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Irrigation Water Management Considerations for Sandy Soils in Minnesota

by
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The following publications related to irrigated crop production can be requested through the county offices of the Minnesota Extension Service or from the Distribution Center, 3 Coffey Hall, 1420 Eckles Ave., University of Minnesota, St. Paul, MN 55108.

AG-FO-2392, *Managing Nitrogen for Corn Production on Irrigated Sandy Soils*
AG-FO-3425, *Potato Fertilization on Irrigated Soils*
AG-FO-3769, *Providing Proper N Credit For Legumes*
AG-FO-3770, *Understanding Nitrogen In Soils*
AG-FO-3774, *Nitrification Inhibitors And Use In Minnesota*

Irrigation Water Management Considerations for Sandy Soils in Minnesota

Most of the irrigated acreage in Minnesota consists of highly permeable, low water holding capacity, sandy textured soils overlying surficial (shallow) and buried sand and gravel aquifers. Figure 1 locates most of these aquifers in the state's glacial outwash sand plains. Most homeowners and farmers in these areas get their drinking water as well as livestock and irrigation water from these aquifers.

If not properly managed, the surficial aquifers are very susceptible to non-point water quality degradation from land use practices. These aquifers are recharged annually by snow melt and rainfall. The water table of these aquifers typically is 6-15 feet below the land surface. Some of the ground water may flow into streams and rivers while some percolates deeper recharging underlying buried aquifers.

Irrigating sandy soils requires increases in fertilizer and pesticides for most crops to produce a maximum economic (profitable) yield. Nitrogen fertilizer and certain pesticides when applied to sandy soils have the potential to move downward (leach) in the soil profile, possibly into the ground water.

The Minnesota departments of agriculture and health report that some wells (domestic and observation) in the cultivated outwash sand plains region contain elevated levels of nitrates and detectable amounts of agricultural pesticides.

This is one of the reasons that the timing and amount of irrigation water applied are crucial decisions for each operator. Applying too much water means increased pumping costs, reduced water efficiency, and increased potential for nitrates' and pesticides' leaching below the rooting zone and into the ground water. Delaying an irrigation until plant stress is evident can result in economic yield loss and, consequently, poor use of some agrichemicals. Some under utilized chemicals are then subject to even greater leaching potential after the growing season when the greatest soil recharge events from rainfall usually occur.

This publication describes some "best" soil moisture management strategies and monitoring techniques that an irrigating farmer should consider in managing irrigation water and soil moisture for optimum crop production and least possible degradation of ground water quality. Information on best nitrogen and pesticide management practices for irrigated crops is discussed in several publications of the Minnesota Extension Service.

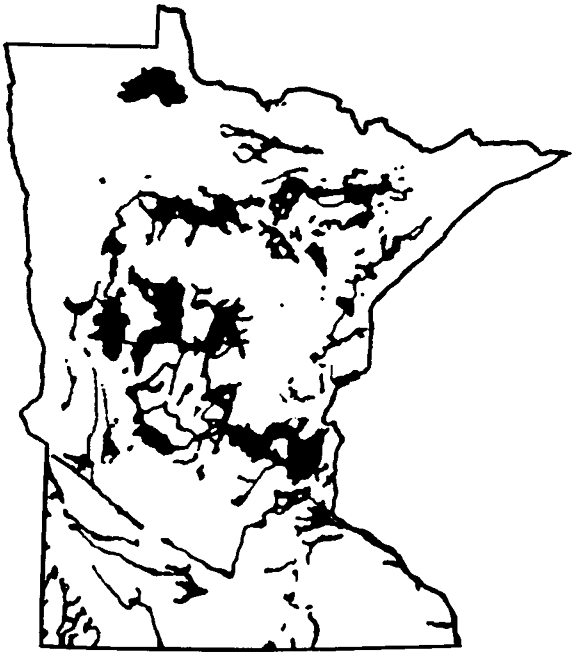

Figure 1. Map of Surficial Aquifers in Minnesota.

