Corn Yield Response to Drainage Water Recycling using Subirrigation

Kelly Nelson, Jeppe Kjaersgaard, Benjamin Reinhart, Jane Frankenberger, Rebecca Willison, Kpoti Gunn, Charlotte Lee, Lori Abendroth, Laura Bowling, Ali Rashid Niaghi

INTRODUCTION

Drainage water recycling is a practice of capturing and storing agricultural surface and subsurface drainage water in a reservoir, and then reusing that water as supplemental irrigation. This innovative approach to drainage water management can provide several benefits within drained agricultural landscapes. First, less nitrogen and phosphorus are lost from the field to impact the downstream waters. Second, the ability to reuse that nutrient-rich water as supplemental irrigation in critical development stages can increase crop yields.

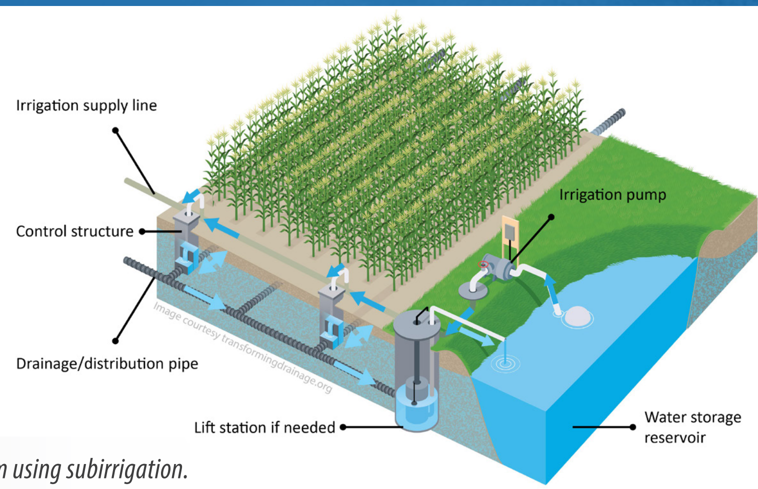


Figure 1. A drainage water recycling system using subirrigation.

Drainage water recycling systems can be implemented and managed in a variety of ways to fit the characteristics of a given site or a management style. Much of the research that was evaluated for this publication focused on the use of subirrigation as the primary irrigation technique (Figure 1). Subirrigation is the practice of applying water back through the subsurface (tile) drains to raise and manage the soil water table within the crop rooting zone. Sprinkler irrigation, drip irrigation, and flood irrigation are other ways to deliver supplemental water from the reservoir to the crops, and each approach may provide different benefits or obstacles for a specific situation that could influence crop yields.

Several studies have shown that the practice of drainage water recycling can improve corn yields by providing supplemental irrigation. These research studies often reflect only one location and a limited number of years. This Extension publication evaluates the results from seven different sites across the U.S. Midwest, drawing lessons about the complex effects of drainage water recycling using subirrigation on corn yield. Because it brings together several sites, the results are expected to be applicable to other sites in the Midwest. This publication provides key findings from a synthesis of available research on corn yields with drainage water recycling by Willison et al. (2021), including:

- yield impacts from drainage water recycling at seven sites across the Midwest;
- an analysis of corn yield impacts based on crop development stage and precipitation patterns;
- examples of sites where drainage water recycling research can provide lessons for other sites;
- an assessment of the potential for the practice across the Midwest; and
- resources available for evaluating potential sites for drainage water recycling and subirrigation.

SUBIRRIGATION SITES USING DRAINAGE WATER RECYCLING ACROSS THE MIDWEST

Of the seven sites with drainage water recycling, six used subirrigation and one used surface drip irrigation. The sites are located in Minnesota (two sites), Missouri (two sites), and Ohio (three sites). The location, irrigation system and reservoir type, dominant soil type, and years of corn yield data from the sites are shown in Figure 2. The total years of data across all sites (referred to as "site-years") is 53. Soil textures ranged from clay to silt loam.

For each site-year, yield comparisons were made between drainage water recycling and conventional (free) drainage treatments, except for the Clay County, Minnesota, site that was compared to controlled drainage and to the county average. Both drainage water recycling and conventional (free) drainage treatments were managed consistently in terms of field and crop management (e.g., tillage, fertility, pest management, and hybrid).

