Chapter 9 Irrigation Water Management

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NJ652.09 Irrigation Water Management

(a) General

Irrigation water management is the act of timing and regulating irrigation water applications in a way that will satisfy the water requirement of the crop without the waste of water, soil, plant nutrients, or energy. It means applying water according to crop needs in amounts that can be held in the soil available to crops and at rates consistent with the intake characteristics of the soil and the erosion hazard of the site.

Management is a prime factor in the success of an irrigation system. Large quantities of water, and often large labor inputs, are required for irrigation. The irrigator can realize profits from investments in irrigation equipment only if water is used efficiently. The net results of proper irrigation water management typically:

- Prevent excessive use of water for irrigation purposes
- Prevent irrigation induced erosion
- Reduce labor
- Minimize pumping costs
- Maintain or improve quality of ground water and downstream surface water
- Increase crop biomass yield and product quality

Tools, aids, practices, and programs to assist the irrigator in applying proper irrigation water management include:

- Applying the use of water budgets or balances to identify potential water application improvements.
- Applying the knowledge of soil characteristics for water release, allowable irrigation application rates, available water capacity, and water table depths
- Applying the knowledge of crop characteristics for water use rates, growth characteristics, yield and quality, rooting depths, and allowable plant moisture stress levels.
- Water delivery schedule effects
- Water flow measurement for on field water management
- Irrigation scheduling techniques
- Irrigation system evaluation techniques

(b) Irrigation Water Management Concepts

The simplest and basic irrigation water management tool is the equation:

$$QT = DA$$

Where:

Q = flow rate (ft^3/s)
T = time (hr)
D = depth (in)
A = area (acres)

For example, a flow rate of 1 cfs for 1 hour = 1 inch depth over 1 acre. This simple equation modified by an overall irrigation efficiency, can be used to calculate the daily water supply needs by plants, number of acres irrigable from a source, or the time required to apply a given depth of water from an irrigation well or diversion. Typically over 80 percent of IWM concerns can be at least partly clarified by the application of this equation.

When to Irrigate: This is dependent on the crop water use rate, (sometimes referred to as irrigation frequency). This can be determined by calculation of ETc rate for a specific crop stage of growth, monitoring plant moisture stress levels, monitoring soil water depletion and rainfall events. Applied irrigation water should always be considered supplemental to rainfall events. The irrigation decisionmaker should leave between 0.5 and 1.0 inch of available water capacity in the soil profile unfilled for storage of potential rainfall. Rainfall probability during a specific crop growing period and the level of risk to be taken must be carefully considered by the irrigation decisionmaker.

Water Measurement: A key factor in proper irrigation water management is knowing how much water is available to apply or is being applied to a field through an irrigation application system. Many devices are available to measure pipeline or open channel flows. Too many irrigators consider water measurement a regulation issue and an inconvenience. Typically less water is used where adequate flow measurement is part of the water delivery system.

(c) Soil-Plant-Water Balance

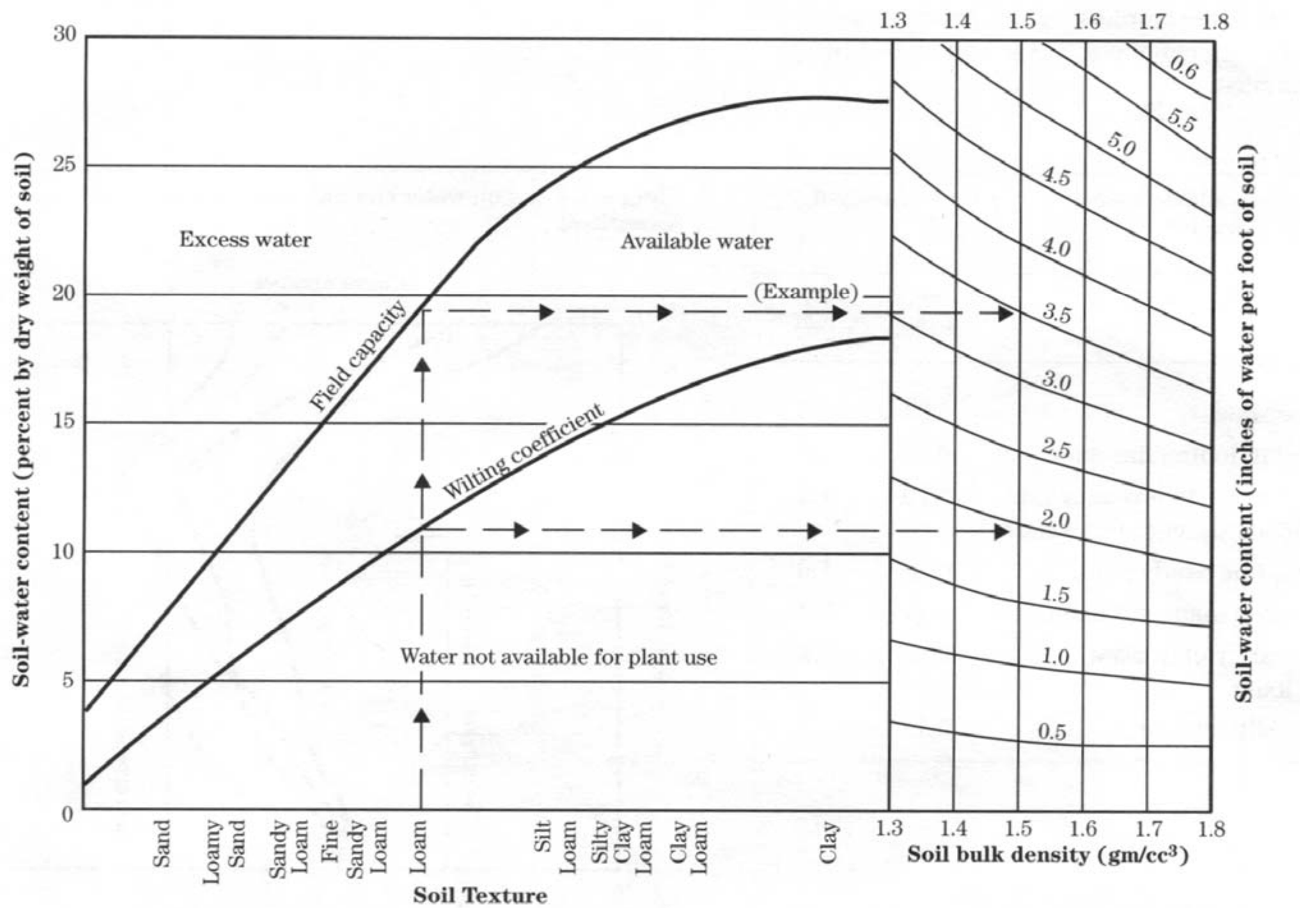
This is described as the daily accounting of water availability to the crop within its effective root zone.

Soil: Soil intake characteristics, field capacity, wilting point, available water capacity, water holding capacity, management allowed depletion, and bulk density, are soil characteristics that the irrigator must take into account to implement proper irrigation water management. Also see Chapter 2, Soils, and Chapter 17, Glossary.

- Field Capacity (FC): Defined as the amount of water remaining in the soil when the downward water flow form gravity becomes negligible. It occurs soon after an irrigation or rainfall event fills the soil. About 10 centibars soil water tension (0.1 atmosphere or bar), for sandy soils, and 30 centibars for medium to fine textured soils.
- Wilting Point (WP): Defined as the soil-water content below which plants cannot obtain sufficient water to maintain plant growth and never totally recover. Generally wilting point is assumed to be 15 atms (bar) tension.
- Available Water Capacity (AWC) is the portion of water in the soil (plant root zone) that can be absorbed by plant roots. It is the amount of water released between field capacity and permanent wilting point. Average available water capacities are displayed in Table NJ 9.1. Average soil-water content based on various textures and bulk density is displayed in Figure NJ 9.1.

- Soil-Water Content (SWC) is the water content of a given volume of soil at any specific time. This is the water content that is measured by most soil-water content measuring devices. Amount available to plants then is SWC – WP.
- Management Allowed Depletion (MAD) is the desired soil-water deficit at the time of irrigation. It can be expressed as the percentage of available soil-water capacity or as the depth of water that has been depleted in the root zone. Providing irrigation water at this time minimizes plant water stresses that could reduce yield and quality.
- Bulk Density is the mass of dry soil per unit bulk volume. It is the oven dried weight of total material per unit volume of soil, exclusive of rock fragments 2mm or larger. The volume applies to the soil near field capacity water content. To convert soil water content on a dry weight basis to volumetric basis, soil bulk density must be used.

Figure NJ 9.1 Total soil-water content for various soil textures with adjustment for changes in bulk density



The rate of decrease in soil-water content is an indication of plant water use and evaporation, which can be used to determine **when to irrigate and how much to apply.** This is the basic concept in scheduling irrigations.

TABLE NJ 9.1 AVAILABLE WATER CAPACITY FOR VARIOUS SOIL TEXTURES

Soil texture	Estimated in/in	AWC in/ft
Sand to fine sand	0.04	0.5
Loamy sand to loamy fine sand	0.08	1.0
Loamy fine sands, loamy very fine sands, fine sands, very fine sands	0.10	1.2
Sandy loam, fine sandy loam	0.13	1.6
Very fine sandy loam, silt loam, silt	0.17	2.0
Clay loam, sandy clay loam, silty clay loam	0.18	2.2
Sandy clay, silty clay, clay	0.17	2.0

Measuring Soil-Water Content: To measure soil-water content change for the purpose of scheduling irrigation, monitoring should be done at several locations in each field and at different soil depths (6” increments). Most devices used indicate relative soil-water values and are difficult to calibrate to relate to specific quantitative values. A calibration curve for each specific kind of soil and soil-water content (tension) should be available with the device or needs to be developed. Methods and devices to measure or estimate soil-water content include:

- Soil Feel and Appearance Method: Soil samples are collected at desired depths and compared to tables or pictures that give moisture characteristics of different soil textures. Refer to NRCS color publication, *Estimating Soil Moisture by Feel and Appearance*. How soil samples taken in the field from appropriate locations and depths feel and look gives some indication of moisture content. A shovel can be used to get samples, but for some soils a soil auger or a sampling tube is better. The appearance and feel of a handful of soil that has been squeezed very firmly can be compared with descriptions in a guide of estimated available-moisture content for different soil textures and conditions. Table NJ 9.2 is a guide that has been used for some time. The feel and appearance method is one of the cheapest and easiest methods to use for estimating water content, but it does require some work to get soil samples. Although this method is not the most accurate, with experience and judgment the irrigator should be able to estimate the moisture level within a reasonable degree of accuracy.