IRRIGATION WATER SCHEDULING

Irrigation water management or scheduling involves more than just turning on the machine because it has not rained for a few days or the neighbor is irrigating. Irrigation scheduling is a decisionmaking process to determine when and how much water to apply to a growing crop to meet specific management objectives (Rogers, 1989). To be successful requires the blending of the latest scientific information, technologies, and personal irrigation experiences into an effective and sound water management program.

A sound irrigation scheduling program can help an operator:

- prevent economic yield losses due to moisture stress.
- maximize efficiency of production inputs.
- minimize leaching potential of nitrates and other agrichemicals below the rooting zone.
- conserve the water resource and maximize its beneficial use.

Leaching of chemicals cannot be totally eliminated by proper irrigation scheduling, according to some specialists (Kranz, 1989; Fishbach et al., 1988; Ritter et al., 1988; Hergert, 1986; and Ritter, 1986). For example, if a significant rainfall occurs shortly after an irrigation, the excess water will percolate deep in the soil and may carry some agrichemicals below the root zone. Likewise, large rainfall during the off-season may leach some agrichemicals that remain in the root zone. It is estimated that 70-80 percent of the annual recharge to surficial ground water in central Minnesota occurs after harvest and before planting (personal communication with Nieber, 1989). Figure 2 shows the normal monthly corn crop water use rates and respective precipitation for west central Minnesota. Months where rainfall is significantly larger than crop use indicate highest potential for ground water recharge and possible leaching of agrichemicals.

Effective irrigation is possible only with regular monitoring of soil-water-plant conditions in the field, predicting future crop water needs, and following the best recommended water management strategies. This also requires a basic understanding of soil-water-plant relationships and soil moisture monitoring techniques.

To set up and operate an effective irrigation scheduling program these sequenced procedures need to be followed for each field:

1. Determine the crop's active rooting depth and the corresponding available water-holding capacity for each soil type in the field.
2. Select the predominant soil type(s) that should be used for irrigation water management purposes.
3. Define the allowable soil water depletion limits for the selected soil types and the crop(s) to be grown.
4. Establish a soil moisture monitoring system and regularly (at least twice a week) keep track of the soil water deficit.
5. Initiate an irrigation when the soil water deficit is expected to approach the selected allowable soil water depletion limit by the time the irrigation cycle is completed.

A brief discussion of each of these steps is presented later in this publication. This procedure typically takes 5 to 20 minutes of the operator's time daily to keep updated after determining the initial soil water characteristics. If operator time is not available to regularly monitor the soil moisture, consider finding a crop consultant to assist in achieving the management objectives.

AVAILABLE WATER IN ROOT ZONE

The frequency and application depth of irrigations depend heavily on the amount of soil water available to the crop's roots.

In most fields there are several soil types and the irrigation manager should review the available water-holding capacity of each type. The irrigation system should be managed to meet the crop water needs from the soil type covering at least 30 percent of the field and having the lowest available water-holding capacity.

County soil surveys identify soil types and available water-holding capacity for most fields. County personnel from the Soil and Water Conservation District (SWCD), Soil Conservation Service (SCS), or Minnesota Extension Service (MES), University of Minnesota, can help determine the soil water storage characteristics.

Available soil water capacity is that portion of the total soil water available for plant use. The maximum amount of available water stored in the soil, soil texture, soil's available water-holding capacity, and the crop's rooting depth are all related. Table 1 shows typical irrigation management rooting depths for several common crops.

