IMPROVING IRRIGATION EFFICIENCY

Gerald Buchleiter
Agricultural Engineer
USDA-ARS Fort Collins, CO
Voice: 970-492-7412   Fax: 970-492-7408
gerald.buchleiter@ars.usda.gov

INTRODUCTION

Declining water supplies, drought, increased competition from other users, and either existing or anticipated restrictions on the amount of water that can be applied over a specified time period, are encouraging many producers to improve the irrigation efficiency of their irrigation systems.

To most people, irrigation efficiency, E_{Irr}, is a general term that indicates how well a water resource is used to produce a crop. Although E_{Irr} can be looked at from several perspectives, this paper deals with it at the field level of a producer. Typically a producer is concerned primarily about making most effective use of water on his farm and does not pay much attention to how individual fields or his farm affects the water budget of an entire watershed. Water that is applied but not beneficially used to produce a crop, is referred to as a loss even though that water may still be physically observed as runoff, etc.

Irrigation efficiency, E_{Irr}, is mathematically defined as:

$$E_{Irr} = Vol_{beneficial} / Vol_{gross}$$

where: $Vol_{beneficial}$ is the volume of water used to produce a crop
Vol_{gross} is the volume of water taken from the water resource

Sometimes the volume of water delivered to a field, $Vol_{delivered}$, is used instead of Vol_{gross}. In situations where there are no significant losses from the water source to the irrigation system such as a center pivot with a well/pump near the pivot, $Vol_{gross} = Vol_{delivered}$. In other situations such as a long, leaky conveyance ditch leading to a field, there are significant losses so that $Vol_{delivered}$ is less than Vol_{gross}. Depending on your perspective or area of interest, it may make sense to include conveyance losses when talking about improving irrigation efficiencies.

Fig. 1 illustrates how the soil water in the root zone varies over time as the evapotranspiration (ET) of the crop withdraws water and periodic irrigations or rains replace water in the root zone. Good water management applies irrigations before the soil moisture level reaches the management allowable depletion (MAD) with an applied depth that just refills the soil profile to field capacity (FC).

The MAD is a management decision of the producer that will vary by crop and his willingness to accept risk of yield reducing stress. If irrigations are too far apart, yielding-reducing water stress will occur. If the applied depth from irrigation or rain causes soil moisture to exceed FC, the excess water either runs off or percolates below the root zone and hence is not beneficially used by the crop.