TABLE NJ 9.2 PRACTICAL INTERPRETATION CHART ON SOIL MOISTURE FOR SOIL TEXTURES AND CONDITIONS

AVAILABLE MOISTURE IN SOIL	FEEL OR APPEARANCE OF SOIL			
	COARSE-TEXTURED SOILS	MODERATELY COARSE TEXTURED SOILS	MEDIUM-TEXTURED SOILS	FINE AND VERY FINE TEXTURED SOILS
0 percent	Dry, loose, and single-grained; flows through fingers.	Dry and loose; flows through fingers	Powdery dry; in some places slightly crusted but breaks down easily into powder	Hard, baked, and cracked; has loose crumbs on surface in some places
50 percent or less	Appears to be dry; does not form a ball under pressure[1]	Appears to dry; does not form a ball under pressure[1]	Somewhat crumbly but holds together under pressure.	Somewhat pliable; balls under pressure[1]
50 to 75 percent.	Appears to be dry; does not form a ball under pressure[1]	Balls under pressure but seldom holds together.	Forms a ball under pressure; somewhat plastic; slicks slightly under pressure.	Forms a ball; ribbons out between thumb and forefingers.
75 percent to field capacity.	Sticks together slightly; may form a very weak ball under pressure.	Forms weak ball that breaks easily; does not slick.	Forms ball; very pliable; slicks readily if relatively high in clay.	Ribbons out between fingers easily; has a slick feeling
At field capacity(100 percent)	On squeezing, no free water appears on soils but wet outline of ball is left on hand.	Same as for coarse-textured soils at field capacity	Same as for coarse- textured soils at field capacity.	Same as for coarse-textured soils at field capacity.
Above field capacity	Free water appears when soil is bounced in hand	Free water is released with kneading	Free water can be squeezed out	Puddles; free water forms on surface

1/ Ball is formed by squeezing a handful of soil very firmly.

- Gravimetric or Oven Dry Method: Soil samples are collected using a core sampler. Samples must be protected from drying before they are weighed. Samples are taken to the office work room, weighed (wet weight), oven dried, and weighed again (dry weight). An electric oven takes 24 hours at 105 degrees Celsius to adequately remove soil water. Percentage of total soil-water content on a dry weight basis is computed. To convert to a volumetric basis, the percentage water content is multiplied by the soil bulk density. Available soil water is calculated by subtracting percent total soil water at wilting point. This procedure is the most accurate method for determining the soil water content, but is time consuming and may be impractical for most farmers.

The following equipment is required:

(1) Moisture proof seamless aluminum or tin sample boxes (cans) with a capacity of 3 ounces or more to contain sample for drying.

(2) Beam balance with a minimum of 500-gram capacity, accurate to 0.1 gram.

(3) Drying oven, with thermometer, capable of maintaining a temperature of 2200 F to 2400F. (105ºC to 115ºC).

(4) A core soil sampler to take bulk density samples. Alternatively, the bulk density can be determined by the sand cone method or water balloon method.

Procedure:

(1) Collect a representative soil sample of known volume using a core sampler.

(2) Determine the wet weight of the sample (WW).

(3) Dry the sample in the oven at 105^0C to 115^0C until it attains a constant weight. This will take about 24 hours. Check the weight at one hour intervals near the end of the 24 hour period. When there is no weight change, the sample is dry.

(4) Determine the dry weight of the sample (DW). Remember to deduct the tare weight of the container when determining wet weight and dry weight.

(5) Compute the bulk density (BD) and total soil water content (TSWC):

$$BD = \frac{DW(g)}{\text{Sample Volume (cc)}} \quad \text{(dry weight basis)}$$

Weight of water lost,

$$WAT = WW - DW$$

Percent Water Content (dry weight basis),

$$WC = \frac{WAT}{DW} \times 100$$

$$TSWC = \frac{BD \times WC}{100} \quad \text{(inches water per inch soil depth)}$$

(6) The total soil water content (TSWC) includes moisture that is not available to the plant at the permanent wilting point. The permanent wilting point (Pw), the

point at which a plant can no longer obtain enough soil water to meet transpiration needs, occurs at 15 atmospheres of tension and is normally determined in the laboratory. When laboratory data are not available, one of the following procedures can be used to estimate the wilting point.

(a) This procedure requires knowledge of the percent clay, less any clay size carbonate particles, of the soil being measured. For many soils, this procedure will provide a close estimate of the wilting point. The wilting point is calculated with use of the following equation:

$$Pw = 0.4 \times \text{clay} (\%)$$

Where:

Pw is the wilting point, using the clay content, expressed as percent of water on a dry weight basis.

(b) This procedure can be used where only the soil texture is known. The values given represent and average wilting point for the given texture.

Texture	Pw
Clay	25
Silty clay	19
Sandy clay	17
Silty clay loam	13
Clay loam	13
Sandy clay loam	11
Silt loam	5.5
Loam	7
Very fine sandy loam	4
Fine sandy loam	4
Sandy loam	4
Loamy fine sand	3
Loamy sand	3
Fine sand	2
Sand	2

Pw is expressed as percent water on a dry weight basis. The values given do not apply to soils having soil fragments larger than 2.0 millimeters.

(7) To determine the soil water content (SWC), Pw percentage is first converted to inches of water (WP). WP is then subtracted from TSWC to obtain SWC.

$$WP = \frac{BD \times Pw}{100} \text{ (inches water per inch soil depth)}$$

$$SWC = TSWC - WP \text{ (inches/inch soil depth)}$$

To determine the SWC for a given increment of depth, multiply SWC by the depth, in inches, being evaluated.

To determine the available water capacity (AWC) for soils not listed in Chapter 2, or for a special case where the data in Chapter 2 are not satisfactory, it is necessary to make soil water content measurements at field capacity. These measurements are made after an irrigation or effective rainfall. Before making the measurements, allow about 24 hours for sand and about 48 hours for clay for the gravitational water to drain. Determine AWC using the above procedure, where SWC becomes AWC.

Figure NJ 9.2 Soil-water content worksheet (gravimetric method)

U.S. Department of Agriculture
Natural Resources Conservation Service

Worksheet
Soil-Water Content
(Gravimetric Method)

Land user__________ Date __________ Field office __________

Taken by __________ Field name/number __________

Soil name (if available) __________ Crop __________ Maximum effective root depth __________ ft

Depth range inches	Soil layer thickness inches d	Soil texture	Sample			Tare weight g Tw	Net dry weight g Dw	Volume of sample cc Vol	Moisture per-centage % Pd	Bulk density g/cc Dbd	Soil-water content in/in SWC	Layer water content inches TSWC
			Wet weight g WW	Dry weight g DW	Water loss g Ww							

Dry weight (Dw) of soil = DW - TW = ________g Weight of water lost (Ww) = WW - DW = ________g Bulk density (Dbd) = $\frac{Dw(g)}{Vol\ (cc)}$ = ________g/cc

Percent water content, dry weight Pd = $\frac{Ww \times 100}{Dw}$ = ________% Soil-water content (SWC) = $\frac{Dbd \times Pd}{100 \times 1}$ = ________in/in

Total soil-water content in the layer (TSWC) = SWC x d = ________inches

- **Chemical Drying Method** (Speedy Moisture Tester) This method of drying soil samples is based on the principle that a given quantity of moisture, when combined with calcium carbide, will react to produce a specific volume of gas (acetylene). By applying this principle, a device known as the Speedy Moisture Tester was developed in England and is commercially available. It confines in a cylindrical pressure chamber the gas produced from this reaction. One end of the pressure chamber is equipped with a cap for inserting the carbide and soil sample and a clamping arrangement to confine the gas during the test. The gas pressure is read on a gage located on the other end of the pressure chamber. The gage is calibrated for a 26-gram wet weight sample of soil and the reading can be converted readily to a dry weight moisture percentage by use of a calibration curve supplied with the instrument, or by use of the conversion chart in Chapter 16.

The calcium carbide gas pressure method is a quick and reasonably accurate way of determining the moisture content of a soil. The time required to dry a sample is about 3 minutes. Its simplicity of use is such that anyone can become proficient enough in a short time to make its use a routine operation.

Care must be taken in measuring the 26-gram soil sample. When the test is finished, examine the sample for lumps. If the soil was not completely broken down by the steel balls, retest and increase the shake-and-rest time by one minute. The calcium carbide gas pressure method should not be used on saturated highly organic soils.

- **Tensiometers**: Soil-water potential (tension) is a measure of the amount of energy with which water is held in the soil. Tensiometers work on the principle that a partial vacuum is created in a closed chamber when water moves out through a porous ceramic tip to the surrounding soil. Tension is measured by a water manometer, a mercury manometer, or a vacuum gage. The scales are generally calibrated in either hundredths of an atmosphere or in centimeters of water. Tensiometers that utilize a mercury manometer are usually preferred as research tools because they afford great precision. Because of their simplicity, tensiometers equipped with Bourdon vacuum gages are better suited to practical use and to irrigation control.

After the cup is placed in the soil at the desired depth, the instrument must be filled with water. Water moves through the porous cup until the water in the cup and the water in the soil reach equilibrium.

Any increase in tension that occurs as the soil dries causes the vacuum-gage reading, which can be read above ground, to increase. Conversely, an increase in soil-water content reduces tension and lowers the gage reading. The tensiometer continues to record fluctuations in soil-water content unless the tension exceeds 0.85 atmosphere, at which point air enters the system and the instrument ceases to function. Then after an irrigation or rain, the instrument must again be filled with water before it can operate.

Some experience is required to use a tensiometer. If air enters the unit through any leaks at the rubber connections, measurements are not reliable. Air leaks can result from faulty cups. They may occur also at the contact points of the setscrews used to secure the porous cup to the metal support. Some manufacturers provide a test pump that can be used to test the gage and to remove air from the instrument.

Tensiometers readings reflect soil-moisture tension only; that is, they indicate the relative wetness of the soil surrounding the porous tip. They do not provide direct information on the amount of water held in the soil. Tension measurements are useful in deciding when to irrigate, but they do not indicate how much water should be applied. A special moisture-characteristic curve for the particular soil is needed to convert moisture-tension measurements into available-moisture percentages. Typical curves for soils are shown in Figure NJ 9.3.

Table NJ 9.3 Guidelines for using soil moisture tension data to schedule irrigation events.

	25% MAD (cb)	50% MAD (cb)
Coarse Sand	12	20
Sand	12	20
Fine Sand	12	20
Loamy Sand	15	25
Loamy Coarse Sand	15	25
Loamy Fine Sand	15	25
Loamy Very Fine Sand	20	40
Sandy Loam	20	40
Fine Sandy Loam	25	50
Very Fine Loam	25	50
Loam	30	60
Silt Loam	40	85
Sandy Clay Loam	40	85
Clay Loam	45	90
Silty Clay Loam	45	90
Sandy Clay	50	95
Silty Clay	50	95
Clay	50	95

cb = Centi bars

Tensiometers do not satisfactorily measure the entire range of available moisture in all soil types. But they probably are the best field instruments to use to determine moisture conditions in the wet range. They are best suited to use in sandy soils, since in these soils a large part of the moisture available to plants is held at a tension of less than I atmosphere. Tensiometers are less well suited to use in fine-textured soils, which hold only a small part of the available moisture at a tension of less than 1atmosphere.