Table 1. Crop rooting depths for irrigation water management

Crop	Depth (inches)
Alfalfa (established)	48
Corn, sugar beet	36
Sweet corn, asparagus	24-36
Potato, small grain	24
Soybean, field bean	24
Tomato, muskmelon	12-24
Broccoli, cauliflower	12-18
Blueberry, strawberry	12-18

Tables 2 and 3 show examples of the available water-holding capacity of two typical irrigated soils. In table 2 note that at a depth of 18 inches there is a root restricting layer of gravel and sand which limits the available water capacity at 3.5 inches for any crop having rooting potential of 18 inches or greater. In table 3 the soil profile allows plant roots to go much deeper. However, for most irrigated crops only the top

Table 2. Available Water Capacity (AWC) of a Renshaw Soil Series

Profile Depth inches	Texture class	AWC-Inches per inch	per zone	cumm.
0-12	Loam	.21	2.52*	2.52
12-18	Sandy Loam	.16	.96	3.48
18-60	Sand and Gravel	.02	.84	4.32

*calculated by multiplying 12" x .21 inches per inch = 2.52"

Table 3. Available Water Capacity (AWC) of a Hubbard Soil Series

Profile Depth inches	Texture class	AWC-Inches per inch	per zone	cumm.
0-12	Sand	.09	1.08	1.08
12-24	Sand	.06	.72	1.80
24-36	Sand	.06	.72	2.52
36-60	Sand	.06	1.44	3.96

2-3 feet would be managed and this would yield an available water capacity of 1.8-2.5 inches for this soil.

The second purpose for determining available water capacity within a field is to establish maximum allowable soil water depletion limits for managing the soil moisture and irrigation system. This is described later.

SOIL WATER DEFICIT

Soil water deficit is the amount of available water removed from the soil within the crop's active rooting depth. Likewise it is the amount of water required to refill the root zone to bring the current soil moisture conditions to field capacity. Soil water decreases as the crop uses water (evapotranspiration) and increases as precipitation (rainfall or irrigation) is added. Expressed in soil water deficit, evapotranspiration increases the deficit and precipitation decreases it. It is usually expressed in inches of water and can be estimated by several methods described later.

ALLOWABLE SOIL WATER DEPLETION

Allowable soil water depletion limits specify the maximum amount of soil water the irrigation manager chooses to allow the crop to extract from the active rooting zone between irrigations. Only a portion of the available water capacity is easily used by the plant before crop water stress develops.

This depletion limit differs among crops and should be varied with crop growth stages. That reduces the probability of moisture stress during critical growth periods and the leaching potential when mild stress can be tolerated or there is a high probability of rainfall.

Historically, irrigations have been planned to prevent the soil water deficit from exceeding 50 percent of the total available water capacity in the rooting zone. But recent research states that the depletion limit can be varied to optimize the field's production depending on the crop, stage of growth, soil water capacity, and the irrigation system's pumping capacity. ***Specific recommendations for some Minnesota crops are discussed in more detail later.***

Allowable depletion is usually expressed as a percentage of the total available water capacity in the rooting zone. It needs to be converted to inches of soil water for a specific crop and soil situation. To convert depletion percentage to inches of water, multiply the given depletion percentage by the total available water in the root zone. For example, if a 30 percent depletion limit is desired for a soil holding 3.50 inches of water, the depletion level in inches of soil water would be 1.05 inches (.30 x 3.50 = 1.05 inches).

RECOMMENDED ALLOWABLE WATER DEPLETION MANAGEMENT STRATEGIES

Table 4 lists recommended allowable soil water depletion limits and management strategies for several irrigated crops grown in Minnesota. These recommendations result from several research projects in the North Central states and published guidelines from other states.

Table 4. Recommended allowable soil moisture depletion limits by crop growth stage

	— — — — Crop stage of growth — — — — Early Mid-Season Late allowable soil moisture depletion percentages
Corn	Emerg 12 leaf Pollination E.Dent Maturity 10* → 70 → 50 → 40 → 50 → 60 → 70
Potatoes	Emerg Tuber Yield formation initiation bulking Ripening 10* → 60 → 40 → 30 → 40 → 65
Soybeans	1st Emerg Flower Full Pod Maturity 10* → 65 → 60 → 50 → 50 → 70
Edible beans	Auxiliary budding Podfill Maturity 10* → 65 → 50 → 40 → 50 → 70
Small grain	1st Node Flowering Milk Maturity 10* → 60 → 50 → 40 → 50 → 70

* 10% depletion at this period refers to only the seed germination zone.

