Technical Advances in Water Use Efficiency

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Advances in irrigation technology over the past 40 years have enabled farmers to produce crops of higher quality with greater yields, and have allowed the productive use of water of marginal quality. One of the largest benefits has been the increase in the efficiency of irrigation water use, but managers and policy makers must understand the complex and often over-simplified hydrologic cycle in which water conservation exists.

Efficiency is one of the most used and abused terms in discussion of irrigation and water conservation. It is used to convey some concept of quality of performance of an irrigation system, but unless it is specifically defined and examined in a broad context, the term efficiency is ambiguous and misleading. Efficiency generally is defined as an output divided by an input. In irrigation terms, the output may be delivery, consumptive use, or beneficial use of water. Input may be release from a reservoir, diversion from a river or aquifer, or delivery to the farm. The implications of the various forms of efficiency vary according to hydrology of the irrigation system.

Conveyance efficiency is the proportion of water diverted from a river or aquifer that is delivered to farms. Mathematically, it is the ratio of farm delivery to diversion, generally expressed as a percentage. Diversion is always larger than (due to seepage and evaporation losses) or equal to delivery (if diversion occurs on the farm), so the conveyance efficiency is less than or equal to 100 percent. High values are common in lined or piped conveyance systems due to the reduced seepage. High values also indicate that excessive water is not being diverted and returned to the system as operational spills. In fact, if a system operator under-delivers water, there will be a very high demand for the water he does divert, and he may have a high conveyance efficiency but some unhappy irrigators who are not getting adequate deliveries. Low conveyance efficiency is not necessarily wasteful, if downstream users can recapture operational spills and canal system seepage.

Application efficiency refers to the efficiency of the irrigation application system. It is the ratio of irrigation water consumed by the crop to the water applied to the crop from the farm ditch or pipeline. The term is somewhat complicated by the fact that crops get some of the water they consumptively use from precipitation, though this is a relatively small amount in New Mexico. Application efficiency varies from 50 percent in rather poorly managed surface irrigation systems to over 90 percent with drip irrigated fields. It is possible to achieve 100 percent in deficit irrigated systems, but the crop will likely show a reduced yield because of moisture stress.

Irrigation efficiency is the ratio of beneficially used irrigation water to water applied to the field. This beneficial use includes the consumptive use plus a leaching fraction, recognizing that leaching is a necessary function of applied water. Only water infiltrated in excess of a specified leaching fraction is considered a deep percolation loss in the determination of irrigation efficiency, but it should be remembered that deep percolation is not necessarily a loss to the system as a whole, because in some settings, such as stream-connected aquifers, deep percolation is either captured and returned to the source, or it may act as ground water recharge. The required leaching fraction is a function of irrigation water quality (higher water salinity requires higher leaching fraction), soil type (soils with more clay require more leaching), crop (more salt-sensitive crops require more leaching), and yield goal (higher yield requires higher leaching fraction). In practice, water availability typically determines leaching fraction, as one cannot apply excess water to leach if one doesn't have the water to apply.

On-farm efficiency is the percentage of delivered water that is consumptively used by the crop. Mathematically, it is the ratio of consumptively used irrigation water to water delivered to the farm. The consumptive use is smaller than delivery, making on-farm efficiency less than 100 percent. Losses or inefficiencies that affect on-farm efficiency include losses in on-farm ditches or pipelines and incidental evapotranspiration. Application efficiency differs from on-farm efficiency in that the former does not include losses in on-farm conveyance systems, whereas the latter does.

Application efficiency, irrigation efficiency, and on-farm efficiency are similar to each other. For simplicity in discussion, application efficiency will be the indicator of efficiency at the farm level, as an improvement

in application efficiency will generally produce an improvement in the other two. Various other combinations of outputs and inputs are sometimes expressed as efficiencies, but conveyance efficiency and application efficiency capture the essence of conveyance and farm application, and will be the basis for discussion of water conservation measures.

On-farm water conservation measures range widely, but can generally be classified by application system type. The two major divisions of water conservation application systems are surface and pressurized systems.