Tensiometers installed at different rooting depths have different gauge readings because of soil water potential change in rooting depths. With uniform deep soil, about 70 – 80% of soil moisture withdrawal by plant roots is in the upper half of the rooting depth. Recommended depths for setting tensiometers are given in Table NJ 9.4.

Table NJ 9.4 Recommended depths for setting tensiometers

Plant root zone depth (in)	Shallow tensiometer (in)	Deep Tensiometer (in)
18	8	12
24	12	18
36	12	24
>48	18	36

Installing tensiometers must be done carefully and good maintenance is required for accurate and reliable results. They also must be protected against freeze damage. Maintenance kits that include a hand vacuum pump are required for servicing tensiometers. The hand pump is used to draw out air bubbles from the tensiometer and provide an equilibrium in tension. Tensiometers should be installed in pairs at each site, at one-third and two-thirds of the crop rooting depth. A small diameter auger (or 1/2” steel water pipe) is required for making a hole to insert the tensiometer. Figure NJ 9.4 shows a tensiometer and gauge and illustrates installation and vacuum pump servicing.

Figure NJ 9.3 Water retention curves for several soils plotted in terms of percent available water removed

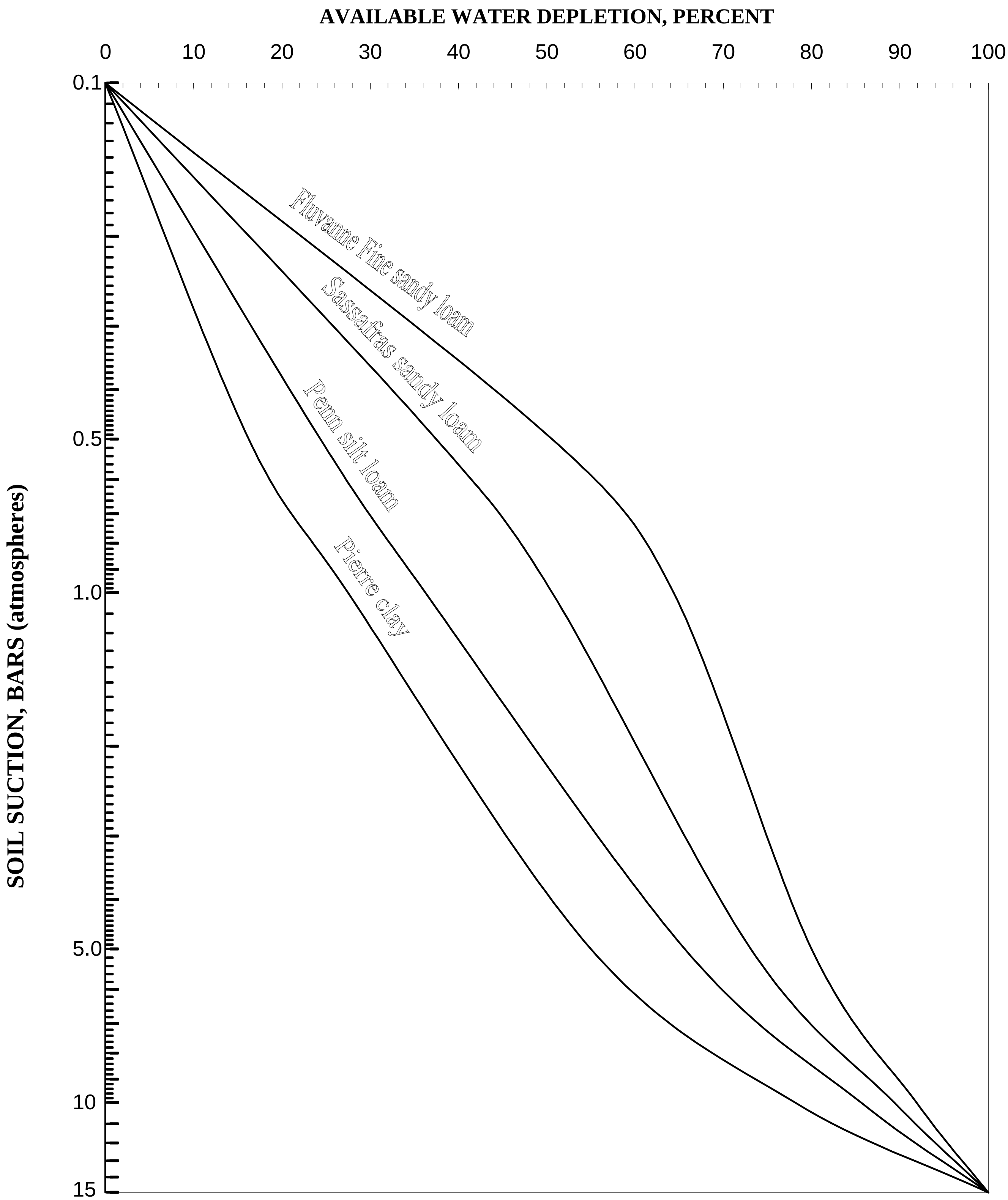
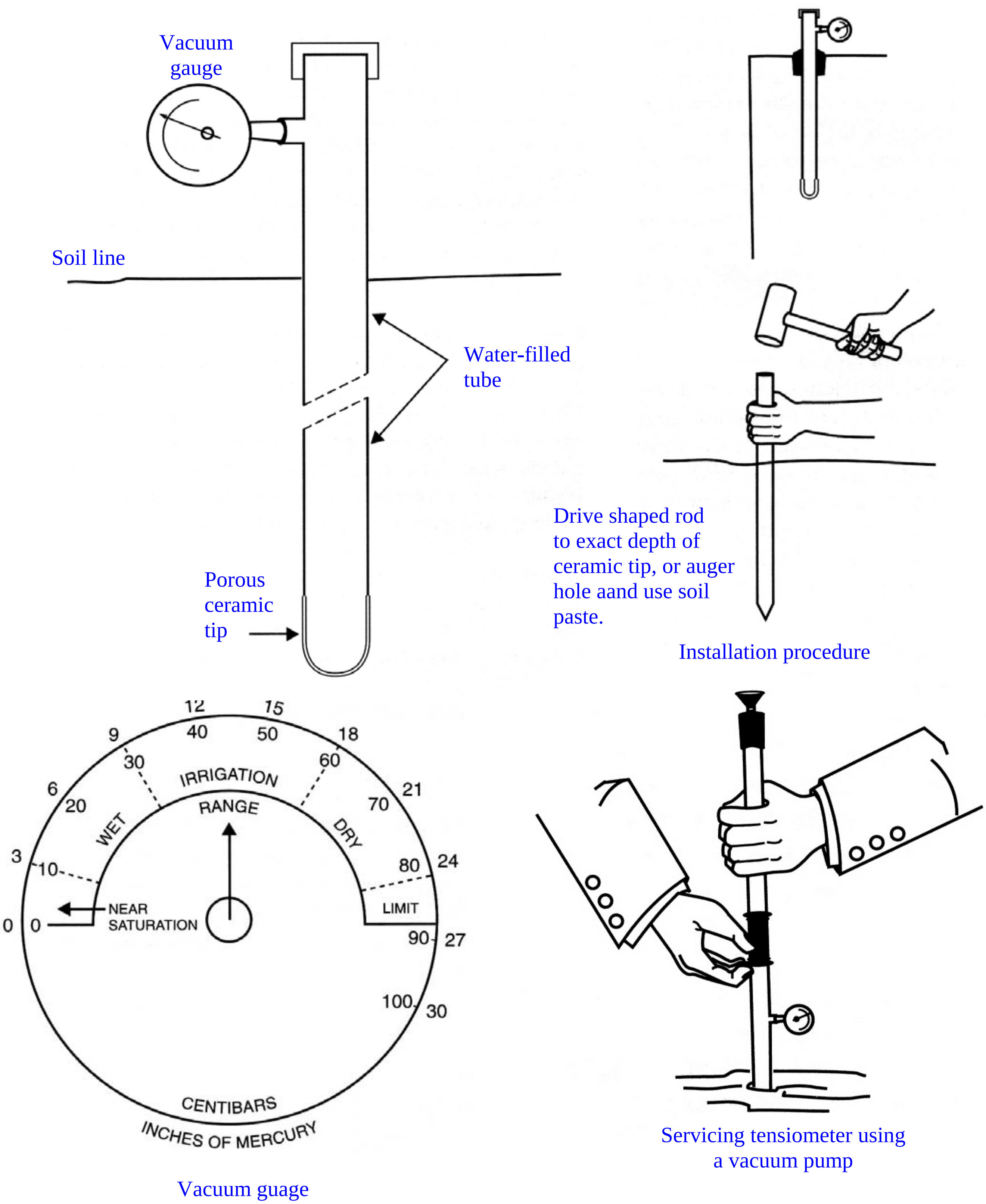


Figure NJ 9.4 Tensiometer, installation, guage, and servicing



Electrical-Resistance Instruments:
These instruments use the principle that a change in moisture content produces a change in some electrical property of the soil or of an instrument in the soil. They consist of two electrodes permanently mounted in conductivity units, usually blocks of plaster of paris, nylon, fiberglass, gypsum, or combinations of these materials. Electrodes in the blocks are attached by wires to a resistance or conductance meter that measures changes in electrical resistance in the blocks. When the units are buried in the soil, they are in close contact with soil particles and respond to changes in soil moisture content. Since the amount of moisture in the blocks determines electrical resistance, measurement of any change in resistance is an indirect measure of soil moisture if the block is calibrated for a particular soil.

Nylon and fiberglass units are more sensitive in the higher ranges of soil moisture than plaster of paris blocks, but often their contact with soil that is alternately wet and dry. is not very good. Nylon units are most sensitive at a tension of less than 2 atmospheres. Plaster of paris blocks function most effectively at a tension between I and 15 atmospheres, and fiberglass units operate satisfactorily over the entire range of available moisture. A combination of fiber glass and plaster of paris provides sensitivity in both the wet and dry range and provides good contact between the soil and the unit.