Source: adapted from the results of several research projects in the north central states and published guidelines from other states (Dorn et al., 1989–Nebraska; Stegman, 1988–North Dakota; Fishbach et al., 1988–Nebraska; Curwen et al., 1985–Wisconsin)

Here are some guidelines to consider in developing a management plan and setting allowable depletion limits. **In the spring**, always make sure the soil in the germinating seed zone and deeper is uniformly moist when crop planting begins. If necessary, irrigate to wet this zone. A dry soil layer below the seed will restrict root development and result in a shallow rooting depth. For corn, the soil water deficit can be allowed to reach 70 percent depletion during the vegetative growth stage up to the 10th-12th leaf under average weather conditions without affecting plant development. If irrigation is needed then, apply a lighter than normal application (0.5-0.7 inches) to partially refill the soil water deficit.

This strategy maximizes the use of rainfall while minimizing the leaching potential of agrichemicals in the soil profile. If irrigation keeps the soil moisture near field capacity, normal rainfall could result in significant leaching of some chemicals. May and June generally produce more rainfall than evapotranspiration for most crops and this also coincides with most agrichemical application events. Figure 2 compares the normal monthly crop water use pattern for corn with the respective monthly precipitation amount for west central Minnesota.

As a crop nears **mid-season**, typical period for most crop's critical growth stages and the peak crop water use, reduce the allowable water depletion limit to minimize the risk of plant moisture stress and subsequent economic yield losses. For most crops, this may mean setting a 30-40 percent depletion limit. Reduction in allowable depletion should start ahead of the crop's critical growth stage. For corn this is pollination and the recommended period of transition for reducing the depletion limit begins at the 12th leaf stage (table 4).

During these critical periods of high crop water demands, project the next three to four days' water needs regularly to avoid stressing any part of the field before irrigating. For example, if a center pivot takes three days to travel the field, project what the soil water deficit will be in three days and use this to determine when to start irrigating. To reduce the leaching potential of rainfall, always consider the weather forecast for the next couple of days in scheduling the next irrigation.

As most crops near **maturity**, the soil water depletion may be allowed to increase to greater limits without causing stress. For example, after corn kernels have begun to dent, research shows that allowing the soil water depletion to increase to 70 percent does not reduce yield. This approach allows greater storage of the late rains in the soil profile and reduces possible leaching.

For irrigation systems with limited pumping capacities on sandy soils (less than 5 gallons per minute per acre) water management alternatives become more restrictive over the season. For example, research with irrigated corn in west central Minnesota shows that to reduce the risk of stress, set the allowable depletion to no more than .75 inch starting in mid-vegetative stage (Bergsrud et al., 1982). For corn this is from the 8th-10th leaf stage and continuing until late dent. This approach increases the potential for leaching due to normal rainfall but is necessary to avoid stress during peak use periods. To minimize leaching, follow the latest weather forecasts closely before irrigating.

