water and record on the worksheet as *Suction Lift* *Suction Pipe Loss* would be 0 if

the gauge is near the pump suction entrance, otherwise measure the length of pipe between the gauge and pump and enter it as *Suction Pipe Length*

inches of Hg × 0 3453 = meters of water

cm of Hg × 0 1359 = meters of water

When a vacuum gauge is not available, the suction head can be estimated as follows

1 Measure the distance from the water surface to the center of the pump intake

2 Identify all sources of friction loss in the suction line and calculate a head loss through each fitting, see Fig 2

Estimate headloss through each fitting by applying the appropriate resistance coefficients For all fittings other than the abrupt and concentric contractions, the headloss is computed as

$$h_f = \frac{KV^2}{2g}$$

where h_f = friction headloss, m, K = resistance coefficient (Table 2), V = flow velocity, m/s, and g = acceleration of gravity = 9 81 m/s^2

For the abrupt contraction, K is calculated from

$$K = 0\ 7\ [1 - (D_r)^2]$$

where D_r = ratio of small to large inside diameter

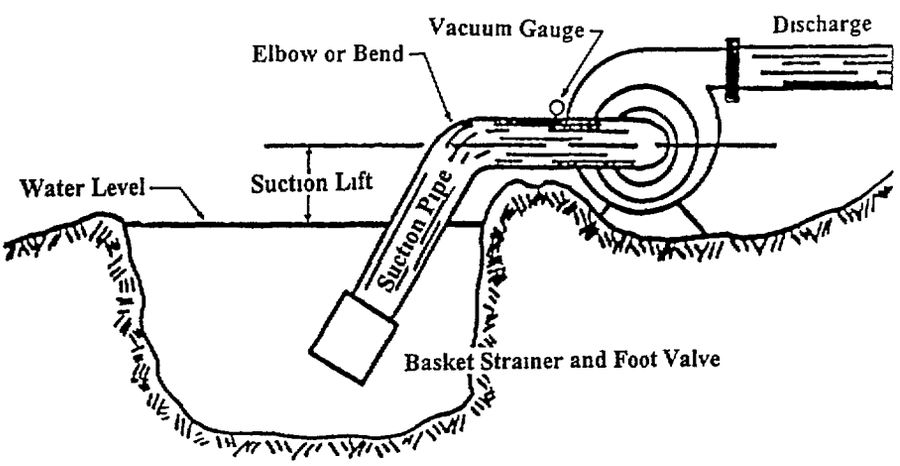

Figure 2 Sources of friction loss in the suction line

3 The total estimated suction head is the sum of all friction head losses and the distance measured in step 1

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Table 2 Values of resistance coefficient K, for standard pipe fittings and valves

Standard fitting or valve	Nominal diameter — mm (in)								
	75 (3)	100 (4)	125 (5)	150 (6)	175 (7)	200 (8)	250 (10)	300 (12)	350 (14)
Elbows Flanged									
Regular 90^0	0 34	0 31	0 30	0 28	0 27	0 26	0 25	0 24	0 23
Long radius 90^0	0 25	0 22	0 20	0 18	0 17	0 15	0 14	0 13	0 12
Long radius 45^0	0 19	0 18	0 18	0 17	0 17	0 17	0 16	0 15	0 15
Elbows Screwed									
Regular 90^0	0 80	0 70							
Long radius 90^0	0 30	0 23							
Regular 45^0	0 30	0 28							
Bends									
Return flanged	0 33	0 30	0 29	0 28	0 27	0 25	0 24	0 23	0 23
Return screwed	0 80	0 70							
Tees Flanged									
Line flow	0 16	0 14	0 13	0 12	0 11	0 10	0 09	0 08	0 08
Branch flow	0 73	0 68	0 65	0 60	0 58	0 56	0 52	0 49	0 47
Tees Screwed									
Line flow	0 90	0 90							
Branch flow	1 20	1 10							
Valves Flanged									
Globe	7 0	6 3	6 0	5 8	5 7	5 6	5 5	5 4	5 4
Gate	0 21	0 16	0 13	0 11	0 09	0 075	0 06	0 05	0 04
Check	2 0	2 0	2 0	2 0	2 0	2 0	2 0	2 0	2 0
Angle	2 2	2 1	2 0	2 0	2 0	2 0	2 0	2 0	2 0
Valves Screwed									
Globe	6 0	5 7							
Gate	0 14	0 12							
Check	2 1	2 0							
Angle	1 3	1 0							
Foot Valve	0 80	0 80	0 80	0 80	0 80	0 80	0 80	0 80	0 80
Basket Strainer	1 25	1 05	0 95	0 85	0 80	0 75	0 67	0 60	0 53
Inlets or Entrances									
Inward	0 78								
Projecting									
Sharp cornered	0 50	All diameters							
Slightly rounded	0 23	All diameters							
Bell-mouthed	0 04	All diameters							

