IRRIGATION SCHEDULING: DETERMINING CROP WATER USE

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INTRODUCTION

One of the fundamental requirements for scheduling irrigation is the determination of crop water use. With this information it is possible to track the status of the crop with regard to the upper and lower limits of available soil water- field capacity and wilting point. One way to do this is by evaluating the water content of the soil in the crop root zone directly. Another method is to determine the crop water use, or evapotranspiration (ET), and then maintain a budget of how water in the soil is depleted by the crop. Whichever method is used, when the water level in the crop root zone is depleted to some critical level, irrigation can be initiated.

SOIL MEASUREMENTS

There are a number of ways to make measurements of soil water status in the crop root zone that can reasonably be used production agriculture. One very accurate method is the use of a neutron scattering probe. This device measures how radiation from the probe is affected by the soil around it. Changes in water content of the soil cause different meter readings. This method is rarely used in production agriculture, except by larger corporate farms, because the meters are expensive and must be handled with special safety precautions.

The feel and appearance of the soil has been used to judge moisture content for many years. An experienced irrigator can gauge soil water content fairly well based on the soil texture and how the soil behaves when squeezed and rolled in the hands. This method evaluates only soil near the surface. To evaluate soil deeper in the root zone would require digging or use of a soil coring device.

There are ways to get a more quantitative determination of soil water conditions. A tensiometer can measure how tightly water is held by the soil. A tensiometer is a water-filled plastic pipe with a porous ceramic tip at the bottom and a vacuum gauge at the top. It is inserted in the soil with the tip at the desired depth. If the soil is dry, water is drawn out of the pipe through the tip. As water is removed, the vacuum formed in the pipe is registered on the gauge. The gauge reading indicates the amount of suction the soil is exerting on the water in the instrument. The drier the soil, the greater the suction. When the soil is at field capacity the gauge reading will be about 10 to 30 centibars of vacuum, depending on the soil texture. The tensiometer will normally quit working when the reading reaches about 80 to 90 centibars of vacuum because the water column in the pipe will separate.

The usefulness of tensiometers in irrigation scheduling depends on the type of soil and the type of crop with which they are being used. In coarse-textured soils, the majority of the water that is managed through irrigation can be measured by tensiometers. In a typical loamy sand soil, one-half of the stored soil water may be depleted by the time the tensiometer reading reaches 70 centibars. However, in fine-textured soils only a small portion of the depletable water can be used by the crop before conditions beyond the operating range of tensiometers develop. A typical sandy clay will have less than 30% of its stored soil water depleted by the time the tensiometer reading reaches 70 centibars. Tensiometers are best suited to coarser soils and crops that require irrigation when one half or less of the available soil water in the root zone is depleted.

Electrical resistance blocks (sometimes called gypsum blocks) are another type of device that measures soil water content indirectly. They are made of porous material such as gypsum and spun polyester fibers. Embedded inside the block are electrical contacts that are connected to wires. The blocks are placed in the soil of the crop root zone at various depths. The porous blocks absorb water until they are at the same water content as the surrounding soil. A meter is connected to the wires to measure the electrical resistance between the two contacts in the block. The resistance to electrical current flow depends on the water content of the block. The blocks are calibrated so that a given meter reading can be related to a given soil water content or soil water suction. The range of operation varies somewhat from manufacturer to manufacturer, but generally they are calibrated to operate at water contents from field capacity to near wilting point. The accuracy of the blocks can be affected by salinity in the irrigation water, fertilization and by temperature changes.

There are some limitations in evaluating crop water status by soil measurements. The measurements are for a single point, at one place in the field and at one depth. Multiple measurements that check the soil all the way through the root zone are needed to get accurate evaluations. Measurements should be made at more than one location in the field to account for variations in soil and crop conditions, and variations in the irrigation system. Measurement sites should be representative of conditions throughout the whole field.

These devices and methods which evaluate the soil water status of the crop root zone will tell an irrigator directly when the critical soil water level is reached. They measure soil water content or soil water tension. With some knowledge of the soil type and the critical water level for crop stress, an irrigator can make the proper scheduling decisions.