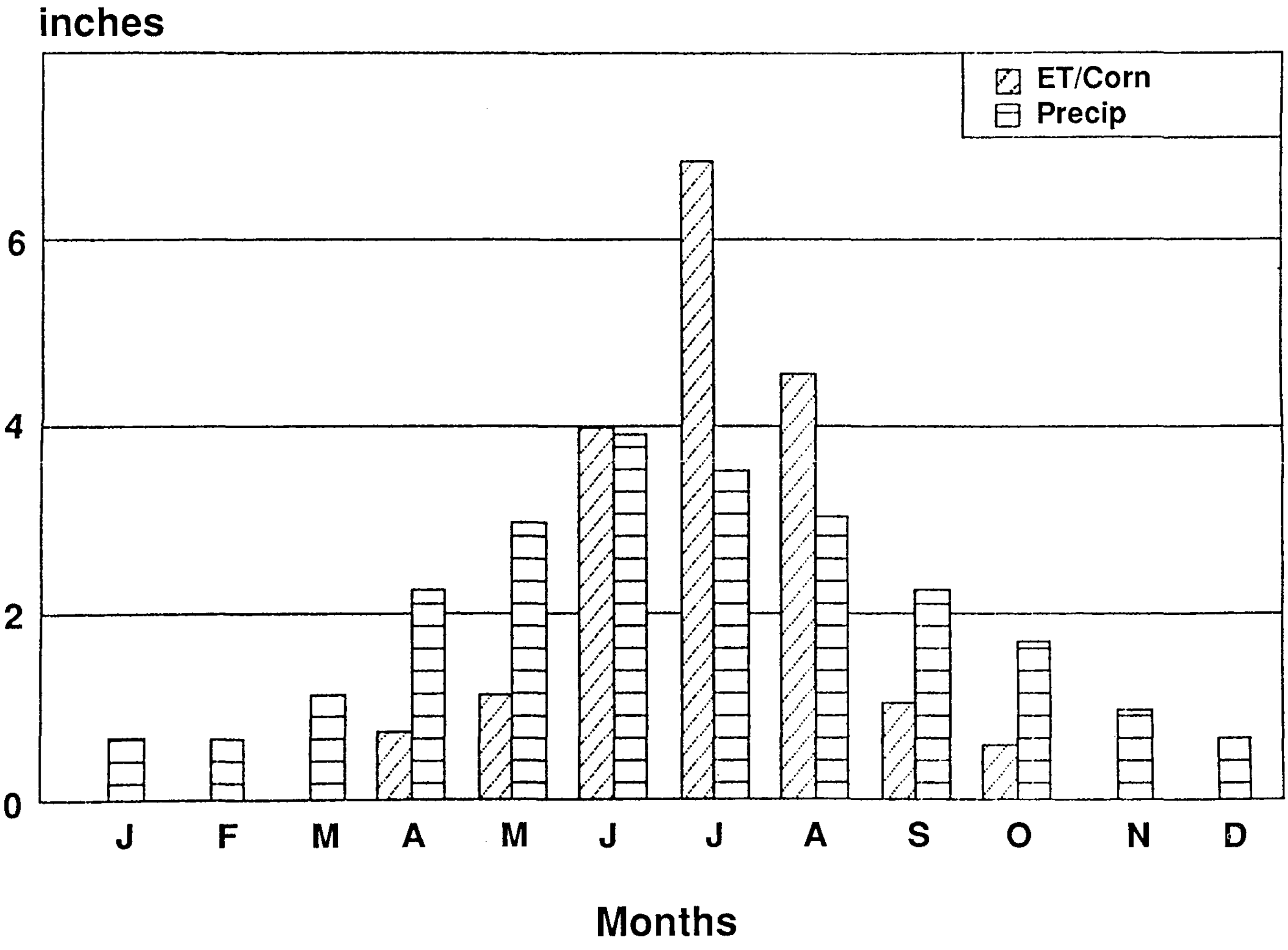

Figure 2. Normal Monthly Corn Crop Water Use and Precipitation Rates for West Central Minnesota.

IRRIGATION WATER DEPTH

It is desirable to have the amount of irrigation water applied be somewhat less than the actual soil water deficit to allow some storage reserve for rainfall. During early plant growth the irrigation depth should be 30-50 percent of the soil water deficit. Use this practice also for most crops during the last two to three weeks before maturity. This approach reduces possible leaching from normal rainfall events.

During the crop's critical growth periods, set the irrigation depth at 60-100 percent of the current soil water deficit depending on the normal operation of the irrigation system. Most center pivot systems obtain greatest water efficiency with 0.75-1.50 inch application depths.

CROP WATER USE

Crop water use is the amount of soil water released to the atmosphere from soil surface evaporation and plant leaf transpiration. This is also called evapotranspiration or ET. It is usually expressed in inches per day or per season. Weather and crop development affect daily crop water use throughout the growing season. Figure 3 shows a typical daily water use pattern for corn in central Minnesota.

