

Principles and Practices for Irrigation Management with Limited Water
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Water availability for irrigation in the Western United States is often limited, and in many cases, declining. Below-average snow pack, drought, interstate conflicts, ground water pumping restrictions, and declining ground water from non-renewable aquifers have all contributed to declining water supplies for irrigation. These water shortages have been occurring in many western U.S. irrigated watersheds and ground water basins to some degree for the past several years. Combined with water transfers from agriculture to municipal and industrial uses and increasing recreational and environmental demands for water, the relevance of irrigation management with limited water supplies has greatly increased. This is the first in a series of six training modules intended to build upon concepts and suggestions for limited-irrigation management, provide updates on research projects relevant to the topic of limited-water irrigation, and suggest further resources and techniques for managing irrigated cropping systems under tighter water supplies.

What is Limited-irrigation?

Full irrigation results when irrigation water is applied to completely meet crop water demand or evapotranspiration (ET) that is not supplied by natural precipitation and soil water storage. In contrast, *deficit* irrigation occurs when irrigation water is insufficient to fully satisfy the soil water deficiency in the entire root zone and subsequently full ET demands cannot be met for part of the growing season. *Limited-irrigation* is a form of deficit irrigation that seeks to maximize water productivity through timing of irrigation applications at critical crop growth stages and through managed soil depletions.

Limited-irrigation situations can occur when any of the following situations exist:

1. Reduced surface water supplies or storage – in regions that rely upon surface water to supply irrigation needs.
2. Restricted ground water pumping allocations from alluvial or designated aquifers. In some instances, the allocations are considerably less than what is required to fully irrigate the crops typically grown.
3. Low capacity irrigation wells due to limited saturated depth of the aquifer. Well yields are then insufficient to meet the peak ET demands of the crop.

Under reduced irrigation water supplies, using typical management practices, yields and returns from irrigated crops will generally be reduced compared to fully irrigated crops. Management strategies can help minimize yield loss and preserve net return. However, in order for irrigators to implement effective management strategies, an understanding of certain concepts and principles is needed. These include:

- an understanding of the relationships between crop yield and water use (ET) of the crops available;
- knowledge about crop response to the magnitude, duration, and timing of moisture stress, especially at critical growth stages;
- options for and consequences of crop residue management for water conservation;

- plant population management in relation to available water;
- crop rotations to balance or reduce water use;
- and techniques and changes that will result in improved irrigation efficiency.

Limited-irrigation systems that incorporate these practices coupled with input cost management can improve water use efficiency and help maintain overall farm profitability.

Yield, Evapotranspiration (ET) and Water Timing

Evapotranspiration (ET) is the sum of evaporation of water from the soil or crop surface and transpiration by the crop. Evapotranspiration is the driving force behind crop yields when all other yield limiting factors, including soil fertility, pests, and agronomic practices, are minimized or taken into account (Figure 1).

In this example, crops such as corn respond with more yield for every inch of ET than winter wheat or sunflowers with the same ET water use. However, corn requires more water for development or maintenance than winter wheat or sunflower before any yield is produced, as indicated by where the yield-ET line intersects the X-axis. Corn requires approximately 10 inches of ET to produce the first increment of harvestable yield, compared to 4.5 and 7.5 inches of ET required by wheat or sunflower, respectively. Additionally, wheat and sunflower also require less ET for maximum production than the ET required by corn for maximum production.

Knowledge of differences in crop response to available water and ET, as in the case of corn versus winter wheat or sunflower, can be a useful tool in making decisions about the best timing of limited irrigation water resources. Forage crops, such as alfalfa,