ATMOSPHERIC MEASUREMENTS

There are some elaborate methods for measuring crop water use in the air above the vegetation that can be extremely accurate. Bowen Ratio and eddy correlation devices can measure ET directly in the air, but the expense of the equipment required and the technical expertise needed to make these measurements it generally makes it reasonable for use only in research applications.

There are other, indirect measurements that can be taken in the air above or near a crop which can determine water use. An evaporation pan allows water to evaporate from an open container. The depth of water evaporated each day can be related to the amount of water used by different crops using experimentally measured coefficients. The coefficients used depend upon the approximate wind and humidity conditions, where the pan is located relative to the crop, and the stage of growth of the crop.

An atmometer also estimates crop water use by evaporating water into the air. Atmometers use a water reservoir with some type of wicking device, such as fabric or blotting paper, to expose the water to the air. The warmer, drier and more turbulent the air, the more rapidly the wick is dried. The amount of water used by the atmometer is measured by a gauge in the reservoir. This is then related to crop water use by a coefficient.

Daily reductions in stored soil water through crop water use can be predicted by evapotranspiration (ET) models which use various types of weather data. These models are mathematical equations which estimate the water use of some reference crop in given weather conditions. Some popular models use air temperature, some use solar radiation, and some use a combination of weather parameters to predict water use. These combination methods take into account both the energy needed to evaporate the water and the effects of wind and humidity on movement of water from the crop leaves into the air.

The weather data required to make the calculations for these ET models must be collected by weather instruments located in the area around the fields for which the scheduling information is required. Modern technology has made it possible to have automated weather stations which collect a wide range of data at frequent intervals. The data can be transmitted by radio or telephone to computers which can do all the calculations to determine the reference ET for a location.

Automated weather stations are relatively expensive and are normally beyond the means of all but large corporate farms. However, several states have developed networks of weather stations in recent years which cover important agricultural areas. These weather networks are often supported financially by university research and extension programs. The information they provide can be used for a wide range of agricultural activities relating to irrigation and crop management, as well as for other uses. The information from these networks can support irrigation scheduling models by providing the information to determine reference ET for several geographical areas.

The reference crop ET in each area is then adjusted to estimate the water use of other crops by means of crop coefficients. The crop coefficient takes into account the crop species and the stage of crop development. Crops with tall, multi-layered canopies generally use more water and have larger crop coefficients than shorter crops. Early in the growing season the coefficient will be small. It will increase to its maximum when a full leaf canopy has developed and the crop is fruiting. It will decrease again late in the season as the crop matures and vegetation begins to die.

Other coefficients are also needed to adjust the ET estimate to take into account limited soil water availability. This is necessary because plants adjust their rate of water use based on how easily water can be extracted from the soil. The drier the soil is, the harder it is to remove more water and the less water plants will use. Sometimes other adjustments are made for increased evaporation from the soil surface right after irrigation or a rainfall event.

There are also limitations related to atmospheric measurements of ET. Any measurements, whether they are made by an evaporation pan, an atmometer or a weather station, must reflect the conditions affecting the field for which crop water use is being estimated. The effects of buildings, windbreaks, roads, ponds and other features can cause these devices to measure conditions which are different than those affecting the crop in the field. If the measuring device is placed in a location which does not represent the conditions of the field accurately, it will give an inaccurate ET estimate.

SOIL WATER BUDGETS

These atmospheric methods of evaluating crop water use measure or estimate daily crop water consumption rather than determining the water remaining in the soil. These methods then require some bookkeeping to determine how much water is left for crop use before the irrigator can make a scheduling decision. This is known as maintaining a soil water budget. It is also frequently called checkbook irrigation scheduling, since the accounting of the soil water budget is much like keeping a checkbook balance.

The initial water content of the crop root zone must be known. This is the beginning balance for the field. The most common way of starting the budget at a known water content is to begin right after a large rainfall event, when the soil has been filled to field capacity. An alternative method is to begin with an irrigation application which is large enough to fill the crop root zone to field capacity.