Electrical-resistance instruments are sensitive to salts in the soil; fiberglass units are more sensitive than plaster of paris. Their readings are also affected by concentrations of fertilizer. Where fertilizer is spread in bands, the unit should be placed well to one side of the bands. Temperature also affects reading in all units, but much less than other sources of variation. In some units, calibration drift has caused changes of as much as I atmosphere of tension in a single season. The magnitude of a change depends on the number of drying intervals and the number of days between each. Readings also vary with soil type. Since the same reading may indicate different amounts of available moisture for different soil textures, the instrument must be calibrated for the soil in which it is to used. For good accuracy, each instrument site shall be calibrated. Due to the possibility of calibration drift, particularly if fertilizer is applied with irrigation, the calibration should be checked once or twice each growing season. Calibration should be done with an accurate method, such as the gravimetric or the chemical drying methods.

If readings are to be representative of an area, the blocks must be properly installed. Individual blocks must be placed in a hole, which disturbs the soil. If the soil is not replaced in the hole at the same density and in the same way as in the rest of the profile, the root-development and moisture pattern may not be representative. A good method is to force the block into undisturbed soil along the sides of the hole dug for placement of the blocks. In one type, the blocks are cast in a tapered stake. A tapered hole, the same size as the stake, is bored into the ground with a special auger. The stake is saturated with water and then pushed into the hole so that close contact is made between the stake and the soil.

Most of the commercial instruments give good indications of moisture content if they are used according to the manufacturer's instructions. For good results, however, the blocks need to be calibrated in the field for each job. Experience and careful interpretation of instrument readings are needed to get a good estimate of soil moisture conditions. Electrical conductivity sensors are becoming a popular tool, and are

Table NJ 9.5 Interpretations of readings on typical electrical resistance meter

Soil water condition	Meter readings [1/] (0—200 scale)	Interpretation
Nearly saturated	180 — 200	Near saturated soil often occurs for a few hours following an irrigation. Danger of water logged soils, a high water table, or poor soil aeration if readings persist for several days.
Field capacity	170 — 180	Excess water has mostly drained out. No need to irrigate. Any irrigation would move nutrients below irrigation depth (root zone).
Irrigation range	80 — 120	Usual range for starting irrigations. Soil aeration is assured in this range. Starting irrigations in this range generally ensures maintaining readily available soil water at all times.
Dry	<80	This is the stress range; however, crop may not be necessarily damaged or yield reduced. Some soil water is available for plant use, but is getting dangerously low.

1/ Indicative of soil-water condition where the block is located. Judgment should be used to correlate these readings to general crop conditions throughout the field. It should be noted, the more sites measured, the more area represented by the measurements.

recommended on finer textured soils with a high water holding capacity. These instruments are calibrated to read centibars of soil water tension correlated to tensiometer readings. Since they are actually measuring electrical conductivity which is converted to centibars of tension, they can operate in a much higher tension range resulting in more accurate readings. However in sandy soils they are not as sensitive as the tensiometer with a longer response time to soil moisture changes.

Diaelectric Constant Method:
The diaelectric constant of material is a measure of the capacity of a nonconducting material to transmit high frequency electromagnetic waves or pulses. The diaelectric constant of a dry soil is between 2 and 5. The diaelectric constant of water is 80 at frequency range of 30 MHz — 1 GHz. Relatively small changes in the quantity of free water in the soil have large effects on the electromagnetic properties of the soil-water media. Two approaches developed for measuring the diaelectric constant of the soil-water media (water content by volume) are time domain reflectometry (TDR) and frequency domain reflectometry (FDR).

For TDR technology used in measuring soil-water content, the device propagates a high frequency transverse electromagnetic wave along a cable attached to parallel conducting probes inserted into the soil. A TDR soil measurement system measures the average volumetric soil-water percentage along the length of a wave guide. Wave guides (parallel pair) must be carefully installed in the soil with complete soil contact along their entire length, and the guides must remain parallel. Minimum soil disturbance is required when inserting probes. This is difficult when using the device as a portable device. The device must be properly installed and calibrated. Differing soil texture, bulk density, and salinity do not appear to affect the diaelectric constant.

FDR approaches to measurement of soil-water content are also known as radio frequency (RF) capacitance technique. This technique actually measures soil capacitance. A pair of electrodes is inserted into the soil. The soil acts as the diaelectric completing a capacitance circuit, which is part of a feedback loop of a high frequency transistor oscillator. The soil capacitance is related to the diaelectric constant by the geometry of the electric field established around the electrodes. Changes in soil-water content cause a shift in frequency. University and ARS comparison tests have indicated that, as soil salinity increases, sensor moisture values were positively skewed, which suggests readings were wetter than actual condition. FDR devices commercially available include:
Portable hand-push probes—These probes allow rapid, easy, but only qualitative readings of soil-water content. Probe use is difficult in drier soil of any texture, soils with coarse fragments, or soils with hardpans. A pilot hole may need to be made using an auger. The probe provides an analog, color-coded dial gauge (for three soil types—sand, loam, and clay), or a digital readout. The volume of soil measured is relatively small (a cylinder 4 inches tall by 1 inch in diameter). Several sites in a field should be measured, and can be, because probes are rapid and easy to use. Proper soil/probe tip contact is essential for accurate and consistent readings.

Portable device that uses an access tube similar to a neutron gauge—The probe suspended on a cable is centered in an access tube at predetermined depths where the natural resonant frequency or frequency shift between the emitted and received frequency is measured by the probe. The standard access tube is 2-inch diameter schedule 40 PVC pipe. Installation of the access tube requires extreme care to ensure a snug fit between the tube and the surrounding soil. Air gaps or soil cracks between the tube and soil induce error.

The device is calibrated by the manufacturer to sand and to an average bulk density for sand. Recalibration is required for any other soil texture and differing bulk density. The volume of soil measured is not texture or water content dependent, and approximates a cylinder 4 inches tall and 10 inches in diameter. Accuracy can be good in some soils with proper installation and calibration, and there are no radioactive hazards to personnel such as when using a neutron gauge. Proper installation of the access tube is essential and can be quite time consuming. Accuracy of data is largely dependent on having a tight, complete contact between the access tube and the surrounding soil. Before making a large investment in equipment, it is highly recommended that adequate research be done on comparison evaluations that are in process by various universities and the ARS. Good sources of information are technical papers and proceedings of ASAE, ASCE, and Soil Science Society of America, as well as direct discussion with personnel doing evaluations.

Other electronic sensors—Numerous sensors are commercially available using microelectronics. Inexpensive devices sold at flower and garden shops measure the electrical voltage generated when two dissimilar metals incorporated into the tip are placed in an electrolyte solution; i.e., the soil water. Most of these devices are sensitive to salt content in the soil-water solution.

Factors to be evaluated for the selection and application of a soil-water content measuring program include:

- Initial cost of device, appurtenances, special tools, and training
- Irrigation decisionmaker's skill, personal interest, and labor availability

- Field site setup, ease of use and technical skill requirements
- Repeatable readings and calibration requirement
- Interpretations of readings—qualitative and quantitative needs
- Accuracy desired and accuracy of device
- Operation and maintenance costs
- Special considerations including licensing from NRC (private individuals do not operate under ARS licensing), storage, handling, film badge use, training required, disposal of radioactive devices, and special tools required for access tube installation.

(d) Irrigation Scheduling

The determination of when and how much to apply requires a knowledge of the available water capacity (AWC) of the soil, the management allowed depletion (MAD) or plant stress level for the specified crop, the crop peak consumptive use, crop rooting depth, and the critical periods in the growing season when the crop should not be stressed.

Most crops should be irrigated before more than half of the available moisture in the crop root zone has been used. Some crops, however, are thought to do better at higher moisture levels (less moisture deficiency at time of irrigation). See Chapter 3, Crops. Generally, however, the need for irrigation is doubtful until the moisture deficit approaches one-third of the AWC of the crop root zone.

Irrigation must begin in time so that the entire irrigated area can be covered before the available moisture level in the last portion of the field to be irrigated reaches a point to cause unfavorable moisture stress of the crop. This aspect of management is crucial for systems that may need several days to irrigate the entire field area. Examples of such systems may be traveling gun systems, hand move lateral systems, and traveling lateral systems. One of the most effective ways of determining when and how much water to apply is to measure or estimate the soil water content as discussed previously. Measurements should be made in that part of the soil from which plant roots extract their moisture and according to the moisture-extraction pattern of the particular crop. There are other methods being developed to determine when to irrigate, but measuring soil moisture is the most effective method in use now.

Measurements should be taken weekly in spring and fall and more frequently during the hot weather and critical growth periods of the crop. The irrigator may be able to reduce the frequency of readings after he or she has become familiar with the pattern of moisture depletion. To accurately predict moisture levels, measurements should be taken and recorded regularly, regardless of the time of year or the stage of crop growth. Comparison of yearly records with crop yields helps the irrigator to improve his or her management of the irrigation system.

Irrigation Scheduling Methods

In New Jersey the following methods are used to schedule when and how much water to apply. These include: soil and crop monitoring methods; the checkbook method; and computer assisted methods. Growers are recommended to use either of these methods depending on their management preference.

Soil moisture content should be monitored to determine if an irrigation is needed based on predetermined critical levels for certain crops. The crop stress index method measures plant condition and compares that status to a well known reference for a well watered plant condition. Soil moisture monitoring before, during, and after the crop growing season is perhaps the most accurate irrigation scheduling tool.

Monitoring actual soil moisture is like receiving your bank statement from the bank, it affirms or cautions you when an error may exist or other adjustments may be needed. It is used together with the Checkbook Method of irrigation scheduling. This method has proven very useful for scheduling irrigations by providing a running account of available moisture in the effective root zone. Similar to bank account records of deposits (irrigation and rainfall) and withdrawals (evapotranspiration), the account balance provides the irrigator with information as to when to irrigate and how much water to apply. The method requires a daily recording of rainfall, estimated consumptive use, net irrigation amounts, and moisture balance throughout the growing season of the irrigated crop.

With internet access, growers can enroll in the South Jersey RC&D Weather Station Network which offers computerized irrigation scheduling using real time climate data to compute daily crop evapotranspiration. Using this service, the computer facilitates irrigation water management data as well as record keeping on the farm. (computer assisted checkbook method).

Irrigation scheduling utilizes two important principles:

1. When an adequate supply of available moisture is present in the effective root zone, the rate of consumptive use by a given crop depends primarily on. the stage of growth and climatological conditions.

2. When the moisture content of the effective root zone is known at any given time, the moisture content at any later time can be computed by crediting moisture gained from effective rainfall or irrigation and subtracting the daily moisture withdrawals during the elapsed time.

To apply the above principles, the following requirements are essential:

(1) Soil with good internal and surface drainage.

(2) An adequate irrigation system and water supply.

(3) Daily consumptive use values for the crop.

(4) Accurate total available moisture values.

(5) Determination of the effective root zone of the crop.

(6) Measurements of effective rainfall and irrigation applications at the site.

(7) Available soil moisture maintained above the lower limit of withdrawal (25 to 30 percent of the total available moisture.) It is desirable to make periodic soil moisture checks to determine actual available moisture.

