

Irrigation, Crop, and Soil Management Impacts on Water Use in Pivots/Laterals

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Highlights

- Accurate evapotranspiration (ET) estimating improves irrigation scheduling and water use evaluation.
- In Utah trials, center pivot irrigation technologies and other drought strategies were evaluated with the soil moisture evapotranspiration (SMET) model.
- Low-elevation sprinkler packages generally yield more crop per inch of water applied.
- Moderate deficit irrigation can be a practical and sustainable strategy.
- Drought-tolerant alfalfa improved water productivity (WP); corn results depend on management.
- Conservation practices such as no-till and cover cropping require time before water use benefits are realized but they can offer long-term advantages for soil health.

Introduction

In Utah and other arid and semi-arid regions where drought cycles are frequent, and most cropland depends on irrigation, the need to use water efficiently becomes an utmost priority. When water is applied to a field, not all of it is used by the crop. The root zone soil water balance provides a framework for monitoring water use by tracking inputs such as precipitation and irrigation, and outputs such as runoff, evaporation, transpiration, soil storage, and deep percolation. Of these, evapotranspiration (ET) is the most important pathway for crop water use and, therefore, is a relevant measurement for farmers.

In this fact sheet, we describe ET, introduce a new tool called the soil moisture evapotranspiration (SMET) model, and share results from multi-year trials across Utah evaluating different center pivot irrigation technologies, deficit irrigation strategies, crop types, drought-tolerant crop genetics, and conservation agriculture practices. These findings highlight how Utah growers can improve

water productivity and maintain profitable production under limited water supplies.

The Agricultural Water Balance

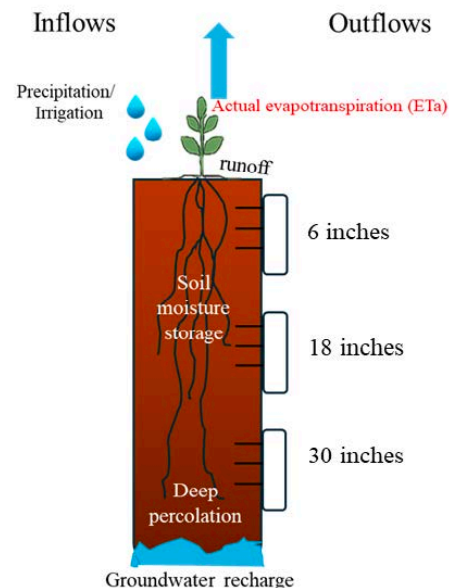
Water applied to fields through irrigation or received as precipitation is not all available to crops. A portion is lost as surface runoff if infiltration is poor (e.g., due to soil texture, compaction, sodicity, or lack of residue cover). Some infiltrated water is stored in the soil and made available to plant roots, while another fraction percolates below the crop root zone and eventually recharges groundwater (Barker, 2023). Often, the largest outflow from the soil is ET, which represents water evaporating directly from the soil surface combined with water transpired by the crop (Figure 1).

A simple equation expresses this balance:

$$\text{Precipitation} + \text{irrigation} = \text{runoff} + \text{evapotranspiration} + \text{change in soil water storage} + \text{deep percolation}$$

Although each term is important for understanding field hydrology, ET is the component that is most directly related to crop growth. Accurately estimating ET allows producers to better schedule irrigation, compare the efficiency of different practices, and evaluate water use productivity.

Figure 1. Pictorial Depiction of a Root Zone Soil Water



Balance

In root zone soil water balance, irrigation and precipitation are inflows into the system and evapotranspiration (ET), runoff, and deep percolation leading to groundwater recharge are outflows. Soil moisture storage is the portion

Notes. In

of water being stored in the soil. Volumetric water content sensors (TEROS 10, shown as white and black sensors) were installed at 6-, 18-, and 30- inch depths to measure soil moisture in the root zone.

Understanding Evapotranspiration

Actual ET reflects the real water consumption of a crop in its specific soil, climate, and management environment. This is as opposed to some models of ET that represent idealized conditions. For farmers, actual ET is an important measure because it represents how much water crops truly use, not just how much is applied. Traditionally, ET has been estimated using expensive methods such as lysimeters (large steel boxes of soil), specialized weather stations (like eddy covariance systems), or satellite remote sensing. While scientifically robust, these methods are often impractical for everyday decision-making on farms due to their high cost, the need for specialized technical expertise, and limited resolution (many cannot be used in research plot trials).