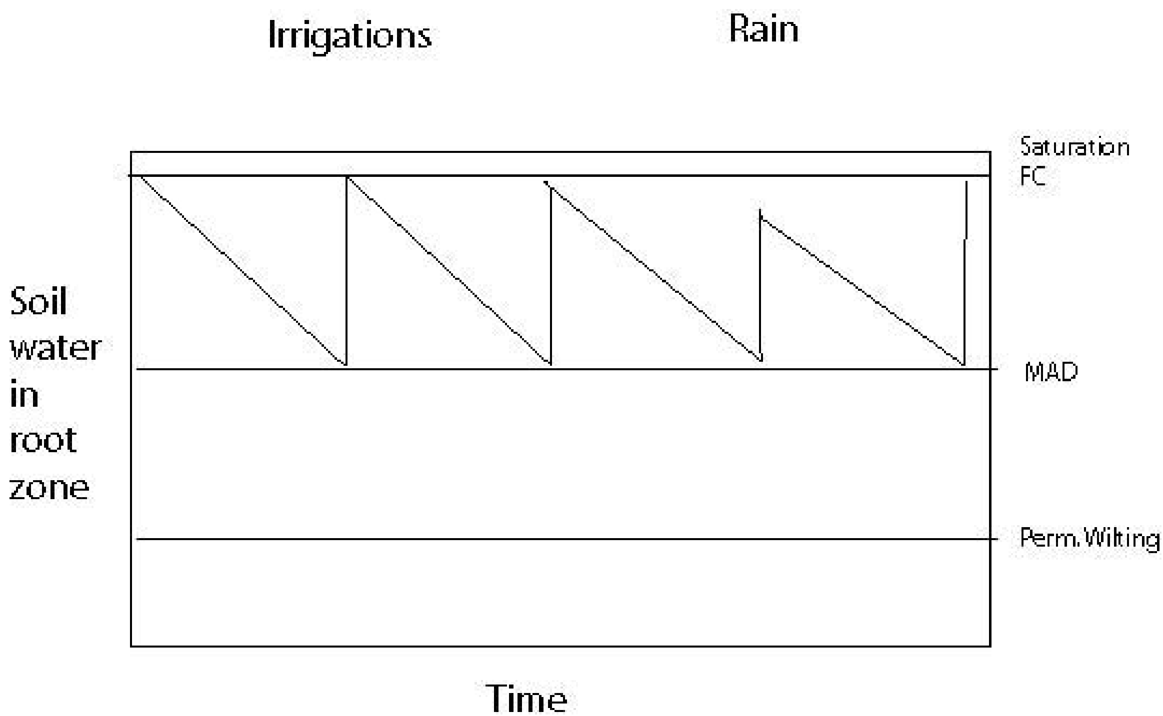

Fig. 1 Schematic of soil water in profile over time

NEED FOR MEASUREWMENTS

It is important to measure the amounts of water beneficially used and delivered to a field in order to document improvements in irrigation efficiency due to management changes and/or upgrades in the irrigation system. Careful measurements of crop water use make it possible to determine the volume of water beneficially used. Other conference papers cover this topic very well.

Accurate measurement of applied water requires properly installed and well maintained equipment. Flumes, such as the Parshall flume, are adequate for open channel flow, unless the headloss through the flume is too great. Another option is to pour a raised concrete sill in an existing concrete ditch. The as-built dimensions can be input into Winflume, an easy-to-use computer program, to create an accurate rating curve for each installation.

Flow meters are typically used for obtaining flow data in the pipelines of pressurized irrigation systems, although other methods can be used. Propeller meters are probably the most common but require periodic maintenance to make sure the propellers turn freely and produce accurate measurements. Ultrasonic flowmeters are non-invasive and very accurate but more expensive. Because they are temporarily attached to the outside of the pipe, they are portable making it possible to measure many irrigation systems with a single piece of equipment. The key to getting accurate measurements from this equipment, is to pay close attention to installation procedures, such as locating the sensors where flows are uniform and the pipe is flowing full.

IMPROVEMENTS TO REDUCE LOSSES

From the definition given above, the closer E_{Irr} is to 1.0, the more efficient is the water use. The most obvious way for increasing E_{Irr} is to reduce losses so Vol_{gross} is as small as possible. A list of possibilities is given below.

1. Significant conveyance losses in an open channel can be reduced by ditch lining, ditch realignment, or installing a closed pipeline.

2. Improve application uniformity to reduce deep percolation

   For surface systems, quicker furrow advance to reduce the differences in infiltration opportunity time along a furrow. Options include land leveling, surge irrigation, furrow firming, etc.

   For sprinkler systems, options include changing sprinkler types, renozzling the system or changing nozzle spacings to improve the overlap between heads.

3. Modify the timing and amount of an irrigation to match the WHC of the soil profile better, thereby reducing percolation and runoff losses.

4. Convert to a more efficient irrigation system (e.g. furrow to sprinkler) to reduce application losses. If the new system is well designed and managed, applications are more uniform reducing deep percolation and runoff.

The implicit assumption is that if a physical change is made in the irrigation system, management also changes appropriately. For example, converting from surface to sprinkler irrigation can greatly reduce water application depths, but if irrigation management does not change as well, then it is still possible to apply as much water as with a surface system.

IMPROVEMENTS TO USE WATER MORE EFFECTIVELY

The previous discussion assumes that available water supply is not limited, so the goal is apply water uniformly at the right time and amount so percolation and runoff are minimal. This may be an ideal situation where the field is managed as a uniform block of soil. The actual situation is likely to be more variable with some water stressed areas where yields are depressed. With the recent interest in adopting new technologies site-specific management of fields, there are additional opportunities for improving E_{Irr} by increasing $Vol_{beneficial}$ in the water stressed areas.