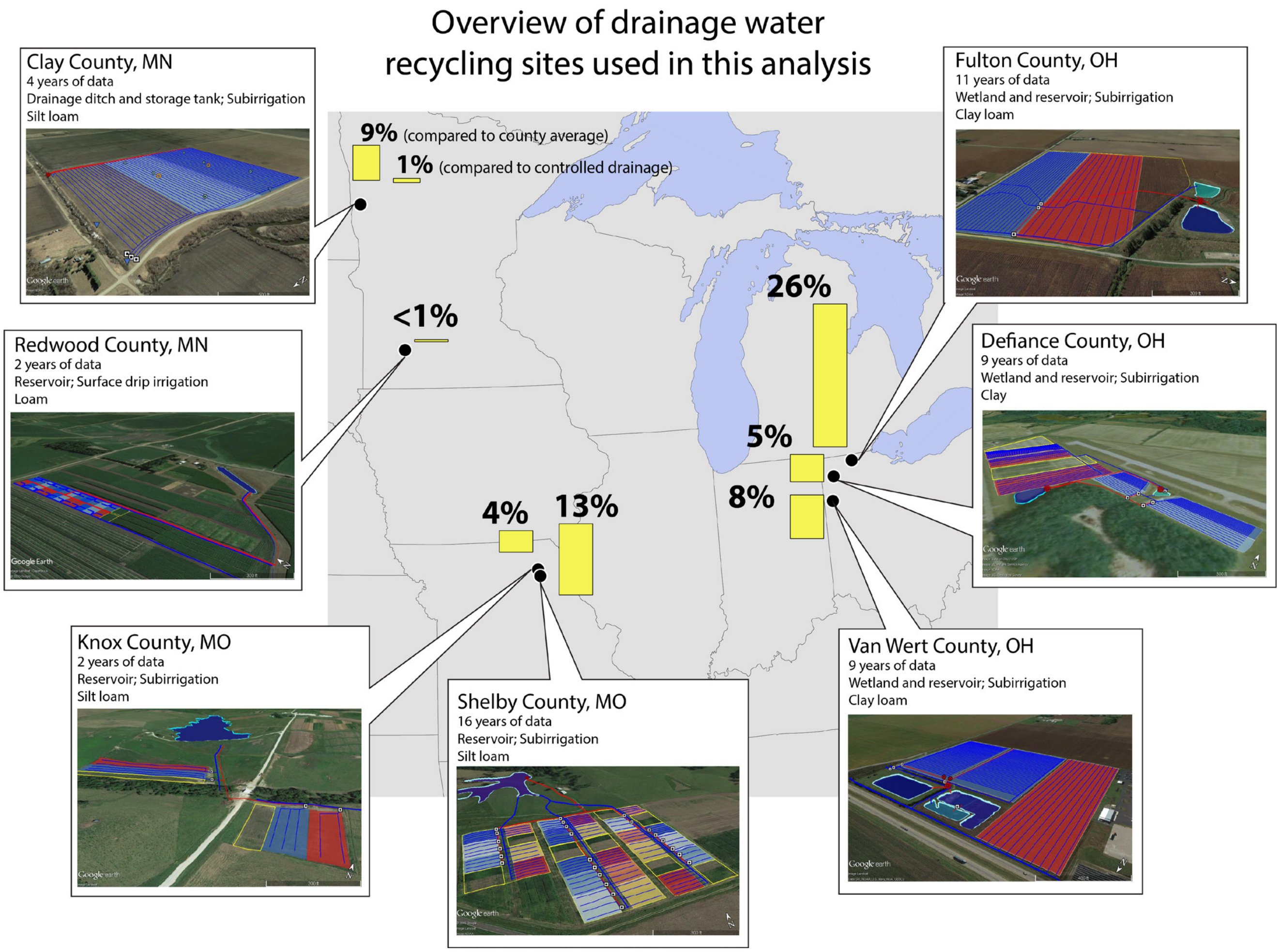


Figure 2. *Seven drainage water recycling sites in Minnesota, Missouri, and Ohio provided 53 site-years of data. For each site, years of corn yield data, type of water storage reservoir, type of irrigation, and dominant soil type are provided. Corn yield increase (yellow bars in the map) ranged from less than 1% to 26%, showing that this practice can be very beneficial in certain conditions and when managed well. References for studies at each location are included in Table 2 of Willison et al. (2021).*

YIELD IMPACTS OF DRAINAGE WATER RECYCLING

Drainage water recycling increased yield over free drainage in 64% of the site-years evaluated, which are those above the diagonal line in Figure 3. The average corn yield increase was 19 bushels per acre (147 bu/ac. for free drainage, 166 bu/ac. for drainage water recycling; Figure 4). This yield increase was greater in dry years. The practice also helped reduce the yield variability from year to year (shown by smaller height of the boxes for drainage water recycling compared to free drainage; Figure 4) by providing additional water during the periods where the corn is most vulnerable to water stress and yield reduction, showing this practice can increase the stability and resiliency of crop yield.