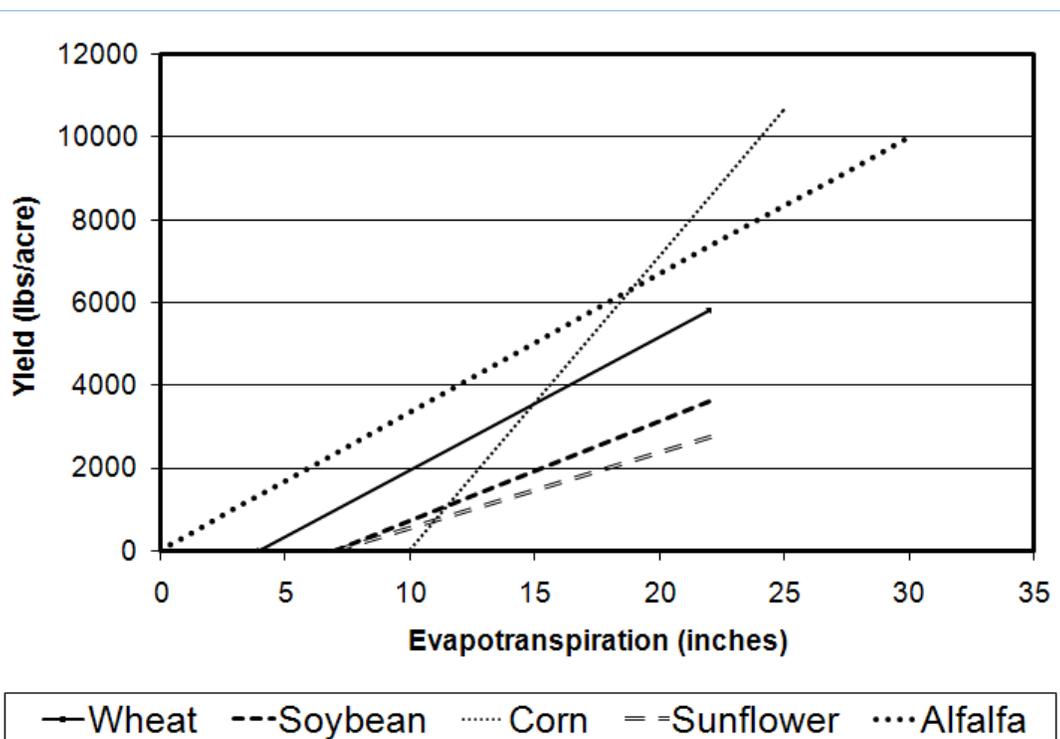


Figure 1. Grain and forage yield as impacted by ET for alfalfa, corn, soybeans, sunflowers and winter wheat (from Schneekloth et al. 1991 and Nielsen, 2005).

produce harvestable forage yield with the first increment of ET and thus are reasonable crop choices for many producers under limited water.

Crop response to water stress varies substantially among growth stages. When good stand establishment is achieved, yields of most grain crops are not impacted as much by water stress during the vegetative growth stage or the late reproductive or grain fill growth stages as they are by stress during the flowering, pollination, and seed-development stages. When producers have limited water supplies, but have control over when they can irrigate, limiting water during the growth stages that are least sensitive to water stress while saving water for the critical growth stages can be a valuable strategy to maximize yield return from water. Saving that water for the reproductive growth stages can be the most advantageous use of the water to maximize grain yield. Having some water available during grain filling will also enhance the quality of the harvested grain.

Crops differ in their water use requirements in both amount and critical timing. Crop rotations that include lower-water-use-crops such as sunflower, spring small grain, drybean or winter wheat, can reduce overall irrigation water needs. Schneekloth et al. (1991) found that when limited to 6 inches of irrigation water, a rotation of corn following winter wheat yielded 13 bu/acre (8 percent) more than continuous corn. The increased corn grain yield in this rotation was due to increased stored soil moisture during the non-growing season following wheat that was available for corn ET. Following higher-value, fully irrigated crops such as sugar beets, potatoes or vegetables with a low water requirement or dryland

crop such as winter wheat is also a rotation option for limited supplies.

Limited irrigation due to low capacity results when the rate of irrigation supply from a ground or surface water source is unable to fully meet the ET rate of crop water demand for a given irrigated acreage. Low capacity most often occurs during peak crop ET and the actual irrigation water capacity required will vary significantly by crop and region. Low capacity wells are those which have limited instantaneous water supply, either because of relatively small well bore size, water being pumped from a relatively thin aquifer, or rapidly changing water level within the well cavity.