Water Use Efficiency and Water Productivity

Efficient water use is essential for profitable and sustainable farming. Two useful ways to understand how water contributes to crop growth are **water use efficiency (WUE)** and **water productivity (WP)**. WUE is a measure of how effectively a crop converts the total water it uses in the form of ET into the yield. It is computed as:

$$WUE = \frac{\text{Aboveground plant biomass}}{ET}$$

WP, on the other hand, measures the yield produced per inch of irrigation water applied through the system. It is computed as:

$$WP = \frac{\text{Aboveground plant biomass}}{\text{Applied irrigation water}}$$

These indicators, together, help us understand how well the crop and irrigation systems are working to make the most of available water. When WUE and WP improve, more crops are produced with less water loss.

The SMET Model: A Research Tool for Understanding Crop Water Use

The **soil moisture evapotranspiration (SMET)** model, developed by researchers in the Department of Civil

and Environmental Engineering at Utah State University (Hargreaves O., 2022; Hashemi et al., 2025), was used in this project to better understand how different management practices influence crop water use. SMET integrates soil moisture changes with reference ET from nearby weather stations to estimate actual crop evapotranspiration (ET). Because soil moisture sensors and weather data were already part of these research sites, SMET provided a practical, cost-effective way for the research team to monitor how water moved through the soil profile and how crops responded to different treatments. In this study, SMET served as a valuable analytical tool for comparing irrigation technologies, deficit irrigation strategies, drought-tolerant genetics, and conservation practices. While the model offers promise, it currently requires data processing steps and technical expertise that limit its direct use by farmers. However, these field trials demonstrate how SMET can generate meaningful insights when embedded within research and extension projects, and future development of farmer-friendly interfaces or decision-support tools could make this type of water-use monitoring more accessible.

Research on Water Optimization Practices in Utah

Beginning in 2020, long-term trials were established near Vernal, Utah, followed by Cedar City in 2021. Researchers chose these sites to represent diverse soils, climates, and cropping systems across the state. The trials were used to test a combination of center pivot irrigation technologies, deficit irrigation strategies, drought-tolerant genetics, and conservation agriculture practices (Holt et al., 2021; Crookston et al., 2025). At each location, researchers used soil moisture sensors and weather stations to estimate actual ET using the SMET model, while crop yields were measured to calculate WUE and WP.

Irrigation Technologies

Four center pivot/lateral sprinkler technologies were evaluated, including **mid-elevation spray application (MESA)**, **low-energy precision application (LEPA)**, **low-elevation spray application (LESA)**, and the **low-elevation Nelson Advantage® application (LENA)**. Figure 2 shows these systems, which differ in nozzle design, wetted diameter, application efficiency, and height above the crop canopy.

Figure 2. Four Irrigation Technologies Evaluated in the

Study

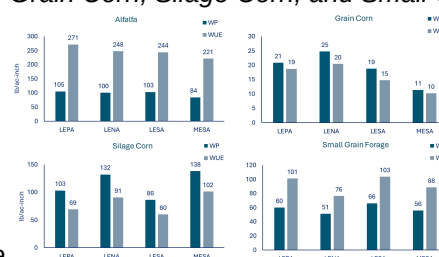
Although low-elevation systems are designed to reduce wind drift, ET was very similar across technologies (Table 1). In most crops, LENA, LESA, and MESA had nearly identical ET values, and LEPA showed slightly lower ET in some cases. These small differences indicate that all systems delivered comparable amounts of water into the soil profile during the growing season, despite known differences in wind drift and evaporation losses that range between 15%–20% for MESA compared to 2%–5% for low-elevation systems (Crookston et al., 2022).

Table 1. Effect of Irrigation Technologies on Estimated Actual Evapotranspiration (ET) for Alfalfa, Grain Corn, Silage Corn, and Small Grain Forage

Crops	Growing season actual evapotranspiration (ET) (inches)			
Low-elevation precision applicatio (LEPA)	Low-elevation Nelson applicatio (LENA)	Low-elevation spray applicatio (LESA)	Mid-elevation spray applicatio (MESA)	
Alfalfa	20	20	21	20
Grain corn	22	26	26	27
Silage corn	22	20	21	21
Small grain forage	19	21	20	20

Because ET did not differ much among technologies, WUE provides the clearest comparison of system performance. Across all crops, WUE was noticeably greater with low-elevation technologies compared to MESA. In alfalfa, LEPA, LESA, and LENA systems produced 23–50 pounds per acre-inch (lb/ac-inch) more biomass than MESA (Figure 3). Grain corn also had greater WUE for low-elevation sprinklers, with 5–10 lb/ac-inch higher

productivity under low-elevation systems. For silage corn, WUE was greatest in MESA (102 lb/ac-inch), with LENA performing next best (91 lb/ac-inch). In small grain forage, LESA, and LEPA improved water productivity by 15 and 13 lb/ac-inch, respectively. However, LENA had a lower WUE (12 lb/ac-inch) compared to MESA. Overall, these results are evidence that low-elevation sprinkler packages generally use water more effectively, delivering measurable improvements in crop production per inch of irrigation water applied.