Equipment Required:

(1) Wedge-shaped plastic rain gage, 2- by 2-1/2 inch minimum top opening.

(2) Record book

(3) Means of measuring average application rate of irrigation emission devices.

Rain Gauge Installation: To obtain a measurement of the rainfall in the irrigated area, the rain gauge should be set on a post located in field or in an open area adjacent to the field being irrigated. Its distance from nearby obstructions that might affect the catch, such as trees or buildings, should.be at least twice the height of the controlling obstruction. The gauge should be 3 to 4 feet above ground level with its top at least 3 inches above the top of the post.
The amount of rainfall in the gauge should be read at the lowest point of the water surface (meniscus). The reading should be made as accurately as possible, preferably to the nearest one-hundredth of an inch. After the rainfall amount has been recorded, the gauge should be emptied and reset in its holder.

Use of the Moisture Balance Sheet for Scheduling Irrigation:
Record all available pertinent information in the heading.

1. Determine the total available moisture-holding capacity of the effective root zone and record it in the heading of the form. Use the value given in Chapter 2, Soils, NJIG.

2. Determine the balance when irrigation is to begin, (MAD). The value frequently used is 50 percent of AWC.

Recording Procedure:
1. On a date near the normal planting date, or start of growth for forage crops and tree fruits, when the field is at field capacity, enter the total available moisture-holding capacity of the soil in the soil water content column on the Scheduling Worksheet.

- When the soil moisture content is below field capacity at the time the moisture balance sheet is started, the available moisture remaining at that time will have to be estimated or measured. If the moisture percentage at field capacity has been previously determined for the field, measurement of present moisture percentage is all that is needed to provide an accurate starting value.
- If field measurement of moisture percentage at field capacity has not been possible, begin the account with an estimated value. At the first opportunity after adequate rain or irrigation, obtain the field capacity moisture percentage and correct the account accordingly.
- If at the time of plant emergence, a week or more has passed since the soil was at field capacity, and land preparation and seeding operations have ensued, the moisture balance may be estimated as being about 0. 5 inch below the field capacity value.
- Early season moisture losses prior to plant emergence may be estimated by using an evaporation rate from the soil surface of 0.03 inch per day for the first week after the soil has been wetted to field capacity. An evaporation rate of 0.03 inch per week may be used for the remaining period. For bare or tilled soil conditions during May or later season plantings, when the mean daily temperature is above 63 degrees F, evaporation from the top 6 inches of soil may be estimated to average 0.1 inch per day for the first 5 days, and 0.05 inch per week thereafter.

- Moisture losses may be estimated by measuring the depth of the dried surface layer and multiplying this depth by the available waterholding capacity of the soil per inch of depth.
- When a sod or cover crop is plowed under shortly before the planting date, the moisture balance may be considerably less than field capacity. Unless total rainfall between plowing and planting has brought the moisture level to field capacity or above, the moisture content of the soil should be measured at the start of record keeping.

2. At the end of the first day of moisture accounting:
   - Estimate crop consumptive use, ETc: Real time weather data from SJRC&D Weather Station Network which calculates ETc; Irrigation Water Requirements Software Program (uses historical weather data and crop coefficients) or evapotranspiration tables for North, South, and Central NJ (Tables NJ 4.2).
   - Record the amount of rainfall or the net amount of irrigation applied. Amounts should be recorded to nearest 0.01 inch.
   - Starting with the preceding day's balance, subtract the Et use value. If there has been rainfall exceeding 0.2 inch, or irrigation, add these values to the daily moisture balance to obtain the new daily balance. If the total exceeds the value for Available Moisture at field capacity in the root zone, enter the Available Moisture recorded in the heading of the form. If the total exceeds the Available Moisture value at field capacity by 0.5 inch or more, continue the full moisture balance value for two succeeding days. During this 2-day period the plants will be using the free water in the root zone.

3. Continue the same process as outlined above at the end of each day during the growing season until the crop has reached the desired maturity level.

Month ____________ Field ____________________

Soil Texture Loam Available water 1.6 inches

Allowable Depletion 0.4 inches (25%)

Irrigate At 30 CB Irrigation Rate of Application 0.078 "/hr (net)

Date	Site #1 Sensor Readings (CB)		Site #2 Sensor Readings (CB)		Rainfall (inches)	Run Time (hours)	Irrigation (inches)	ET (inches)	Moisture Balance	Fertigation (hours)
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
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21										
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24										
25										
26										
27										
28										
29										
30										
31										

Total For Month: ET ____________ Rainfall ____________ Irrigation ____________

Weather Station- ______________________________

When the daily moisture balance is allowed to drop below 50 percent of the total available moisture value, soil moisture tensions will increase to the point where it becomes increasingly difficult for the plants to obtain the moisture they need for continuous vigorous growth. In such cases, daily evapotranspiration will be reduced.

If for some reason irrigation is not accomplished when the daily moisture balance has reached the 50 percent level, Et values must be reduced. The actual reduction in Et rates varies with the kind of crop and is difficult to define; however, the following factors can be used as a guide for estimating probable daily Et rates:

Moisture level, percent	Factor
40-50	0.8
30-40	0.6
20-30	0.2

The net application is determined by (1) obtaining the difference between the recorded daily balance prior to the start of irrigation and the available moisture at field capacity in the root zone; (2) adding to this value the estimated Et for that day; and (3) making proper allowance for any effective rainfall that may have occurred since recording the last daily balance. The gross application is determined by dividing the net application amount by the expected efficiency of the irrigation method used on the particular field.

Variations in the procedure may be used to fit individual situations.

The time required to apply the required gross application is determined by dividing the gross application amount by the application rate of the irrigation system as determined from an on-site evaluation of the irrigation system.

Location of Soil-Moisture Devices

The selection of soil moisture measurement stations is important. The stations should be located so that average soil moisture conditions in the root zone of the crop are measured. Excess water from leaks in pipe joints, low spots in a field, etc., should not be allowed to come in contact with the measurement station. High spots with excessive water runoff should not be chosen because the soil profile in this area will not represent average root zone conditions. Average soil and slope conditions in the field should be represented in station locations. Measurements should be made at other locations as indicated by any critical condition in the soil, such as an area that dries out first. It is a good practice to have at least two measurement stations in each critical area and two or three stations in areas that are typical of the field. This information provides direction for adjusting the amount and frequency of irrigation for different parts of the field or for different periods in the growing season.

Measurement Depth:

(1) In uniformly textured soils, one measurement should be made at the midpoint in each quarter of the root zone. For shallow rooted crops (maximum 3 foot deep root zones), it is probably desirable to take three measurements. As an example, in a 24-inch root zone, measurements may be taken from the 6-, 12-, and 18-inch depths.

(2) In stratified soils, one measurement should be taken from each textural strata. It may not be necessary to take a measurement in very thin layers when this thin layer can be

lumped with another layer for estimating soil moisture. Where the strata is thick, a sample should be taken in 1-foot increments as a minimum. Thickness of the strata should be noted.

(3) The crop root depth for annual crops changes through the early part of the growing season. Measurements should be made in the soil profile according to the current depth of the majority of the crop roots.

Location in Relation to Plants: For row crops, locate the measurement in the crop row as near the plants as possible. For complete cover crops, such as alfalfa and small grains, locate in representative soil and slope areas of the field. For trees, locate about 4 to 6 feet from the trunk, but inside the tree drip line.

Location in Relation to Irrigation Systems:

(1) Lateral move (side roll or hand move) sprinklers-locate measurement stations halfway between adjacent sprinkler heads and 10 to 15 feet from the lateral.

(2) Center pivot sprinklers - locate measurement stations at about two-thirds of the total lateral distance from the pivot.

(3) Solid set sprinklers - locate measurement stations where the diagonals from four adjacent sprinkler head cross.

(4) Trickle systems - locate in the wetted ball in the root zone.

(5) Furrows and corrugations - measurement stations should be located in about the center of the furrow or corrugation bed near the plants.

Location in Field for Sprinkler or Trickle Irrigation System: Sprinkler and trickle irrigation systems lose pressure down the lateral due to friction loss throughout the lateral, so sprinkler heads farthest from the main lines put out the least irrigation. Locate measurement stations as follows:

(1) 50 to 100 feet downstream from the beginning of the lateral.
(2) 50 to 100 feet upstream from the distal end of the lateral.
(3) At least one measurement close to the center of the lateral. For laterals 1,320 feet to 2,640 feet long, locate two measurement stations at the one. For shorter laterals, one center third points along the lateral measurement should be adequate.

(e) IRRIGATION SYSTEM EVALUATIONS

The performance of an irrigation system can be determined by making field observations and evaluations. These observations can be used to determine average net water applications, uniformity, and efficiency. The results can be used to improve the irrigation system and water management techniques. These improvements should save money by conserving water and energy, reducing nutrient loss and improving crop yields. Simple evaluation techniques are presented in this chapter for sprinkler and trickle irrigation systems. For more complete evaluations and for other irrigation systems, refer to the National Engineering Handbook, Section 15, Irrigation, Chapter 3, National Irrigation Guide, Chapter 9, and Farm Irrigation System Evaluation: A Guide for Management.

Irrigation Efficiency Definitions

Irrigation efficiencies are a measure of how well an irrigation system works as well as the level of management of the system. Refer to the National Irrigation Guide page 9-31 – 9-32 for definitions.

Sprinkler Irrigation Field Evaluation

Successful operation of sprinkle irrigation systems requires that the frequency and quantity of water application be accurately scheduled. Field application efficiency must be known to manage the quantity of application. Since system performance changes with time, periodic field checks are recommended. Since many sprinkler systems are moved from field to field, a measurement of application performance is essential for each layout.

Sprinkler Performance

Often it is desirable to check the performance and output of a specific sprinkler head. The pressure at a sprinkler is measured with a gauge equipped with a pitot tube. The pitot tube must be centered in the discharge jet, which must impinge directly onto the tube tip. The tip should be held about 1/8 inch from the sprinkler nozzle and rocked slightly. Record the highest pressure reading shown. To measure the actual output of a sprinkler, slip a short length of hose over the sprinkler nozzle and collect the flow in a container of known volume. The hose should fit loosely enough to prevent a syphoning action. Record how long it takes the container to fill. Repeat several times and compute the average. If the sprinkler has two nozzles, measure the outputs from each nozzle separately. Check nozzle erosion with a feeler gauge, such as a drill bit that has the diameter specified for the nozzle.

Application Rate and Amount:

An accurate determination of the average irrigation application is important in the Moisture Accounting Method. As a minimum, sufficient depth-of-application data needs to be obtained for the control area which is chosen for moisture accounting. The following procedures can be used to obtain the necessary data where application rate does not exceed intake rate and sprinkler patterns are not distorted by wind.