Sudden enlargement $K = [1-(D_r)^2]^2$ where D_r = ratio of small to large inside diameter

Concentric expansion $K = 2\,6\sin(\theta/2)\left[1-(D_r)^2\right]^2$

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2 2 2 Discharge Pressure

The pump not only expends energy to lift water but also to put the water under pressure To measure the discharge pressure calibrated pressure gauges are used

2 2 2 1 Procedure

1 Install the pressure gauge as close to the pump discharge as possible, before any branches in the pipe system The pressure gauge must be placed (upstream) before any valve in the pipe line

2 When the system is operating and stabilized, take the reading The discharge pressure should equal that normally used for irrigation

3 Convert the pressure reading to meters of water and record on the worksheet

The total dynamic head is the difference between the gauge readings Given that the suction side reading is a vacuum i e , a negative pressure the TDH is the sum of the two *absolute* values

2 2 3 Gauge Installation

Most pressure and vacuum gauges will have a 1/4" tapered pipe thread If an existing hole in the pipe is larger use a reducing bushing to install the gauge

If no tapped hole is available for use, a 7/16" hole can be drilled at the proper location and tapped for 1/4" pipe threads Do not drill into thin steel or aluminum pipe, the pipe wall thickness must be at least 1/16" in order to tap the holes

2 2 3 1 Procedure

1 Use a center punch to mark the pipe at the proper location for the pressure gauge

2 Use a 1/4" drill bit to drill through the pipe at the center punch mark

3 Use a 7/16" drill bit to enlarge the 1/4" hole to the proper size for the tap Be sure to drill squarely into the pipe

4 Tap the hole using a 1/4"-18 National pipe thread size tap Use a lubricant on the tap A 7/16" 8-point socket can be used with a 3/8" drive ratchet to drive the tap if a tap drive handle is not available If the tap begins to turn hard, reverse the direction 1 turn, and then continue Be sure to tap squarely

Important Only tap into the pipe about halfway on the tap Tapping too deeply may make the threads too large to use a pipe plug to seal the hole after the test.

Be careful not to over tighten the gauge as damage may result to the threads Use a wrench to tighten the gauge, it need only be snug A pipe sealing compound or teflon tape is recommended to eliminate leakage and provide lubrication for the gauge threads

2 3 Energy Use

2 3 1 Electric Motors

The energy use rate in kilowatts (kW) can be determined by using the existing watt-hour meter (electric meter) at the pump site The kW usage is found by counting the disc revolutions over a period of time and doing a simple calculation

Important Often there are additional loads on the electric meter other than the pump motor If possible, these other loads must be turned off during the test

2 3 1 1 Procedure

1 The motor and pump should be allowed to operate a few minutes before taking the reading

2 Locate the revolving disc in the Existing watt-hour meter for the pump and the black mark on this disc, see Fig 3

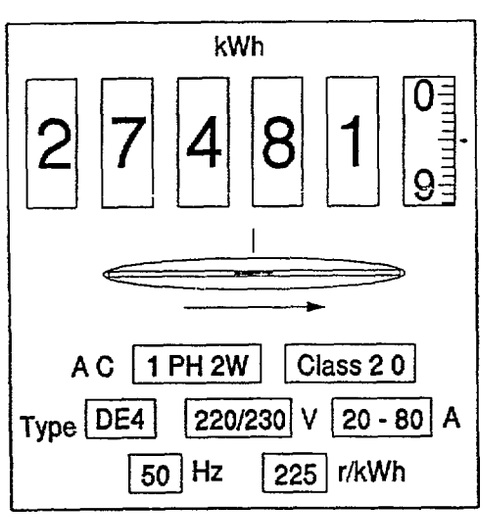

Figure 3 Face of a typical electric kWh meter

3 Start the stopwatch when this black mark is in view and begin counting the revolutions

4 Continue counting until at least 10 revolutions have occurred Seldom is 20 or more revolutions necessary

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5 Stop the stopwatch when the black mark on the watt-hour meter disc passes the same point where you started