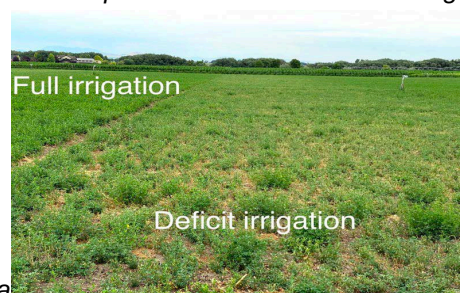
Figure 3. Water Productivity (WP) and Water Use Efficiency (WUE) (lb/ac-inch) Under Four Irrigation Technologies (MESA, LEPA, LESA, and LENA) for Alfalfa, Grain Corn, Silage Corn, and Small Grain

Forage

Note. The four irrigation technologies evaluated: mid-elevation spray application (MESA), low-energy precision application (LEPA), low-elevation spray application (LESA), and low-elevation Nelson Advantage (LENA)

Deficit Irrigation

Deficit irrigation, in which less water than the full crop demand is applied, was tested at 50% of crop ET (Figure 4). This approach can help conserve water while maintaining acceptable yields, especially during dry years when water allocations are limited.

Figure 4. Comparison of Full and Deficit Irrigation in

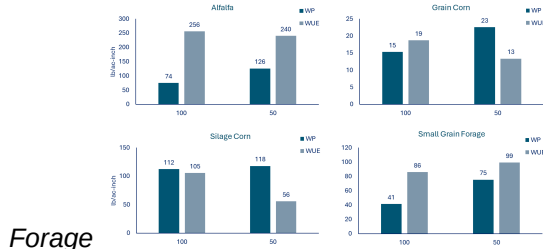
Alfalfa

Table 2. Effect of Deficit Irrigation on Actual Evapotranspiration (ET) for Alfalfa, Grain Corn, Silage Corn, and Small Grain Forage

Crops	Growing season actual evapotranspiration (ET) (inches)	
100% irrigation level	50% irrigation level	
Alfalfa	20	19
Grain corn	25	25
Silage corn	22	21
Small grain forage	20	20

In field trials in Utah, deficit irrigation reduced ET (Table 2) and substantially increased WP across most crops by increasing yield per inch of applied irrigation water. In alfalfa, WP improved by 52 lb/ac-inch with 50% irrigation compared to full irrigation, while small grain forage had a similar trend with an increase of about 34 lb/ac-inch (Figure 5). Grain corn also demonstrated moderate improvement of 8 lb/ac-inch in WP under deficit irrigation. Silage corn showed a smaller improvement of about 6 lb/ac-inch compared to full irrigation. However, WUE decreased with deficit irrigation for alfalfa (16 lb/ac-inch), grain corn (6 lb/ac-inch), silage corn (49 lb/ac-inch), but increased for small grain forage (13 lb/ac-inch). These differences indicate that alfalfa and small grain forages can tolerate moderate water stress more efficiently than silage corn. In addition to conserving water, deficit irrigation often enhances forage quality by improving fiber content and feed value, which can add market value during periods of feed shortage. This practice provides an important management option to stretch limited water supplies across more acres without severely reducing yield. Overall, these results are evidence that moderate deficit irrigation can be a practical and sustainable strategy to balance production, profitability, and water productivity.

Figure 5. Water Productivity (WP) and Water Use Efficiency (WUE) (lb/ac/inch) Under Full (100%) and Deficit (50%) Irrigation for Alfalfa, Grain Corn, Silage Corn, and Small Grain



Drought-Tolerant Genetics

Genetic improvement is another pathway for increasing water productivity. In the trials, we tested drought-tolerant alfalfa (Ladak II) and corn (DKC 47-27 hybrid) varieties against conventional counterparts (Figure 6). These drought-tolerant varieties are designed to maintain yield and quality when exposed to moderate water stress by using water more efficiently and maintaining leaf function during dry periods. Table 3 presents ET data for drought-tolerant genetics in alfalfa and the combined effect of drought-tolerant genetics, no-till, and cover cropping in grain and silage corn.

Figure 6. Drought-tolerant (DT) genetics of corn compared to conventional varieties.