For irrigators with low capacity, planting multiple crops with smaller acreages provides some variability in crop water needs and allows for water to be applied at amounts and times when the various crops most need the water. On a whole-farm scale, crop rotations which include a diversity of crops also spread the irrigation season over a greater time period, as compared to a single crop. When planting multiple crops such as corn and winter wheat under irrigation, the irrigation season is extended from May to early October, compared to continuous corn, which is predominantly irrigated from June to early September. Additionally, crops such as corn, soybean and wheat have different timings for peak water use (Figure 2). The net effect of irrigating fewer acres at any one point in time is that ET demand of that crop can be better met and farm-wide efficiency of water use may be increased. Timing and amount of irrigation water applied can be on an 'as needed' basis rather than in anticipation of crop ET.

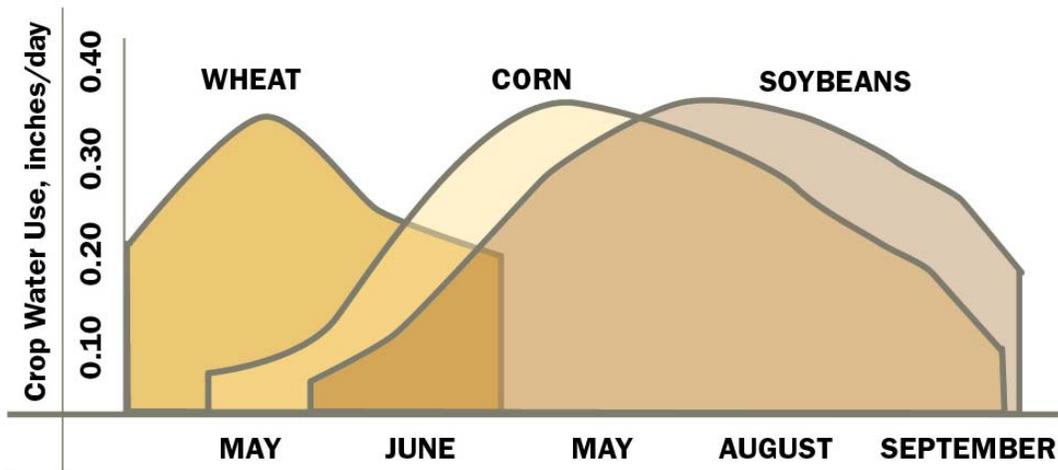


Figure 2. Example of daily ET patterns of winter wheat, corn, and soybeans.

Residue Management is a proven, effective management tool for capturing and storing rain, snow, and irrigation water in limited-irrigation cropping systems (Hatfield et al., 2001). Crop residues, whether standing or lying down, and reduced tillage, which minimizes surface disturbance and/or leaves the soil surface rough, can significantly increase the capture and storage of water by reducing evaporation and runoff and increasing snow catch. Standing residue is more effective than flat residue for snow catch. Studies in northeastern Colorado found that standing sunflower residue increased the amount of snow captured, resulting in nearly 2 inches in increased soil moisture, compared to fields with flat residue (Nielsen, 1998).

Residue can also have significant impact upon water conservation during the growing season. Researchers in Kansas found that wheat residue beneath irrigated corn reduced the amount of evaporation from the soil during the growing season, when compared to evaporation from bare soil. The reduction in evaporation amounted to nearly 2.5 inches of additional water available for use by the corn crop. Most of these savings

occurred before the corn crop reached full canopy (Todd et al., 1991). Residue also reduces runoff of precipitation and irrigation water, causes longer opportunity time for infiltration, increases infiltration and decreases rainfall and irrigation impact. The net effect is generally a decrease in incidence of surface sealing, thereby maintaining higher infiltration rates. As droplets impact the soil surface, they can destroy the surface structure, sealing the soil surface and reducing infiltration rates (Ramos et al., 2003). Residue also acts as small dams that slow water movement down slope and allow more time for the water to infiltrate into the soil.