Yield of most crops is directly related to seasonal ET and especially transpiration. If plant transpiration is limited, yield usually decreases proportionally. Transpiration may decrease whenever the soil water deficit exceeds the recommended allowable soil water depletion limits. Daily crop water use can be estimated by several methods such as the evaporation pan, Jensen-Haise ET model, or temperature-based ET tables. Each of these methods is discussed later.

SOIL WATER MONITORING TECHNIQUES

The status of the soil water for an irrigated crop needs monitoring regularly to assist the irrigation manager in making irrigation decisions.

Several soil water monitoring methods exist to assist in scheduling. The recommended method is a combination of an in-field monitoring and a daily soil water accounting system like the University of Minnesota's Extension Service ''Irrigation Scheduling Checkbook Method'' (AG-FO-1322). If there isn't time to conduct a regular monitoring program, hire a crop consultant to monitor soil moisture. Brief descriptions of several available monitoring methods follow:

Soil Feel and Appearance. This involves soil sampling from several layers in the root zone and estimating the soil water deficit from soil feel and appearance. Table 5 gives a brief description of how some soil textures feel and appear for various soil moisture conditions. Take samples with a probe or shovel every 6 inches and add individual deficit estimates to determine the total soil water deficit. This method is fairly accurate but requires some field experience to learn the art of estimating consistently.

Soil Water Sensors. Sensors measure such items as soil tension or electrical resistance when placed in the soil profile. Several types of sensors exist. Laboratory developed charts like table 6 convert readings from sensors to soil water deficit values.

Soil tension or suction indicates the energy required by plant roots to extract water from soil particles. As soil water is removed its soil tension increases. Tension relates directly to soil water content. Soil tension is expressed in centibars or bars of atmospheric pressure.

Some sensors are portable but those field-placed for the season give best results, allowing soil water measurement at the same location throughout the season. Sensors are typically placed in pairs at one third and two thirds depth of the crop root zone and at

Table 5. Guide for judging soil water deficit based on feel and appearance

	Soil texture classification		
Soil moisture deficiency	Loamy sand	Sandy loam	Loam
(numbers indicates inches of water deficit per foot of soil)			
0-25%	Tends to stick together slightly, sometimes forms a very weak ball under pressure. 0.0–.30"	Forms weak ball, breaks easily, will not stick. 0.0–0.40"	Forms a ball, is very pliable, slicks readily if relatively high in clay. 0.0–0.60"
25–50%	Tends to stick together slightly, crumbles easily, will not form ball. 0.3–0.60	Tends to ball under pressure but seldom holds together. 0.4–0.90	Forms a ball, somewhat plastic, will sometimes slick slightly with pressure. 0.6–1.10
50–75%	Appears to be dry, will not form a ball with pressure. 0.60–1.00	Appears to be dry, will not form a ball. 0.90–1.30	Somewhat crumbly but holds together from pressure. 1.10–1.60
75–100%	Dry, loose, single grained, flows through fingers. 1.00–1.30	Dry, loose, flows through fingers. 1.30–1.80	Powdery, dry, some times slightly crusted but easily broken. 1.60–2.10

Adapted from Israelsen and Hansen, Irrigation Principles and Practices, 3rd Edition.

Table 6. Soil water deficit in inches per foot of soil for various tensions

	Soil tension–centibars						
Soil texture	10	30	50	70	100	200	1500*
Coarse sands	0	0.1	0.2	0.3	0.4	0.6	0.7
Fine sands	0	0.3	0.4	0.6	0.7	0.9	1.0
Loamy sands	0	0.4	0.5	0.8	0.9	1.1	1.4
Sandy loams	0	0.5	0.7	0.9	1.0	1.3	1.7
Loams	0	0.2	0.5	0.8	1.0	1.6	2.2

*Soil deficit at 1500 cbs is equal to total available soil water capacity.

two or more locations in the field. The most common sensors are discussed in the following.

- *Tensiometer* sensors are made from a porous ceramic tip sealed to the base of a water-filled plastic tube, sealed at the top with a removable air tight cap. A vacuum gauge connected to the tube measures the soil tension. Tensiometers work best for sandy soils because the vacuum gauge is only effective up to 80 centibars—equivalent to 50 to 70 percent soil water depletion for these soils. Tensiometers require more preparation time and maintenance than electrical sensors.