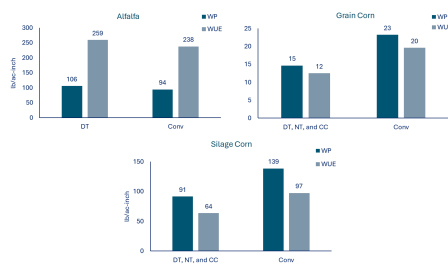
Table 3. Effect of Drought-Tolerant Genetics on Actual Evapotranspiration (ET) in Alfalfa and Combined Effects of Drought-Tolerant Genetics, No-Till Cultivation, and Cover Cropping in Grain and Silage Corn

Crops	Growing season actual evapotranspiration (ET) (inches)	
Drought tolerant	Conventional	
Alfalfa	20	20
Grain corn	25	25
Silage corn	22	21

A drought-tolerant variety of alfalfa (Ladak II) improved WUE by 21 lb/ac-inch compared to conventional alfalfa varieties (Figure 7). In grain corn, however, the combined use of drought-tolerant hybrids with conservation practices such as no-till and cover cropping did not lead to greater productivity. In grain corn and silage corn, WUE was reduced by 8 and 33 lb/ac-inch, respectively. Overall, these results are evidence that while drought-tolerant genetics can enhance performance in deep-rooted, perennial crops like alfalfa, their benefits in annual crops such as corn may depend heavily on management

systems and growing-season conditions. Recent studies have shown similar trends, with drought-tolerant maize hybrids performing well under certain water-limited scenarios but not consistently across all environments or management practices (Hao et al., 2024; Zhao et al., 2025). Even modest genetic gains in water efficiency can become meaningful across large acreages, helping producers maintain production stability during drought years.

Figure 7. Water Productivity (WP) and Water Use Efficiency (WUE) (lb/ac-inch) of a Drought-Tolerant Alfalfa Variety and the Combined Effect of Drought-Tolerant Hybrids, No-Till, and Cover Cropping in Grain and Silage Corn as Compared to Conventional Varieties and



Management

Notes. DT = drought-tolerant; NT = no-till; CC = cover cropping; conv = conventional

Conservation Agricultural Practices

Researchers evaluated conservation agriculture, including no-till and cover cropping, for its potential to improve soil water storage and long-term sustainability (Figure 8). These practices aim to improve soil health. No-till practices, which retain a majority of crop residue on the soil surface, can improve infiltration and reduce evaporation losses over time.

Figure 8. Comparison of Tillage vs. No-Tillage vs. Cover Cropping in a Water Optimization Experiment Field in Utah

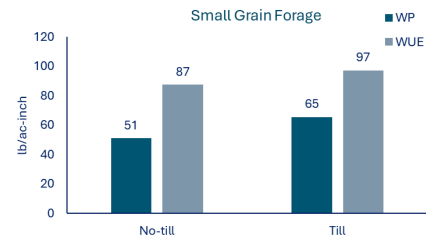


Table 4. Effect of No-Till Cultivation in Small Grain Forage on Actual Evapotranspiration (ET)

Crop	Growing season actual evapotranspiration (ET) (inches)	
No-till	Conventional	
Small grain forage	20	20

No-till in small grain forage did not influence ET (Table 4) but reduced WUE by 10 lb/ac-inch (Figure 9). Similar trends were observed for grain corn and silage corn under combined drought-tolerant hybrids, no-till, and cover cropping treatment, as explained previously (Figure 7). These findings are evidence that during the initial transition period, stands were often reduced with no-till, leading to lower ET and productivity. This pattern is consistent with global analyses showing that no-till frequently results in yield reductions of 5.1% across 50 crops (Pittelkow et al., 2015). Overall, conservation practices have potential benefits for soil health and long-term resilience but require patience and adaptation during the transition years.

Figure 9. Water Productivity (WP) and Water Use Efficiency (WUE) (lb/ac-inch) Under Conventional Tillage and No-Till in Small Grain



Forage

Summary

Results from long-term trials indicate that low-elevation irrigation systems, moderate deficit irrigation, and drought-tolerant alfalfa varieties can substantially improve WUE and WP. Conservation practices add long-term value but require a transition period before clear benefits emerge. By focusing on actual ET rather than only applied irrigation, growers can make more informed decisions about which practices maximize yield per unit of water consumed. Continued collaboration among producers, researchers, and water managers will be critical for refining these and other strategies and expanding their adoption across the state. Furthermore, SMET could be a tool for evaluating how to improve WP and WUE with a variety of irrigation crops and soil management practices to address water scarcity and optimize water in Utah and other arid regions.

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