Place a minimum of two rows of sampling cans perpendicular to the lateral lines, one row located near the sprinkler and the other midway between sprinklers or individual sprinkler settings. The spacing between sampling cans should be no more than 10 percent of the lateral line spacing. The first can from the lateral line and the last can of each row should be placed at a distance equal to one-half of the regular spacing between cans. The row of cans at the sprinkler head should be located a distance of one-half space upstream or downstream from the sprinkler. For cases where only one lateral line of sprinklers or individual giant hydraulic type sprinkler is in operation at a time, the rows of sampling cans extend each way from the lateral line for a distance about equal to the lateral spacing.

See Figure NJ 9.5 for example arrangements of sampling cans.

The sampling cans should be straight sided with thin rims. Oil cans, fruit juice cans, coffee cans or similar may be used by cutting out the tops. The cans should be placed plumb and with the top rim a minimum of 4 inches above the vegetation.

Measurement of sprinkler application should be made when climatic conditions are normal. The layout of the sampling stations may be made prior to starting the sprinklers. When this is done, the sprinklers adjacent to the sampling area should be temporarily fixed so that jets are directed away from the sampling area. When the system has developed full pressure and normal jet characteristics, the sprinklers are released and the time is noted. For convenience in determining the application rate, the duration of the test should be I hour. After 1 hour's operation, the cans are removed from the sampling area for measurement. For convenience of measurement, the water in the cans for each row may be poured into one can and measured with a rule.

When two adjacent laterals are operating simultaneously (Figure 9.IA), the total application in inches is:

$$\frac{A + B}{2N} \quad \text{(eq. 9. 1)}$$

The application rate in inches per hour is:

$$\frac{A + B}{2NH} \quad \text{(eq. 9.2)}$$

Where:

A = total accumulation in row A
B = total accumulation in row B
N = total number of cans in rows A and B
H = number of hours of test

When only a single lateral or an individual sprinkler is operating (Figures 9.lB and 9.IC), the total application in inches is:

$$\frac{A_1 + A_2 + 2(B_1 + B_2)}{\frac{N}{2}} \quad \text{(eq. 9.3)}$$

and the application rate in inches per hour is:

$$\frac{A_1 + A_2 + 2(B_1 + B_2)}{\frac{N}{2}H} \quad \text{(eq. 9.4)}$$

Where:

A_l and A_2 = total accumulation in rows A_l and A_2

B_1 and B_2 = total accumulation in rows B_1 and B_2

N total number of cans in rows A_1 , A_2 , B_1, and B_2

The above method applies to rectangular, square.or triangular sprinkler spacings.

The average application rate may be determined by measuring the discharge in gallons per minute from individual sprinklers. The average application rate in inches per hour is determined by the formula:

$$\text{application rate} = \frac{(96.3)\ (\text{gpm})}{(\text{Sm})\ (\text{S1})} \quad \text{(eq. 9.5)}$$

Where:

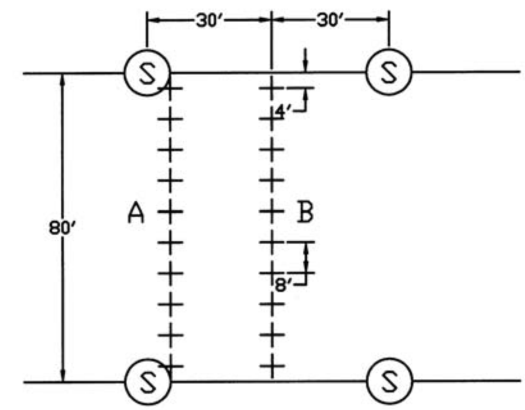
application rate is in inches per hour

gpm = measured discharge from sprinker in gallons per minute

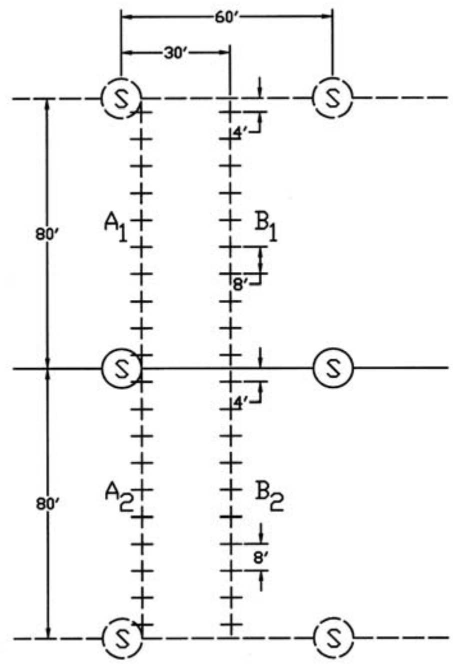
Sm = spacing of laterals along the main, in feet

S1 = spacing of sprinklers on the lateral, in feet

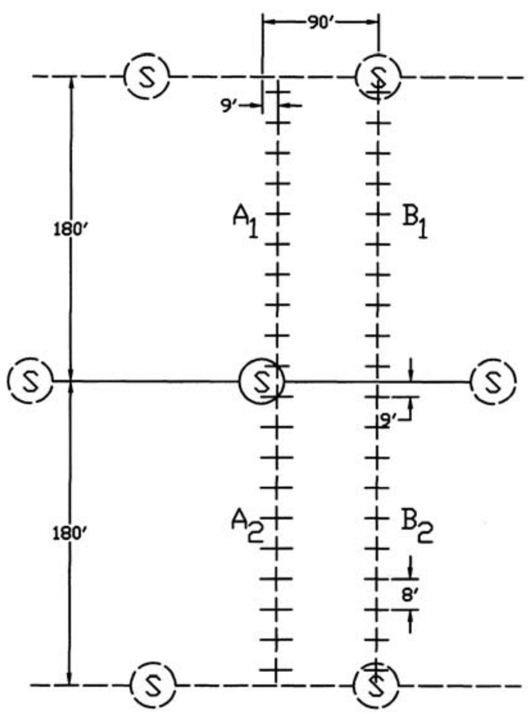
Figure NJ 9.5 Example Arrangements of Sampling Cans



Two adjacent laterals in operation
Sm = 80; S1 = 60
Figure NJ 9.5 A



Single lateral operation
Sm = 80; S1=60
Figure NJ 9.5 B



Single sprinkler operation
Sm = 180; S1 = 180
Figure NJ 9.5 C

Symbols

———	Operating lateral
(S)	Operating sprinkler
+	Sampling can
(S)	Subsequent setting, sprinkler
– – – –	Subsequent setting, lateral
A, B, A_1, A_2, B_1, B_2	Rows of sampling cans

System Evaluation:
The following guidelines can be used when evaluating sprinkler systems operating in sets. Any recommendations as a result of an evaluation must be based on good judgment and consideration of all factors involved for the specific site, including, but not limited to, the irrigator's management style, crop needs, system type, and economics:

1. Loss in mainline should not exceed 30 percent of pump pressure. Higher losses in the mainline may indicate a poor design, or damage or degradation of the system. Due consideration must be given to pressure loss because of elevation change.

2. Pressure in lateral should not vary more than 10 percent from average pressure. This will assure a minimum application rate of at least 90 percent of maximum rate.

3. Spacing of nozzles along lateral should not be more than 50 percent of the wetted diameter. Spacing of laterals should not exceed 60 percent of wetted diameter. Wider spacings are very susceptible to non-uniform water distribution caused by wind.

4. The following rule-of-thumb may be used. The average sprinkler discharge can be computed as the discharge at the first nozzle less three-fourths the difference between the first and last nozzle.

5. When the time of set is near completion, the water applied by a nozzle should disappear from the surface by the time the nozzle makes a complete revolution. This indicates that all of the applied irrigation is absorbed by the soil and no runoff occurs.

Procedure:
Determine the following by field observation and review of design data:

1. The estimated net irrigation that is needed.
2. Spacing of sprinklers and laterals.
3. Size of sprinkler nozzles.
4. Size of main and lateral lines.
5. Size of field and predominant slope.
6. Elevation differences in the system, if significant.
7. Pressure at pump. Use a pressure gage.
8. Pressure at first and last nozzle. Use pitot tube gage.
9. Pressure at, and location of, high point of line, if significant. Use pitot tube gage.
10. Maximum length of main and lateral lines.
11. Location of line in relation to field boundaries.
12. Diameter of spray pattern.
13. If application rate is exceeding soil intake rate.

Example:

1. Soil: Adelphia, with predominant 2 percent field slope. Maximum allowed application rate = 0.5 inch/hour (Table NJ 2.1). Crop is corn. Net irrigation needed is estimated to be 2.0 inches (near 50% AWC depletion, Tables NJ 2.1, NJ 3.4). (Field check)

2. Spacing of laterals is 60 feet, and sprinklers are 40 feet apart on the lateral (field observation). There are 33 sprinklers per line.

3. The sprinkler nozzles are 13/64 x 5/32 (field check).

4. The main line is 7-inch and lateral lines are 4-inch diameter (field observation).

5. Field slope is 2%.

6. Elevation difference is relatively small, about 5 feet along the lateral.

7. Pressure at pump is 60 psi (pressure gauge).

8. Pressure at first nozzle is 45 psi, pressure at last nozzle, 1300 feet from main, is 28 psi. (Pressures were measured with pitot tube gauge.)

9. Pressure at high point, 580 feet from main, (15th nozzle) is 30 psi. (Pitot tube).

10. Maximum main length is 1290 feet, lateral lines are 1300 feet maximum length. Laterals branch off of central main line. Field checks made at 990 feet from pump.

11. Main line is located in middle of irrigated area, with laterals going to edge of field.

12. Diameter of spray pattern is 100 feet at last nozzle (field observation).

13. No water remains on surface by the time the nozzle makes a complete revolution. No runoff observed. (Field observation.)

Solution:

1. Discharge from first nozzle at 45 psi pressure is 8.1 + 4.7 = 12.8 gpm. (Table NJ 6.10)

2. Discharge at high point at 30 psi pressure is 6.5 + 3.9 = 10.4 gpm. (Table NJ 6.10)

3. Discharge at last nozzle at 28 psi pressure is 6.3 + 3.7 = 10.0 gpm. (Table NJ 6.10)

4. Average discharge to high point:

   12.8 - 3/4 (12.8 - 10.4) =11.0 gpm

   Average discharge, high point to end:

   10.4 - 3/4(10.4-10.0) = 10.1 gpm

   Average sprinkler line discharge:

   $$\frac{15(11.0) + 18(10.1)}{33} = 10.5 \text{ gpm.}$$

5. Pressure variance is 45 - 23 or 17 psi. The average pressure is

   $$\frac{45 + 28}{2} = 36.5 \text{ psi.}$$

   The pressure varies 8.5 psi each way from the average or a pressure variance of

   $$\frac{8.5}{36.5} = 23 \text{ percent from average.}$$

   (Pressure variance should not exceed $\pm$ 10 percent; therefore, lateral lines are too small, item 2, page 9.5)

6. Loss in 7" main line = 14 psi for 990’ length. For 1,290’ to last lateral connection, the equivalent loss would be

   $$\frac{1{,}290 \times 15}{990} = 19.5 \text{ psi.}$$

   Maximum main line loss should be approximately 30 percent of pump pressure (page 9.5, item 1). 30% of 60 psi = 18.0 psi; therefore, main line is slightly small for optimum design but this loss is only at maximum distance and would not justify purchasing larger pipe.