6 Record the revolutions and time on the data worksheet

7 On the meter dial face you will need to find the "r/kWh" factor see Fig 3 Record this number on the worksheet (Typical r/kWh numbers are 200 for 20 - 80 A meters, or 450 for 10 - 40 A meters)

8 Calculate the energy use rate in kW using the worksheet

2 3 2 Diesel Engines

To determine the energy use rate in liters/hour, the amount of diesel fuel used is measured over a period of time The fuel can has a sight gauge that is marked in liters and has 1/4 liter divisions between the liter marks The sight gauge is used to determine the number of liters used and the time interval to use that fuel From this data the liters of fuel used per hour can be determined

2 3 2 1 Equipment Setup

1 Fill a calibrated 20 liter fuel can with sight gauge, see Fig 4 with diesel fuel

2 Most diesel engines will have a fuel supply line to the engine and a return fuel line to the tank Both need to be used with the fuel can

3 Hook up the supply line from the bottom of the fuel can to the engine, or use the existing supply line and connect it to the fuel can

Important When switching from the diesel supply tank to the fuel can all air must be removed from the hoses and fittings Bleed air from these lines by allowing diesel fuel to run free through the line before making the connection

Air in the fuel system can cause the engine to stall and may require repriming of the fuel system

4 If the engine has a return line, connect it to the top fitting on the can, or use the top hose on the fuel can and connect it to the return line fitting on the engine Loosen the fill cap on the can to allow air to enter

Note The return line may be placed into the fill spout on the fuel can if you wish

2 3 2 2 Procedure

1 The engine and pump should be allowed to warm up and stabilize before beginning the test

2 Start the stopwatch when the diesel level in the can crosses a division line on the sight gauge, see Fig 5 Record this start reading on the data worksheet

3 Allow the system to run long enough for a minimum of 4 liters of fuel to be used The more diesel fuel used will allow for a more accurate measurement

4 Stop the stopwatch when the fuel level in the sight gauge crosses a division line, see Fig 5 Record this reading and the time on the data worksheet

5 Calculate the fuel use in liters/hour using the worksheet

6 Reconnect the fuel and return lines after the test Again, make sure the air in the line is bled off

3 DATA ANALYSIS

The pumping plant energy use is compared to the *expected* energy consumption required to produce the same horsepower if the pumping plant is efficient Therefore, the calculated efficiency is a comparative efficiency The expected or performance standards are given in Table 1 Table 3 gives an evaluation of the action needed based on the measured comparative efficiency

Table 3 Evaluation of the pumping plant test

Comparative Efficiency percent	Evaluation
≥ 90	Operating satisfactorily
80 - 90	Corrective action should be considered
< 80	Immediate corrective action needed

3 1 Common Causes for Inefficiencies

- A plugged intake line screen
- Worn pump impellers, often caused by sand in the irrigation water Centrifugal pump impellers should be inspected for wear and that they are of the correct diameter
- The requirements of the system have changed from the design system expansion, worn nozzles/emitters, or leaking pipes
- See Table 4 Pumping plant trouble shooting

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Table 4 Pumping Plant Trouble Shooting

Problem	Cause Requiring Correction
Pump fails to prime	• Air leaking into the suction pipe or pump Insufficient priming Leaks in suction pipe couplings Delivery valve not fully closed Suction pipe inlet not far enough below the water surface • Suction pipe inlet blocked by debris • Priming system may be faulty
Pump fails to deliver sufficient pressure or discharge	• Air may be leaking into the suction pipe or pump, but not enough to lose prime • Suction pipe inlet or pump impeller may be partially blocked with debris • Suction lift may be too high • Pump speed may be too low A loss of 20% in pump speed will reduce the discharge by 20% and the pressure by 44% • Pump bearings may be worn and water is leaking back into the suction side
Output pressure increases but the discharge decreases	Pipes or line filters may be blocked This is characteristic of a centrifugal pump running at a constant speed
Pump delivers water but later stops delivering	• Air may have accumulated at a high spot in the suction pipe If this air suddenly moves up into the pump it may cause loss of prime • Air may enter the suction inlet if the water level drops during pumping Watch the water surface for a whirlpool near the inlet through which air can enter • See above listed problems and causes
Pump takes too much power	• There may be leaks in the mainline or laterals or a pipe burst This causes the pressure to fall and the discharge to rise thus increasing the power requirement • Pump speed may be too high • There may be mechanical defects in the pump or power unit Check that the pump can be easily rotated by hand, if not check the lubrication system and look for binding parts If pump rotation is not a problem open the pump and check the impeller for wear or damage
Output, efficiency, and power consumption low	Partial air blockage in the impeller eye a solid obstruction upstream of the impeller, or rough water flow passages