Plant Population management has drawn attention recently as a tool with a place in limited-irrigation circumstances. Plant populations for non-irrigated cropping systems are often intentionally less than populations for irrigated production. This is done to reduce competition among individual plants for available soil moisture. At first glance, lowering plant populations for limited-irrigation may also seem like a good management strategy, particularly for corn with its associated high seed cost.

However, to reduce actual ET and plant-to-plant competition for water during periods of peak ET demand, hybrid corn plant populations must be reduced to less than approximately 18,000 plants/acre. Lowering corn plant population to that level will dramatically reduce yield potential, but may not help with limited irrigation water. For example, Lamm and Trooien (2002) found that corn grain yields generally increased as plant populations increased from 22,000 plants/acre to 34,000 plants/acre for irrigation capacities ranging from as little as 0 to as much as 0.25 inches per day. Even at the lower irrigation levels, little yield penalty was observed for using higher plant populations, compared to lower populations. However, the lower populations did reduce yield potential during cropping years with above average moisture and good growing conditions.

It should also be noted that the Lamm and Trooien study involved irrigation by sub-surface drip methods, which reduce and can even eliminate evaporation of water from the soil surface, which is higher in traditional irrigation systems. When reducing populations to reduce seed costs, producers should choose a corn hybrid with a high potential for ear flex. Consistent with other inputs, corn plant populations under limited irrigation should be adjusted to match yield potential. For many other irrigated crops, the relationship between plant population and field-scale ET has not been extensively studied.

Preseason irrigation is a strategy that is often recommended under limited-irrigation, particularly when using low capacity irrigation wells. This strategy attempts to

ensure that soil water storage is filled to near field capacity before the growing season. Pre-irrigation may also be necessary to help minimize soil moisture deficiencies at planting and to compensate for reduced pumping capacity of wells during critical periods of the growing season. However, producers should consider the low storage efficiency of pre-irrigations when considering pre-irrigation. Lamm and Rogers (1985) found that the storage efficiency of non-growing season precipitation was reduced as the fall available soil water content was closer to field capacity. This same principle is likely applicable to pre-season irrigation. Although pre-irrigation may be needed in years with low fall and winter precipitation, decisions on pre-irrigating should be made closer to spring planting time to take advantage of non-growing season precipitation.

Irrigation application efficiency typically refers to the amount of irrigation water available for crop ET divided by the gross irrigation water applied to a field. The amount of water available for the crop is that water which is stored in the soil. Given that crop ET is a primary driver of crop yield, minimizing irrigation water losses and reserving as much water as possible to

support ET are critical to maximizing productivity when irrigation water is limited. Losses occur through runoff, deep percolation (drainage), evaporation, and conveyance losses.

Irrigation system efficiencies vary dramatically, as shown in Table 1. For most situations, managing limited supplies of irrigation water with low efficiency irrigation systems is challenging at best. Upgrading to a higher efficiency system will

Table 1. Typical irrigation efficiencies.

Irrigation System	Range	Mean
	----- % -----	
Conventional furrow	25 - 60	40
Furrow with surge	40 - 80	60
Impact sprinkler	80 - 90	85
Spray head sprinkler	85 - 95	90
Drip	80 - 98	90

offer several advantages under limited-irrigation, but may not always be technically or economically feasible.

Management adjustments can be made to help increase irrigation application efficiency. One source of inefficiency in surface irrigation is the circumstance when excess irrigation water is applied in order to get water to the end of the row. This problem becomes more acute for long irrigation runs (>1,000 ft.) and/or coarse-textured soils. As Figure 3 shows, this leads to poor uniformity, with excess water applied at the upper end of the field and not enough water applied on the lower end of the field. Additionally, the extra set time required to adequately soak the bottom of the field often results in runoff losses or excess water accumulating and being lost to drainage at the lower end of the field.

Furrow irrigation systems can be improved by a variety of management practices such as:

- Shortening row length
- Increasing stream size and cutting back on set time
- Using optimum set time
- Packing furrows
- Using surge valves or manually surging rows

Most surface irrigation systems are inherently inefficient and limit irrigation options when water is in short supply. However, growers can make some management adjustments to improve their systems and maximize water available for crop production (Table 2).