7. Spray pattern diameter – 100’ (observed). Lateral spacing should not exceed 60 percent of spray pattern or more than 60 feet. Therefore, lateral line spacing is satisfactory for 40’ x 60’ spacing.

8. Maximum application rate of 12.8 gpm on 40’ x 60’ spacing is approximately 0.5”/hr. Maximum allowable rate for corn is 0.5 inch/hour. (Table NJ 2.1)

9. Minimum application rate is 10.0 gpm (last nozzle). Maximum rate is 12.8 gpm (first nozzle). Minimum rate is, therefore,

   $\frac{10.0}{12.8}$ or 78% of maximum.

   Minimum rate should be at least 90 percent of maximum. There fore, pressure loss in lateral lines is excessive.

10. Design efficiency is 6 5 percent.

11. Minimum application rate of 10.0 gpm on 40’ x 60' spacing is 0.4"/hr. To apply 2 inches net application at 65 percent efficiency would require

    $\frac{2.0}{0.4 \times 0.65}$ = 7.7 hours.

12. No runoff was noted, so application rate does not exceed soil intake rate.

Recommendations:
For more uniform application, increase lateral lines to 5 inch diameter for first 600 feet of each lateral. Economic feasibility should be determined.

Plan to irrigate on 8-hour schedule.

Center-Pivot Evaluation

Procedure:
1. Determine operating pressure at pivot and gpm entering system.

2. Calculate rate of speed and time to make circuit of field.

3. Set spray catch cans as shown in sketches below, ahead of Sprinklers so one complete pass is made over cans. Set cans level and support above the vegetation. Catch cans should be calibrated so that volumetric measurements can be made. Quart oil cans are satisfactory and these hold approximately 200 cc per inch of depth. Therefore, 10 cc would be equivalent to 0.05 inch.

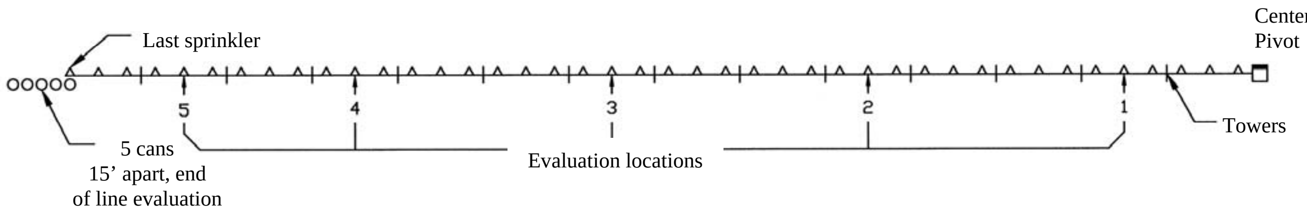
4. Observe the rate water enters the soil, particularly at the far end of the line. If there is appreciable runoff, erosion or ponding that will damage crops, the rate is too high. Record distance from pivot to point where runoff is evident.

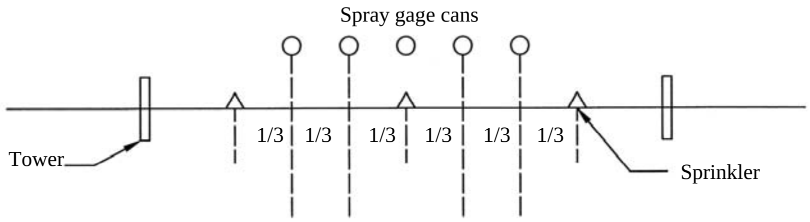
5. Determine if end gun operates on entire circle or at corners only.

6. After the discharge of the sprinklers is out of range of the cans, measure the water in each group of cans. Use a graduated cylinder that is divided into cc’s.

7. From can catch, determine:
   A. Uniformity of distribution.
   B. If applied amount will meet Peak periods use needs.

8. To make evaluation, use the following:
   A.100 gpm 0.221 acre-inch per hour
   B. Distance traveled is 6.28 times radius to drive wheel





Example:

1. Soils are Collington, with average field slope of 4 percent (from irrigation plan); maximum allowable application rate is 0.6 inch/hour (Table NJ 2.1). Field is square, 160 acres. 134 acres irrigated. (Irrigation plan).

2. Crop: Corn (field observation).

3. Operating pressure at pivot: 72#/sq. in. (Pressure gauge reading).

4. Water supplied by pump is 745 gpm (meter on system).

5. System length is 1300 feet total, 1250 feet radius to outside drive wheel (from system details).

6. Time for outside drive wheel to travel 100 feet is 85 minutes (field observation, timed).

7. Wetted diameter for sprinklers on outside sections is 100 feet (field observation).

8. End gun is used in corners only (observed).

9. Spray catch cans were set as shown in the sketch. After the system completely passed the cans, the samples were collected, recorded and averaged.

   Average catch in cans (quart oil cans were used, so 10 cc =0.05 inch):

   Group #I: 230 cc or 1.15 inches
   Group #2: 210 cc or 1.05 inches
   Group #3: 190 cc or 0.95 inches
   Group #4: 200 cc or 1.00 inches
   Group #5: 180 cc or 0.90 inches

   Cans at end of system:

   #1:200 cc or 1.00 inches
   #2:180 cc or 0.90 inches
   #3:140 cc or 0.70 inches
   #4: 90 cc or 0.45 inches
   #5: 40 cc or 0.20 inches

10. There was minor ponding observed at the outside drive wheel area, but no significant runoff was observed at any location.

Solution:

1. Rate of travel is

$$\frac{100'}{85\text{ min.}} = 1.18\text{ ft./min.}$$

2. Travel distance for 1,250 feet radius

$$6.28 \times 1{,}250 = 7{,}850\text{ feet}$$

3. Travel time for one complete circuit

$$\frac{7{,}850\text{ feet}}{1.18\text{ fpm} \times 60\text{ min.}} = 111\text{ hours or }4.6\text{ days}$$

4. Gross application: (note: 100 gpm = .0.221 acre inch/hour)

   Gross application

   $$\frac{745 \text{ gpm}}{100} \times 0.221 \text{ ac.in/hr} \times 111 \text{ hr.} = 182.8 \text{ ac.in.}$$

   A 1300 foot system covers an area of 134 acres with the gun sprinkler used in the corners only. Therefore, gross application = 182.8/134 = 1.36 inches.

5. Average catch for least catch area (except end gun) is 0.90 inch for Group #5. The travel time for one circuit is 4.6 days, so the system can supply 0.90/4.6 = 0.20 inches/day. The minimum design consumptive use rate is 0.20 inches per day for central New Jersey (pg 4-5).

6. Net application varies from 0.90 to 1.15 inches. Minimum is then 79 percent of maximum.

7. Average amount caught (net application) is 1.01 inches, or 74 percent of gross application.

8. There is no problem with runoff, so the application rate is satisfactory for this soil. Ponding at outer drive wheel area indicates application rate is near soil intake rate for the furthest out section.

Recommendation:
The irrigator should be careful to begin irrigating well before the AWC is depleted by 50 percent. The system has barely enough capacity to supply water at the consumptive use rate when operated full time, and the system takes 4.6 days to make a full circuit. This allows little margin for late starts or equipment breakdown. Application rate can not be significantly increased without causing runoff and erosion (#8 above).

<u>Micro Irrigation Field Evaluation</u>
Successful operation of micro irrigation requires that the frequency and quantity of water application be accurately scheduled. The field application emission uniformity, EU', must be known in order to manage the quantity of application. Unfortunately, EU'often changes with time; therefore, periodic field checks of system performance are necessary.

The data needed for fully evaluating a trickle irrigation system are available by determining:

1. Duration, frequency, and sequence of operation of normal irrigation cycle.
2. The management allowed deficit (MAD) and the soil moisture deficit (SMD). The soil moisture deficit is the difference between field capacity and the actual soil moisture in the root zone at any given time.
3. Rate of discharge at the emission points and the pressure near several emitters spaced throughout the system.
4. Changes in rate of discharge from emitters after cleaning or other repair.
5. The percent of soil volume wetted.
6. Spacing and size of trees or other plants being irrigated.
7. Location of emission points relative to trees, vines, or other plants and uniformity of spacing of emission points.
8. Losses of pressure at the filters.
9. General topography.

Equipment Needed
The equipment needed for collecting the necessary field data is:

1. Pressure gauge (0-50 psi range) with 'IT" adapters for temporary installation at either end of the lateral hoses.
2. A stopwatch or watch with an easily visible second hand.
3. Graduated cylinder with 250 ml capacity.
4. Measuring tape 10 to 20 ft long.

5. Funnel with 3- to 6-in diameter.

6. Shovel and soil auger or probe.

7. Manufacturer's emitter performance charts showing the relationships between discharge and pressure plus recommended operating pressures and filter requirements.

8. Sheet metal or plastic trough 3 ft long for measuring the discharge from several outlets in a perforated hose simultaneously or the discharge from a 3-ft length of porous tubing. (A piece of I- or 2-in PVC pipe cut in half lengthwise makes a good trough.)

Field Procedure
The following field procedure is suitable for evaluating systems with individually manufactured emitters (or sprayers) and systems that use perforated or porous lateral hose.

1. Record field, soil, and crop characteristics.

2. From the operator, determine duration and frequency of operation, how SMD is determined, and MAD.

3. Determine pressures at the inlet and outlet of the filter, and determine integrity of filter if possible.

4. Determine and record emitter and lateral hose characteristics, including manufacturer, sizes, types, materials, rated capacity or discharge, etc. Record the system discharge rate, if the system is equipped with a water meter. Sketch the system layout and note the general topography, manifold in operation and manifold where the discharge test will be conducted. Try to select a manifold which appears to have the greatest head differential for evaluation.

5. Locate four emitter laterals along the manifold; one should be near the inlet and two near the "third" points, and the fourth near the outer end.

6. For laterals having individual emitters, measure the discharge at two adjacent emission points at each of four different tree or plant locations on each of the four selected test laterals. Collect the flow for a number of full minutes (1, 2, and 3, etc.) to obtain a volume between 100 and 250 ml for each emission point tested. To convert ml per minute to gallons per hour (gph), divide by 63. Compute the average discharge for each pair of emission points.