Reduced output and efficiency, power requirements unchanged	Obstruction to flow or excessively rough water flow passage ways between impeller and point of pressure measurements
Shutoff head remains unchanged but falls off rapidly with increased flow rate	Obstruction to water flow downstream (discharge side) of the impeller
Low flow rate, decreasing flow rate	Entrapped air or air leakage into pump Common problem cause sites are Joints in suction line flanges, bushings, nipples, drain plugs Suction side of the pump casing
Pitting and eating away of metal on pump case and/or impeller	Corrosion from chemicals, highly saline water, dissimilar metal contact
High power demand, surging vibration, and air pumped	Inexact pump-motor-pipe alignment
Impeller and pump case damage, pump knocking	Water vapor bubbles collapsing on impeller and casing causing cavitation
Reduced pump output and vibration	Clogged impeller

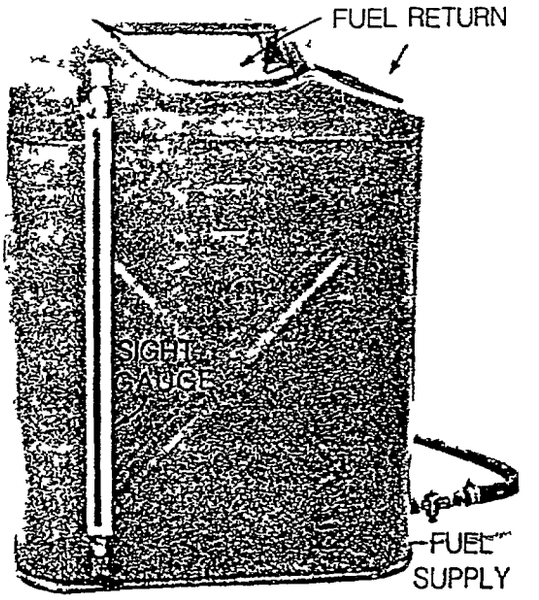

Figure 4 Diesel fuel test can with calibrated sight gauge

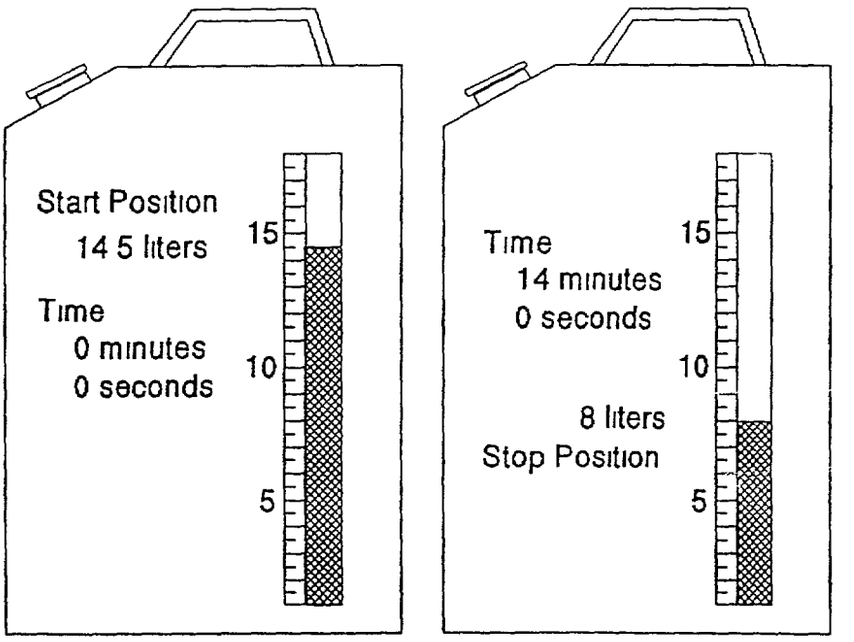

Figure 5 Example start and stop positions

Example calculation

$$\text{Fuel Use} = \frac{\text{liters} \times 60}{\text{minutes}} = \frac{(14\ 5 - 8)_{\text{liters}} \times 60 \text{ minutes / hour}}{(14 - 0)_{\text{minutes}}} = 27\ 86 \text{ liters / hr}$$