Reductions in soil water due to crop water use are deducted. Using the reference ET and the appropriate crop coefficients, each day's water use is calculated and subtracted from the previous day's balance. Each day the withdrawals from the stored soil water bring the balance closer to the minimum level allowed. As the stored soil water is depleted to the critical minimum balance where crop growth will be affected, the irrigator makes the decision to replenish the soil water content by irrigating.

Of course any rainfall that occurs during the growing season will add to the stored soil water. It acts as a deposit to the balance of the soil water budget. Not all of the rain that falls is effectively stored in the soil for the crop to use. Surface evaporation, runoff and limited storage capacity in the root zone must be taken into account. Depending on the timing, amount and intensity of rainstorms, the soil conditions and the crop type, only a small portion of a rainfall event may effectively offset the irrigation needs of the crop. Where rainfall is highly scattered and variable it is necessary to have rain gauges at each field being scheduled in order to evaluate the contribution of a given rain storm to crop water requirements.

Not all of the applied irrigation water is stored in the crop root zone either. Even with a well managed and maintained system certain assumptions must be made about how much water actually reaches the plants. The application efficiency of surface irrigation systems can vary widely, depending on soil type, slope and level of management. Efficiency may range from 20% to 80% or more. The application efficiency of center pivot sprinkler systems depends on the sprinkler type, operating pressure, wind speed and humidity. Typical efficiencies in the high plains may range from less than 70% to over 90%. Inefficiency due to evaporation, runoff and deep drainage losses must be accounted for when determining the net amount of irrigation water applied by any type of system.

SCHEDULING DECISIONS

The decision to initiate an irrigation is normally triggered when the water resources of the crop are depleted to some critical level. The allowable depletion is based in part on the crop being irrigated and its response to water stress, and in part on the management strategy of the irrigator. The greater the amount of water depleted between irrigations, the greater the stress on the crop and the greater the potential for yield reduction. But the longer interval between irrigations also allows for a greater chance of making beneficial use of any rainfall that occurs during the growing season, saving the cost of pumping irrigation water.

Research has been done on some relatively complex irrigation scheduling procedures which make use of rainfall probability forecasting and the potential loss of yield associated with delaying irrigation. Few scheduling systems used in production agriculture make use of decision methods this complicated. The most common approach is to start irrigation when the water stored in the crop root zone is depleted to some critical percentage of the available soil water. For most agronomic crops, irrigation water is applied when 50% of the available water in the crop root zone has been depleted. For some crops that are more drought tolerant, such as cotton and sorghum, 65% of the available soil water may be removed from the root zone without significant effects on crop growth or development. Other, less tolerant crops require more frequent irrigation. For example, horticultural crops in which the harvested product has a high water content should be irrigated when only 35% or less of the available soil water is depleted or else crop yield or quality may be affected.

For nearly every crop there will be critical periods during the growing season when water stress is especially damaging. For most crops this most critical stage occurs when the crop is flowering and beginning to set fruit or grain. Water stress at this time will have a much greater effect on yield than at other times. Normally moderate water stress early in the season when the crop is producing vegetation only is less damaging. Likewise, late in the season when the crop is maturing, stress may not be as damaging. Irrigation decisions during critical growth stages should be made carefully.

SUMMARY

Irrigators should keep in mind that all scheduling methods can have occasional problems. Wires on resistance blocks can break, gauges on tensiometers can stick, or weather data can be in error. It is important that occasional field observations be made of the crop to determine that the condition shown by the scheduling program is in agreement with the observed condition of the crop in the field. This is a necessary safety measure to protect against a scheduling program breakdown.

There are a variety of ways to determine soil water status and crop water use for scheduling purposes. All methods have their plusses and minuses. Some methods require constant monitoring of instruments in the field. Some methods may not be readily adaptable to some locations. For instance, if detailed weather data is not available in a given area, checkbook scheduling with ET models is probably not a reasonable choice for a scheduling method. Of course there can be outside limitations on the practical use of any type of irrigation scheduling program. Irrigators on surface water development projects may have to time their irrigation according to scheduled releases of water within the project. Irrigators who use electric power for pumping ground water may have their hours of operation limited by power distributors during periods of peak electrical demand. But, any scheduling method that attempts to evaluate the use of water by the crop based on the currently existing growing conditions will provide improved management and profitability.