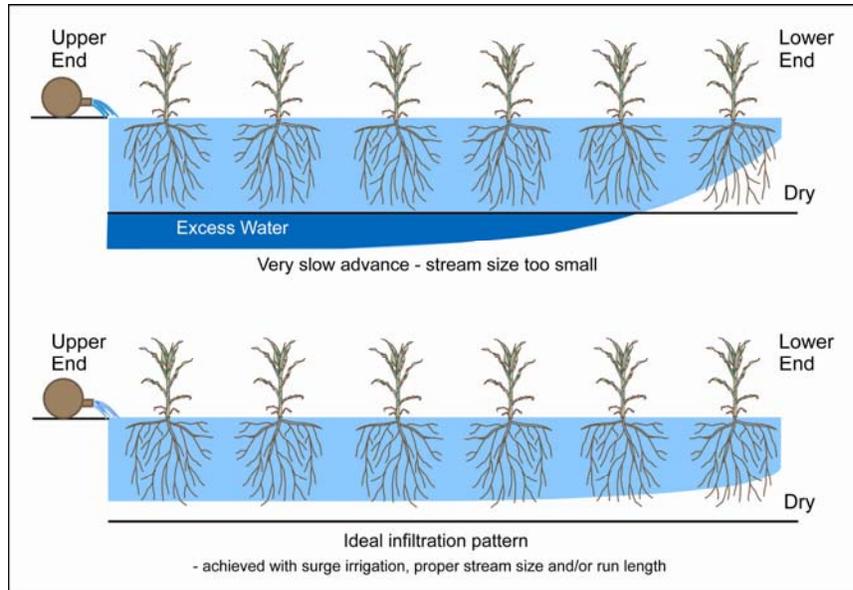


Figure 3: Water infiltration pattern under furrow irrigation.

Table 2. Adjustments to surface irrigation systems to increase efficiency or uniformity.

Practice	Benefit(s)	Management notes
Row Length	Proper row length improves uniformity.	Leveled fields should not exceed 660' on coarse soils and 1300' on fine textured soils.
Stream Size	Should be adjusted for slope and texture, and rate doubled when using linear polyacrylamide (PAM).	Easy management to adjust with both siphon tubes and gated pipe irrigation.
Length of set	Allows irrigator ability to control volume of application.	Should be adjusted for stream size and run length. 12-hour sets are convenient, but not appropriate for many situations. Reduce set times during early growth periods.
Furrow packing	Can increase advance rate 15-20% on some soils.	More effective when using a designed furrow forming/packing tool than when driven with a tractor.
Alternate row irrigation	Reduces gross irrigation by 46%, net by 29%. Allows for rainfall storage in dry row.	Not appropriate for steep slopes or soils with infiltration problems.
Surge irrigation	Can greatly improve uniformity and can improve efficiency by 10-30%.	Once learned, reduces labor requirement. Opportunity for fully-automated operation.
Crop residue	Increases infiltration. Reduces erosion and runoff.	Furrow irrigation can be accomplished under conservation tillage with proper management changes.* Residue generally increases advance time.
Polyacrylamide	Reduces erosion by up to 90%. Increases lateral wetting and infiltration.	Must increase stream size to maintain advance times. PAM concentration should be 10 parts ppm in advancing water for optimum results.

*See Guidelines for Using Conservation Tillage Under Furrow Irrigation TR02-6 at <http://www.colostate.edu/Depts/AES/>

Summary: Crop yields and gross returns from limited-irrigation will generally be less than a fully irrigated crop production system. However, changes in agronomic and irrigation management practices can help maintain respectable yields and net economic returns. Many of the production practices necessary for maximizing production under limited-irrigation systems are similar to practices for dryland (non-irrigated) production in semiarid areas. These practices often involve a shift in thinking toward maximizing the efficiency of utilization of both irrigation and precipitation. A combination of management strategies such as rotations with lower water use crops, reduced tillage

and residue management, irrigation timing and improved irrigation efficiency can help stretch limited water supplies in many situations.

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