   These steps will produce eight pressure readings and 32 discharge volumes at 16 different plant locations for- individual emission points used in widespaced crops with two or more emission points per plant.

   For perforated hose or porous tubing, use the 3-ft trough and collect a discharge reading at each of the 16 locations described above. Since these are already averages from 2 or more outlets, only one reading is needed at each location.

   For relatively wide-spaced crops such as grapes where one single outlet emitter may serve one or more plants, collect a discharge reading at each of the 16 locations described above. Since the plants are only served by a single emission point, only one reading should be made at each location.

7. Measure and record the water pressures at the inlet and downstream ends of each lateral tested in step 6 under normal operation. On the inlet end, this may require disconnecting the lateral hose, installing the pressure gauge, and reconnecting the hose before reading the pressure. Some systems are equipped with tire valve stems at the inlet end and pressure can be read with the use of portable gauge. On the downstream end, the pressure can be read after connecting the pressure gauge the simplest way possible.
8. Check the percentage of the soil that is wetted at one of the tree or plant locations

on each test lateral and record. It is best to select a tree or plant at a different relative location on each lateral. Use the probe, soil auger, or shovel -whichever seems to work best - for estimating the area of the wetted zone in a horizontal plane about 6 to 12 inches below the soil surface around each plant. Determine the percentage wetted by dividing the wetted area by the total surface area represented by the plant.

9. If an interval of several days between irrigations is being used, check the soil moisture deficit in the wetted volume near a few representative plants in the next area to be irrigated and record it. This is difficult and requires averaging samples taken from several positions around each plant.

10. Determine the minimum lateral inlet pressure, MLIP, along each of the operating manifolds and record. For level or uphill manifolds, the MLIP will be at the far end of the manifold. For downhill manifolds, it is often about two-thirds down the manifold. For manifolds on undulating terrain, it is usually on a knoll or high point. When evaluating a system with two or more operating stations, the MLIP on each manifold should be determined. This will require cycling the system. Compute the system average MLIP.

11. Determine the discharge correction factor, DCF, to adjust the average emission point discharges for the tested manifold. This adjustment is needed only if the tested manifold happened to be operating with a higher or lower MLIP than the system average MLIP. If the emitter discharge exponent, x, is known, use equation 9.6. Otherwise use equation 9.7.

$$DCF = \left(\frac{\text{average MLIP}}{\text{test MLIP}}\right)^x \qquad \text{(eq. 9.6)}$$

$$DCF = \frac{2.5 \times (\text{average MLIP})}{(\text{average MLIP}) + 1.5 \times (\text{test MLIP})} \qquad \text{(eq. 9.7)}$$

12. Determine the average and adjusted average emission point discharges according to equations 9.8 - 9.11.

Test manifold emission point discharges:

Test manifold average

$$= \frac{\text{(sum of all averages)}}{\text{(number of averages)}} \qquad \text{(eq. 9.8)}$$

Manifold low 1/4 average

$$= \frac{\text{(sum of low 1/4 averages)}}{\text{(number of low 1/4 averages)}} \qquad \text{(eq. 9.9)}$$

Where the "averages" are the average discharges of the emitter pairs computed in Step 6. The "low 1/4 averages" are the average discharges of the lowest 25% of the emitter pair discharges.

Adjusted average emission point discharges for system:

q_a = System average discharge = (DCF) x (Test Manifold Average) (eq. 9.10)

q_n = System low 1/4 average = (DCF) x (Manifold Low 1/4 Average) (eq. 9.11)

Utilization of field data

In trickle irrigation, all the system flow is delivered to individual trees, vines, shrubs, or other plants. Essentially, there is no opportunity for loss of water except at the tree or plant locations. Therefore, uniformity of emission is of primary concern, assuming the crop is uniform. Locations of individual emission points, or the tree locations when several emitters are closely spaced, can be thought of in much the same manner as the container positions in tests of sprinkler performance.

Average application depth. The average depth applied per irrigation to the wetted area, D_{aw}, is useful for estimating MAD.

$$D_{aw} = \frac{1.604\, e_n\, q_a T_a}{A_w} \qquad \text{(eq. 9.12)}$$

where:

D_{aw} is the average depth applied per irrigation to the wetted area (in.)
e_n is the number of emission points per tree or plant.
q_a is the adjusted average emission point discharge of the system from equation 9.10.
T_a is the application time per irrigation (hrs).
A_w is area wetted per tree or plant from Step 8 above, (ft2).

The average depth applied per irrigation to the total cropped area can be found by substituting the plant spacing, Sp X Sr, for the wetted area, Aw, in eq. 9.12.

Therefore:

$$D_a = \frac{1.604\ e_n\ q_a\ T_a}{S_p \times S_r} \quad \text{(eq. 9.13)}$$

in which:

D_a is the average depth applied per irrigation to the total cropped area (in)

S_p and S_r are plant and row spacing, ft.

Volume per day. The average volume of water applied per day for each tree or plant is:

$$G = \frac{e_n\ q_a\ T_a}{F_i} \quad \text{(eq. 9.14)}$$

in which

G is the average volume of water applied per plant per day (gal/day)

Fi is the irrigation interval (days)

Emission Uniformity. The actual field emission uniformity, EU', is needed to determine the system operating efficiency and for estimating gross water application requirements. The EU' is a function of the emission uniformity in the tested area and the pressure variations throughout the entire system. Where the emitter discharge test data is from the area served by a single manifold:

$$EU'm = \frac{100}{q_a} q_n \quad \text{(eq. 9.15)}$$

in which EU'm is the field emission uniformity (percent) of the manifold area tested and q_a and q_n are from equations 9.10 and 9.11.

Some trickle irrigations systems are fitted with pressure compensating emitters or have pressure or flow regulation at the inlet to each lateral. Some systems are only provided with a means for pressure control or regulation at the inlets to the manifolds, others are provided with regulators at each lateral. If the manifold inlet pressures vary more than a few percent (due to design and/or management), the overall EU' (of the system) will be lower than EU'm (of the tested manifold). An estimate of this efficiency reduction factor (ERF) can be computed from the minimum lateral inlet pressure along each manifold throughout the system by:

$$ERF = \frac{\text{average MLIP} + (1.5\ (\text{minimum MLIP}))}{2.5\ (\text{average MLIP})} \quad \text{(eq. 9.16)}$$

in which

ERF is the efficiency reduction factor

MLIP is the minimum lateral inlet pressure along a manifold (psi)

Average MLIP is the average of the individual IMLIP along each manifold (psi)

Minimum MLIP is the lowest lateral inlet pressure in the system (psi)

A more precise method for estimating the ERF can be made by:

$$ERF = ((\text{minimum MLIP})/(\text{average MLIP}))^x \quad \text{(eq. 9.17)}$$

where x is the emitter discharge exponent.

The ERF is approximately equal to the ratio between the average emission point discharge in the area served by the manifold with the minimum MLIP and the average emission point discharge for the system. Therefore, the system EUI can be approximated by:

$$EU' = ERF \times EU'm \qquad \text{(eq. 9.18)}$$

General criteria for EUI values for systems which have been in operation for one or more seasons are: greater than 90%, excellent; between 80% and 90%, good; 70 to 80%, fair; and less than 70%, poor.

Gross application.required.. Since trickle irrigation wets only a small portion of the soil volume, the SMD must be replaced frequently. It is always difficult to estimate SMD because some regions of the wetted portion of 'the root zone often remain near field capacity even when the interval between irrigation is several days. For this reason, SMD must be estimated from weather data or information derived from evaporation devices. Such estimates are subject to error and, since there is no practical way to check for slight underirrigation, some margin for safety should be allowed. As a general rule, the minimum gross depth of application, I_g , should be equal to (or slightly greater than) the values obtained by eq. 9.19.

$$I_g = \frac{I_n \times T_r}{EU'/100} \qquad \text{(eq. 9.19)}$$

in which

I_g is the gross depth per irrigation, inches

T_r is the peak use period transpiration ratio

EU' is the emission uniformity, percentage

I_n is the net depth to be applied per irrigation, inches.

The Tr is the ratio of the depth of water applied (total needed) to the depth of water transpired during the peak use period. It represents the extra water which must be applied, even during peak use period, to offset unavoidable deep percolation losses. These losses are due to excess vertical water movement below the active root zone which is unavoidable in porous and shallow soils when sufficient lateral wetting is achieved. With efficient irrigation scheduling and for design purposes, use the following peak use period T_r values:

I. T_r = 1.00 for deep (greater than 5 ft) rooted crops on all soils except very porous gravely soils; medium (2.5 to 5 ft) rooted crops on fine and medium textured soils; and shallow rooted (less than 2.5 ft) on fine textured soils.

II. T_r = 1.05 for deep rooted crops on gravely soils; medium rooted crops on coarse textured (sandy) soils; and shallow rooted crops on medium textured soils.

III. T_r = 1.10 for medium rooted crops on gravely soils; or shallow rooted crops on coarse textured soils.

Simplified Irrigation System and Water Management Evaluation

Some simple evaluation items can be done by irrigation system operators that will help them make management and operation of irrigation equipment decisions. They include:
Item 1-For sprinkler and micro irrigation system, they can check:

- Operating pressures at pump, mainline, sprinkler heads, upstream and downstream of filters to assure they match design.
- Application depth for the irrigation set by using a few 3- to 4-inch random placed, straight sided, vegetable or fruit tin containers for catch containers. Measure water depth in catch containers with a pocket tape. Does it match design and what is desired?
- Discharge from a few microsystem emitters using a one-quart container and a watch. Do not raise emitter more than a few inches. Compute flow in gallons per hour. Do flows match design?
- Translocation and runoff from sprinkler systems.

Item 2-For all irrigation systems, simplified field checking by the operator can include calculation of depth of irrigation for a set using the basic equation,

$$QT = DA.$$

where:
Q = flow rate (ft^3/S)
T = time of irrigation application (hr)
D = gross depth of water applied (in)
A = area irrigated (acres)

Item 3-Using a probe, shovel, soils auger, or push type core sampler, the operator can put down a few holes after an irrigation to determine depth of water penetration. Does it match plant rooting depths? Depending on the irrigation system and soil, checking on water penetration could be anywhere from an hour after the irrigation to the next day.

Item 4-Check runoff. Is it excessive? Does it contain sediment?

Abbreviated Water Management and Irrigation System Evaluations

An abbreviated evaluation can determine whether a problem exists in a field and how serious it may be. Such an evaluation should always precede a more detailed evaluation. With some guidance the irrigation decision maker can perform abbreviated system evaluations themselves. Many times, needed changes can be identified in less than an hour. Refer to National Irrigation Guide, Chapter 9.