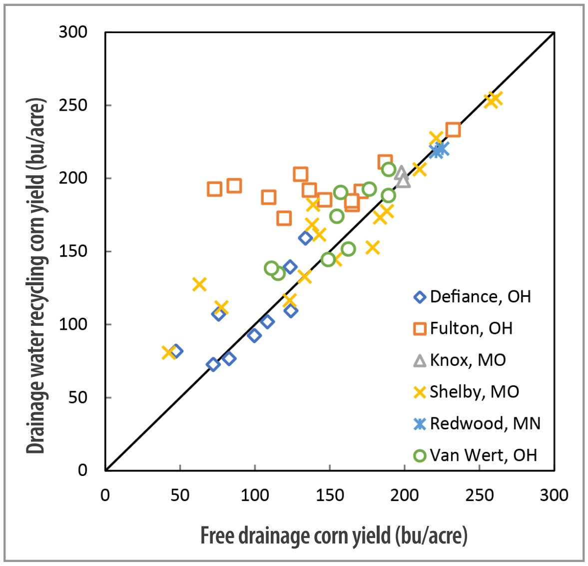


Figure 3. *Drainage water recycling and free drainage corn yield for all years and locations. The 1:1 line indicates equal yields for DWR and FD.*

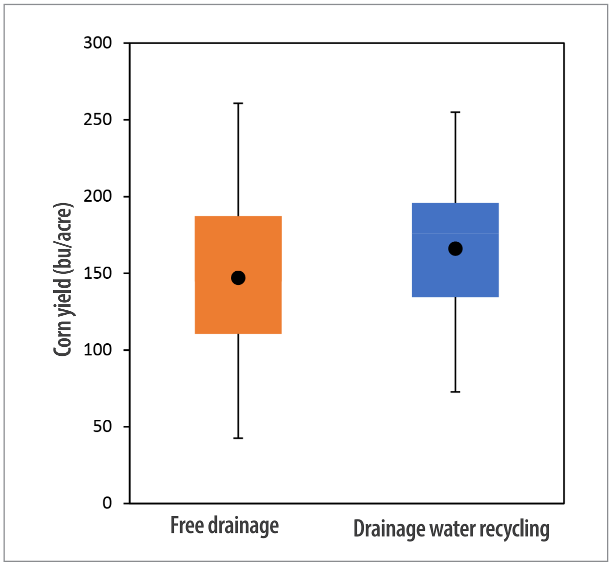


Figure 4. *Summary of yields for drainage water recycling and free drainage. The boxes indicate yields between the 25th and 75th percentiles, whiskers show the minimum and maximum yields, and the points show average yield values.*

YIELD IMPACTS DURING VARIOUS CORN DEVELOPMENT STAGES

Corn growth is often classified into development stages, which is used to describe and manage corn through the season (Box 1). The sensitivity of corn yield to wet or dry conditions varies depending on which development stage the stress occurs, and is most sensitive during the late vegetative state, pollination, and early grain filling. This study examined the relationship between precipitation during various stages and the resulting yield impacts with and without drainage water recycling. Precipitation below a certain threshold during a sensitive stage of crop development would lead to greater yield impact from subirrigation than during an earlier or later period of crop development.

Based on the models develop by Willison et al. (2021), precipitation during most stages (V1-V8 and R3-R6) did not clearly increase yield due to subirrigation. However, precipitation during the period from V9 (late vegetative stage) to R2 (early reproductive stage) showed a strong yield benefit of drainage water recycling.

BOX 1: CORN DEVELOPMENT STAGES

Corn development stages are classified as vegetative (V) or reproductive (R). The vegetative stages are based on the number of visible leaf collars. For example, stage V9 means that 9 leaf collars are visible. Vegetative leaf staging ends when the corn develops a tassel (VT), and the reproductive stages begin. R1 is referred to as "silk," and R2 as "blister," meaning that kernels resemble blisters with clear liquid.