SURFACE SYSTEMS

The oldest and most widely used class of irrigation is surface irrigation, including basin, furrow, border, and other techniques that apply water to the soil surface at the head of the field and allow the flow to advance to the tail, wetting part or all of the soil surface. Because the soil is used both to infiltrate and store water and to convey the water across the field, there are inherent inefficiencies in the irrigation process. Generally, the objective of surface irrigation conservation technologies is to advance the water from the head of the field to the tail as rapidly as possible without eroding the soil surface, thereby minimizing the differences in infiltrated water between the head and tail of the field. Common conservation technologies used in surface irrigation systems are:

- Laser leveling, where the field is precision-graded to allow uniform advance of water and eliminate high and low spots in the field. This is very commonly practiced in New Mexico; it can improve application efficiency from 10 to 20 percent.
- High-flow turnouts are used to provide rapid advance. These turnouts are most commonly used in conjunction with laser-leveled fields, and the combination can produce application efficiencies in excess of 80 percent.
- Surge irrigation is used to improve the infiltration uniformity, and therefore efficiency by advancing the water down the field in pulses. It is best suited to very long furrow or border runs and has not seen wide application in New Mexico.
- Alternate furrow irrigation allows some improvement in uniformity, because the available flow is directed into every second furrow, thereby doubling the flow per furrow over conventional furrow irrigation.
- Tailwater recovery and recycling systems capture runoff from the tail of the field and recirculate it to the head of the field. This also is rarely applied in New Mexico.

High flow turnout on pecans.

PRESSURIZED SYSTEMS

Whereas surface systems rely on the soil to convey water from the head of the field to the tail, pressurized systems rely on pipes. Pressurized systems also lend themselves to automation. The two main classifications of pressurized systems are sprinkler and trickle (or drip), though these descriptions represent ends of a spectrum rather than distinctly different systems.

Sprinkler systems can be either solid set, with permanently fixed sprinkler head positions, or moving. Moving systems are moved mechanically or by hand. In New Mexico mechanical moving systems are widely used, with center pivots being the most common.

Center pivot irrigation of alfalfa.

Center pivot sprinklers reduce the amount of applied water necessary to irrigate a field because they apply water more uniformly than surface irrigation systems typically do. Center pivots are also capable of irrigating gently rolling land, reducing the need for leveling. Drawbacks are the wetting of the plant during irrigation, evaporative losses, and wind drift. Low pressure systems can reduce these losses by applying water near, within, or below the crop canopy. Typical application efficiencies with center pivots are 75–80 percent.

Drip is the racehorse of irrigation. Managed correctly, this type of system can produce the highest yield, and the highest quality, for a wide variety of crops. Drip proves in many cases to be economically quite viable. Unfortunately, like a racehorse, anything less than the highest level of management can create serious problems. Clogging of emitters is the biggest problem faced by most growers, particularly when using sediment-laden surface water. Clogging may result from sediment, precipitation of minerals at the emitter outlet, and biological growth within the drip lines. An acid flush will generally take care of precipitants and biological growth, but removal of sediment requires multi-stage filtration and frequent cleaning of filters.

In identifying potential water conservation measures in New Mexico, one must look at conservation from two perspectives:

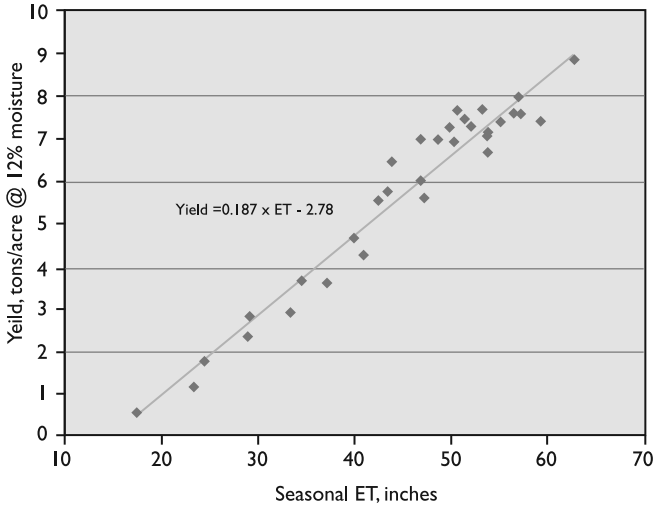
Drip-irrigated strawberries.

Characteristic	Surface	Sprinkler	Drip
Irrigation efficiency	50–85%	70–85%	90–100%
Yield potential	low-mod	moderate	high
Depletion/acre	low-mod	moderate	high
Diversion/acre	high	moderate	mod-low
Capital investment	low	moderate	high
Labor requirement	high	low	low
Labor skill level	low	moderate	high
Soil types	fine	mod to coarse	any
Topography (slope)	0–2%	0–5%	0–15%+

Irrigation system characteristics: general performance characteristics of improved surface, sprinkler, and drip irrigation systems. Note that the actual performance of an irrigation system has a great deal more to do with the operation and scheduling of irrigations than does the hardware.

- The farm perspective, where water use and water accounting is based on application of water to the crop. The primary goal is to reduce application of irrigation water and to conserve allocated water for later use.
- The system perspective, where the system manager has a responsibility to deliver water to irrigators while meeting obligations to downstream water users. In order to meet downstream obligations, the primary long-term concern is depletions rather than farm application of water. Depletion and application are certainly related, but they are not one in the same, as application efficiency is generally less than 100 percent.