In many irrigated fields, there are significant differences in soil texture that have a large effect on the water holding capacities of the soils. Accurate delineation of these differences is difficult if the only resources available are the USDA-NRCS soil survey and a few soil cores taken across the field. However, recent research has shown that soil texture correlates very well with the bulk electrical conductivity (EC) of soil when the salinity levels are low. The Veris 3100 EC system equipped with global positioning system (GPS) equipment, makes it possible to map the bulk soil EC at a rate of 30-40 ac/hr. Depending on the soil variability, 6 to 12 soil cores are taken, and analyzed for soil texture and other soil properties of interest. The EC values at the sample sites are statistically correlated with the various soil parameters to estimate soil texture and water holding capacity over the entire field. Using this map, the producer can identify the sizes of areas that are of particular concern when he is making management decisions about when and how much water to apply.

Since summer precipitation is generally unpredictable in the western part of the Great Plains, most irrigators do not consider possible rain when they make decisions about irrigation timing and amount. By scheduling irrigations according to the water needs in areas of the field with the lowest water holding capacities, significant water stress affecting yield can be avoided across the entire field.
If water stress affecting yield is detected using remote sensing, yield map from previous year, or some other method, it may be possible to make some changes in the irrigation system or management to reduce the stress and resultant yield reduction in low WHC areas. The course of action with the least cost is to increase the irrigation frequency and decrease the applied depth so the soil water depletion does not exceed the MAD in the low WHC areas. Unless there are very unusual circumstances, the frequency should not be less than 2 days because of the inherent inefficiencies of applying very small depths. Obviously, if adequate water is unavailable because of diminished well yields, management changes cannot increase the available supply. However, if the well yield is sufficient but system capacity is insufficient, redesign with different applicators and/or renozzling the system could increase the available water and reduce stress in the crop.

Obtaining and analyzing a good quality yield map is a good starting point for quantifying the extent and magnitude of yield depressions. Since depressed yields can have various causes, additional information is needed to determine whether irrigation is the primary cause. Aerial images in color and/or infrared wavebands, can be very useful in identifying variability in biomass throughout the season. In-depth field observations are usually very helpful in ground-truthing aerial images.   If there is good evidence that the irrigation regime has caused yield depressions in certain areas of the field, operational changes during an irrigation should be made to best satisfy the irrigation needs over the entire field.

If the available water is limited and water is being applied to minimize water-stressed areas with minimal losses, then increasing $Vol_{beneficial}$ is the only way to improve irrigation efficiency. A clear understanding of what beneficial means is crucial in considering various options. Since a primary objective of irrigation is to optimize crop production for the available water supply, management decisions must consider the how much water is required to achieve at least reasonable economic production. If taken to the extreme where all of the available water supply is applied over a large enough area so there is no percolation or runoff, there could be very little economic production (e.g. no grain production because of severe water stress) even though the irrigation efficiency approaches 1.0. However, a forage crop could be at an economic production level so $Vol_{beneficial}$ is greater than 0, although the optimum balance would probably have more water applied on a smaller area.

This example illustrates two options for management changes that would increase $Vol_{beneficial}$. One possibility is to change the irrigated area so the seasonal application depth would produce an economical production level so $Vol_{beneficial}$ approaches Vol_{gross}.   Another option would be to grow different crops so $Vol_{beneficial}$ could match the available water supply. Although there are a lot of possible scenarios for managing a limited water supply, E_{Irr} will probably be high (near 1.0) and may not change even if the crops grown are changed to produce a larger economic return per unit of water beneficially used. Other conference papers discuss these options in much more detail.

FUTURE

Numerous factors will continue to encourage improvements in on-farm irrigation efficiencies. The trend to convert from surface to pressurized systems will continue, in part at least, to lower labor requirements. Although this conversion enables the producer to apply less water over the season and reduce runoff and deep percolation, there is probably very little reduction in the amount of water used by the crop. The reduction in runoff and percolation translates into fertilizer and chemical savings, has very positive environmental implications, and makes it possible to maintain good production in areas where legal restrictions limit the amount of water that can be withdrawn over time. However, in areas where applied depths are not restricted by law, it is unclear whether there are significant financial benefits from just reducing the amount of water diverted or pumped for irrigation.