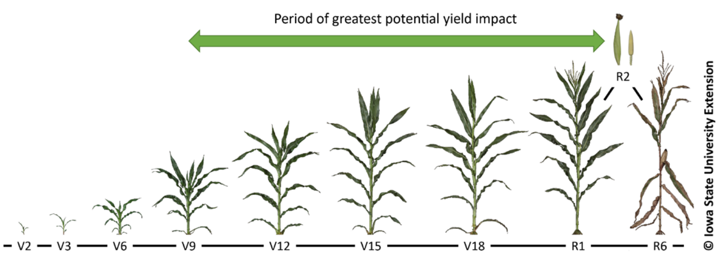


Figure 5 shows the estimated yield response to precipitation during two periods, V9 to VT and R1 to R2 for drainage water recycling (solid lines) and free drainage (dashed lines). The threshold (indicated by where the lines cross) was on average 3 inches in the first period (V9 to VT), and 2 inches in the second (R1 to R2), for a total of about 5 inches from V9 to R2. To the left of the threshold, precipitation amounts during the crop development period were low, and drainage water recycling resulted in a yield advantage (area shown in green). Under these dry conditions, drainage water recycling increased yield – compared to free drainage – by providing supplemental water to minimize deficit water stress conditions. To the right of the threshold, the precipitation amounts were higher and, in general, yields decreased with drainage water recycling. However, this yield decrease was not significant and was likely due to the fact that subirrigation systems were not switched to drainage mode during wet periods, resulting in waterlogged conditions that impacted crop development.

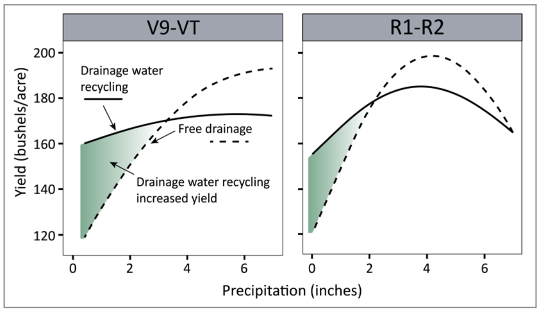


***Figure 5**. Precipitation during the V9-VT and R1-R2 development stages and the modeled yield response. The green shaded area indicates a yield advantage for drainage water recycling.*

YIELD IMPACTS OF PRECIPITATION FROM DEVELOPMENT STAGES V9-R2

To further evaluate the yield impact from V9 to R2, precipitation amounts during this period for all site-years were classified as dry (driest 25% of years), normal, and wet (wettest 25% of years). During dry years, drainage water recycling increased average yield by 43 bu/acre. (Figure 6). During wet years, yields for free drainage and drainage water recycling were similar.

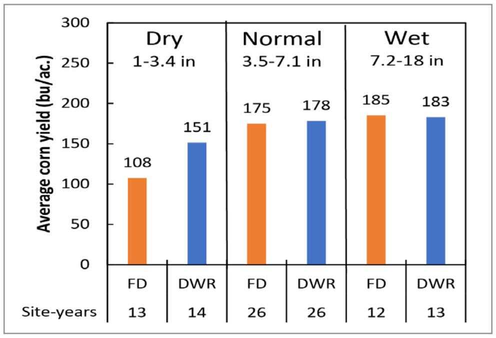


***Figure 6**. Average grain yield for drainage water recycling (DWR) and free drainage (FD) during years in which corn development stages from V9 to R2 were classified as dry, normal or wet.*

ACTIVE MANAGEMENT IS IMPORTANT; TOO MUCH WATER IS A PROBLEM TOO

The study also confirmed that active management of control structures, meaning that the outlet is lowered before a precipitation event, is important for drainage water recycling systems using subirrigation. Figures 5 and 6 suggest that there is potential for drainage water recycling using subirrigation to negatively impact yields during the V9 to R2 period if excessive precipitation occurs. Subirrigation, which relies on managing the water table near the crop root zone, can put crops at risk of waterlogging conditions if large precipitation events occur during the growing season. Actively managing or automating the control structures to allow excess water to drain from the soil profile prior to or shortly after a precipitation event can minimize excess water stress during the V9 to R2 period.

POTENTIAL YIELD IMPACTS ACROSS THE MIDWEST

To better understand potential impacts of drainage water recycling across the Midwest, precipitation during the V9 to R2 critical period for dry conditions was analyzed. This critical period occurs at different times across the region (Figure 7). For example, in Missouri it typically starts in late June while in northern states it starts in July. These dates were determined based on USDA NASS planting records for each state, average corn hybrid maturity by county, and gridded temperature data from 2000 to 2015. Growing degree days were summed from the date that 50% of the corn was planted during this period. See Lee et al. (2021) for data sources and methods.