Crop yield is related to seasonal evapotranspiration, and therefore depletion. As a crop consumptively uses more water, the yield will increase. In Rio Arriba County in northern New Mexico, for example, the average yield of alfalfa is approximately 2.4 tons per acre (12 percent moisture content). In the Middle Rio Grande Conservancy District (MRGCD), located south of Rio Arriba County, the warmer weather and higher solar radiation allow growers to produce an alfalfa yield of approximately 4.5 tons per acre. Still farther south in Elephant Butte Irrigation District (EBID), farmers achieve a yield of approximately 7.5 tons per acre, three times that of their Rio Arriba counterparts.



Water production function for alfalfa at 12 percent moisture (from Abdual-Jabbar, 1983).

From this relationship, one may infer that the yield of 2.4 tons per acre Rio Arriba County consumptively used 2.3 feet of water, MRGCD's yield of 4.5 tons per acre consumptively used 3.2 feet, and EBID's yield indicates a consumptive use of 4.6 feet of water. These yields reflect irrigation management, as well as other cultural practices. Pressurized irrigation systems allow more frequent watering of crops than surface irrigation, thereby reducing moisture stress, and may increase both yield and consumptive use of water. The increased efficiency and operational advantages of pressurized systems may actually allow increased consumptive use while decreasing application and diversion of water.

Weather is not the only factor affecting a given crop's evapotranspiration and consumptive use. Timing of irrigation affects the moisture stress on a crop. As a crop's root zone soil moisture is depleted, evapotranspiration is decreased, thereby producing a reduction in yield. Diseases, pests, and nutrient stress may similarly reduce a crop's vigor, hence reducing its evapotranspiration and yield.

AGRICULTURAL WATER CONSERVATION

Seckler (1996) examined water conservation efforts in various parts of the world and pointed out a relevant distinction in conserved water. In systems where return flows produced by processes traditionally considered to be losses (such as canal seepage and deep percolation from irrigated fields) are recaptured and reused by downstream users, reduction in these losses does not actually create more water to the system. For example, if a canal lining project were to reduce the quantity of water "lost" to seepage, conveyance efficiency would increase, but return flows would be reduced. Although less water would need to be diverted, the savings essentially came out of the return flow, which is not a loss term. This is a local savings but a system-wide break-even proposition. Seckler termed this "dry water" conservation, because it does not provide a net reduction of water use for the system as a whole.

"Dry water" conservation may produce significant benefits when water is kept in irrigation, as farmers can use seepage and deep percolation reduction to increase their available supply in times of drought, essentially borrowing from the ground water system. Keeping water upstream in storage also allows the active management of that water to match supply to crop demands, rather than allowing it to return as drain flows, which can be managed only passively, and may not reach the river at a useful time.

Reduction in depletion is a different matter. If depletions (which in the case of irrigation are primarily associated with evapotranspiration) are reduced, more water becomes available to other users in the study area. For example, if a farmer who has been growing alfalfa switches to onions, he reduces the amount of water his crop is depleting, and the savings actually results in more water available for delivery and depletion by another user. This is what Seckler termed "wet water" conservation.

In some circumstances the distinction between wet and dry water conservation is irrelevant. For example, irrigators pumping water from the Ogallala aquifer in eastern New Mexico can improve on-farm efficiency by reducing deep percolation losses and extend the life of their resource. Because the deep percolating water does not return to the aquifer in any operational time frame, deep percolation is functionally a loss to the system, and reducing it (and making a higher percentage of the applied water available to the crop) reduces the required diversion from the aquifer.

This distinction between wet and dry water conservation is critical in evaluating conservation measures intended to provide additional water. Wet water conservation truly frees up water that may then be assigned to another use whether considered from the farm or district perspective. Dry water conservation, from the district perspective, has less impact on increasing the water supply, but may offer management advantages that justify investment of resources.

There may be unforeseen negative consequences to water conservation measures, along with the positive ones. For example, on-farm conservation measures that increase application efficiency reduce the required application of irrigation water to achieve a given level of yield (and depletion). Although this is generally a benefit, it will also reduce the return flow to drains, which may provide important habitat. Although the return flows may be reduced, their salinity and the salinity in the shallow ground water will likely become more concentrated. It is, therefore, important to examine direct and indirect consequences of conservation measures to ensure that they are consistent with specific conservation objectives that fit the local hydrology and institutional setting of both the farm and the larger system.

SUGGESTED READING

Abdual-Jabbar, A. S., Sammis, T. W., Lugg, D. G., Kallsen, C. E., and Smeal, D., 1983, Water use by alfalfa, maize and barley as iInfluenced by available soil water: Agricultural Water Management, v. 6, pp. 351–363.

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