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IRRIGATION PUMPING PLANT EFFICIENCY WORKSHEET

CASE STUDY I

GENERAL INFORMATION

DA - 25 Farm Unit No 217 Date 1 / 11 1996

Farm Name JVA

Pump Testers WERSC

Pump Type and Model Centrifugal, Cornell 4WB

Pump Age 10 000 hr Power Source Electric motor

Motor Horsepower 32 2 Drive Type Direct Drive

FLOW RATE

Totalizer Reading Start 2144 7 m^3 End 2171 2 m^3

Elapsed Time 10 min × 60 = 600 sec

Pumping Rate 0 04417 m^3/sec [(m^3 stop – m^3 start) / time = m^3/sec]

TOTAL DYNAMIC HEAD

* Suction Lift 2 5 m Suction Pipe Length 6 m

* Suction Pipe Loss 0 12 m [Suction pipe length × 0 02]

* Discharge Pressure 40 05 m
[psi × 0 7032 = m , bar × 10 3327 = m , kPa × 0 1033 = m]

Total Dynamic Head (TDH) 42 67 m [Sum of three starred (*) items]

Water Power (kWh) 18 48 [(m^3/sec × TDH) / 0 102]

ENERGY

Electric

"r/kWh" Factor 450 No of Revolutions 15

Time for revolutions 3 35 sec

Energy Use (kWh/hr) 35 82 [(Rev × 3600)/(Factor × sec]

Hours used Annually 1,525 Energy Cost 0 042 JD/kWh

Diesel

Fuel level readings Start _____ liters Stop _____ liters

Elapsed time _____ min / 60 = _____ hr

Energy use (liters/hr) _____ [($liters_{start}$ – $liters_{stop}$) / hr]

Hours used Annually _____ Energy Cost _____ JD/liter

PUMPING PLANT EFFICIENCY

Measured Pumping Efficiency 0 52 [Water Power / Energy Use]

Comparison Efficiency 78 8 %
[(Measured Pumping Efficiency / Standard Pumping Efficiency) x 100]

Extra Energy Use 7 59 kWh/hr or Liter/hr
{[(100 - Comparison Efficiency)/100] × Energy Use}

Additional Energy Cost 483 385 JD/year
[Extra Energy Use × Energy Cost × Hours used Annually]

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PUMPING PLANT LAYOUT

Gauges and Meters

Pressure Yes ___ No ___ Age _____

Scale Range _____ Model _____

Manufacturer _____

Vacuum Yes ___ No ___ Age _____

Scale Range _____ Model _____

Manufacturer _____

Flow meter Yes ___ No ___ Age _____

Type _____ Model _____

Manufacturer _____

Sketch of System Layout

IRRIGATION PUMPING PLANT EFFICIENCY WORKSHEET

GENERAL INFORMATION

DA - _____ Farm Unit No _____ Date ____/____/199__

Farm Name _____

Pump Testers _____

Pump Type and Model _____

Pump Age _____ Power Source _____

Motor Horsepower _____ Drive Type _____

FLOW RATE

Totalizer Reading Start _____ m^3 End _____ m^3

Elapsed Time _____ min × 60 = _____ sec

Pumping Rate _____ m^3/sec [(m^3 stop – m^3 start) / time = m^3/sec]

TOTAL DYNAMIC HEAD

* Suction Lift _____ m Suction Pipe Length _____ m

* Suction Pipe Loss _____ m [Suction pipe length × 0 02]

* Discharge Pressure _____ m
[psi × 0 7032 = m , bar × 10 3327 = m , kPa × 0 1033 = m]

Total Dynamic Head (TDH) _____ m [Sum of three starred (*) items]

Water Power (kWh) _____ [(m^3/sec × TDH) / 0 102]

ENERGY

Electric

"r/kWh" Factor _____ No of Revolutions _____

Time for revolutions _____ sec

Energy Use (kWh/hr) _____ [(Revs × 3600)/(Factor × sec]

Hours used Annually _____ Energy Cost _____ JD/kWh

Diesel

Fuel level readings Start _____ liters Stop _____ liters

Elapsed time _____ min / 60 = _____ hr

Energy use (liters/hr) _____ [($liters_{start}$ – $liters_{stop}$) / hr]

Hours used Annually _____ Energy Cost _____ JD/liter

PUMPING PLANT EFFICIENCY

Measured Pumping Efficiency _____ [Water Power / Energy Use]

Comparison Efficiency _____ %
[(Measured Pumping Efficiency / Standard Pumping Efficiency) x 100]

Extra Energy Use _____ kWh/hr or Liter/hr
{[(100 - Comparison Efficiency)/100] × Energy Use}

Additional Energy Cost _____ JD/year
[Extra Energy Use × Energy Cost × Hours used Annually]