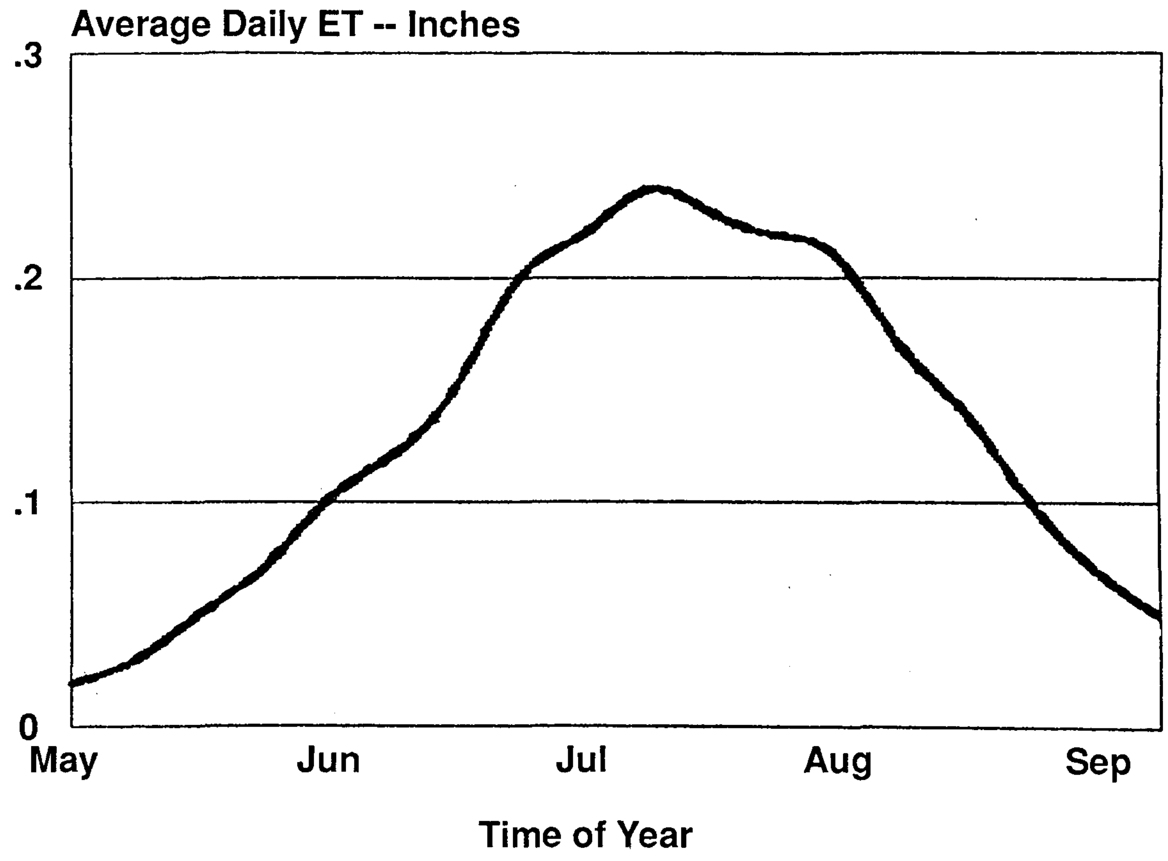

Figure 3. A Typical Crop Water Use Pattern for Corn in Central Minnesota.

- *Electrical resistance sensors* indirectly estimate soil tension by measuring the electrical resistance between two wire grids embedded in a block of gypsum, plaster, or a special material which maintains its moisture content in equilibrium with adjacent soil. The electrical resistance within the block varies with soil water content. A manufacturer's calibration curve converts the reading to soil tension. Then table 6 is used to estimate a soil water deficit for the specific soil. Some sensor models are more sensitive in the 0-100 centibars tension range which is a benefit for sandy textured soils. Resistance blocks require little preparation before installation and require no maintenance during the season.
- *Heat dissipation sensors* are similar to the electrical resistance sensor but employ the principle of heat dissipation to estimate water content within a porous ceramic block. The rate of heat dissipation in the block is directly related to soil water tension. Sensors can read from saturation to over 300 centibars. These sensors are more expensive because the manufacturer individually calibrates them.

Soil Water Accounting. This method estimates the current soil water deficit from daily inputs of rainfall, irrigation depths, and estimated daily crop water use (ET). The daily accounting process is computed on a balance sheet like in a checkbook. Field gauges measure rainfall and irrigation amounts in the field. Depending on what weather data are available, estimate daily crop water use (ET) values by ET tables or research based models.

ET tables give estimates of daily crop water use (ET) for different growth stages (for example, days after emergence) based on average weather conditions for a given region. ET tables exist for several field crops (for example, corn, potatoes, soybeans) grown in central Minnesota. Minnesota tables estimate daily ET by week after emergence and the maximum daily air temperature. Look for them in the "Irrigation Scheduling Checkbook Method" publication referred to on page 5. Minnesota tables tested out quite accurate in most years but still recommended is bi-weekly field verification of the estimated soil water deficit.

ET models are research-based empirical equations that estimate the daily potential ET for full cover grass or alfalfa crop using specific weather measurements such as solar radiation, temperature, humidity, and wind. To estimate potential ET for other crops, a correction factor is applied called a crop coefficient, which varies by growth stage. These crop coefficients are research developed and are specific to both crops and geographic regions.

There are several ET models available, such as Penman, modified Penman, Jensen-Haise, etc. In Minnesota the modified Jensen-Haise ET model gives reasonable success when used with crop coefficients developed by North Dakota researchers (Stegman et al., 1977).

ET models are most effective when incorporated into a user friendly computer program that allows the user to modify the crop coefficients and input weather and soil data. Several private and public computer software programs are available (Wisconsin–Curwen and Massie, 1986; North Dakota–Stegman and Coe, 1984).

Water evaporation devices such as the U.S. Weather Bureau class A pan can estimate daily crop ET when appropriate research-based crop specific correction factors are available. Crop curves have been published for a few crops in Minnesota but limited research has been done in developing curves (Seeley and Spoden, 1982). Farmers in western states have used in-field evaporation devices such as a wash tub or modified atmometer, but Minnesota experience has not produced consistent results.

Other Methods. There are several other methods available for helping an operator monitor soil moisture in the field but most are either too expensive or lack sufficient calibration for Minnesota use. Some of these include:

Neutron probe measures the actual soil moisture at various depths with a radiation source. The operator must be licensed and receive special training to use this. The unit is expensive and requires a lot of time to make field readings.

Infrared thermometer measures the temperature of the plants' leaves. Research shows that the leaf canopy to air temperature difference for a given crop, coupled with several other weather factors, can be related to the soil moisture stress the plant is experiencing at measurement time. This device is generally packaged with several other sensors and a small computer that can be carried to the field. The unit should be used only during full sunshine (11 a.m.-2 p.m.) for accurate measurements. The system is working well where cloud free days predominate and sufficient research data are available.

SUMMARY

An effective irrigation water management program is needed to produce efficient and profitable yields for an irrigated crop and to minimize the potential risks of leaching of some agrichemicals into the ground water. Excessive irrigation is likely to cause some agrichemicals to leach into the underlying ground water.

Several irrigation scheduling and soil water monitoring methods are available to assist the irrigating farmer in managing a crops' soil water needs and knowing when to irrigate. If the irrigation operator hasn't time to regularly monitor soil water status in the field for water scheduling, hire an irrigation crop consultant to assist in achieving an effective irrigation water management program.

Obtain more information on irrigation water management practices from personnel in the county offices of the Minnesota Extension Service, Soil and Water Conservation District, and Soil Conservation Service, or from their respective state irrigation/water quality specialists.

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