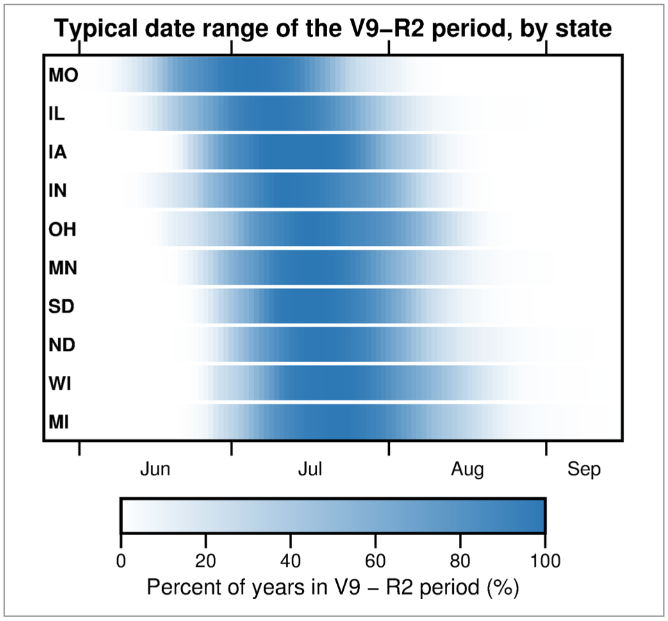


***Figure 7**. Typical date range of the growing degree day calculated V9-R2 period during 2000–2015. The percent of time each day of the year fell within the V9-R2 period is plotted by state.*

PRECIPITATION DURING THE CRITICAL PERIOD

Drainage water recycling is likely to improve corn yield in years when precipitation is below the critical threshold of 5 inches during the V9 to R2 period. Therefore, to evaluate the potential for this practice to increase yield across the Midwest, precipitation during this critical period was summed for each year between 2000 and 2015. Figure 8 shows that in many areas across the Midwest, precipitation during the V9 to R2 period was below the 5-inch threshold in at least 50% of the years, suggesting there is substantial potential for drainage water recycling to improve corn yields throughout the region. Extreme temperatures during the critical period may also exacerbate the effects of limited precipitation and increase the potential impact of drainage water recycling.

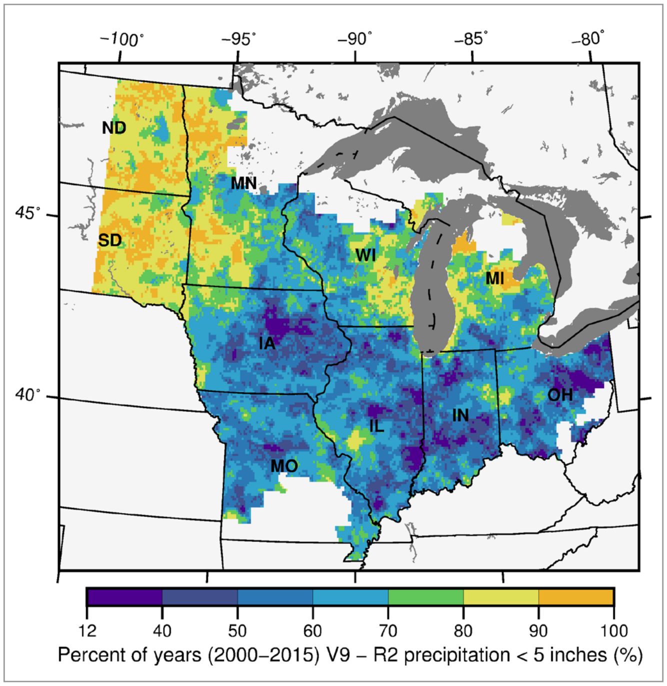


Figure 8. *Percent of years during the 2000-2015 period where V9-R2 precipitation was less than the 5-inch threshold.*

SOIL FACTORS AFFECTING RESPONSE TO SUPPLEMENTAL IRRIGATION

Soil characteristics also play an important role influencing the potential yield benefits of drainage water recycling. Deep soils with high water-holding capacity are less likely to be impacted by short periods of water deficit during critical crop growth stages and may benefit less from irrigation. Shallow soils and soils that are predominantly sandy or clayey are examples of soils where water holding capacity may be less, and where the potential for drainage water recycling may be greatest.

POTENTIAL SUITABILITY FOR SUBIRRIGATION

Drainage water recycling can use any method of irrigation. If subirrigation is used, areas suitable are limited to those with certain characteristics including the following:

- higher soil hydraulic conductivity to allow water to move faster from the tiles into the soil in the field,
- an impermeable layer in the soil to allow the water table to be raised to a desired depth, and
- flat topography.

See the Subirrigation Suitability Tool (page 8) to identify locations that might be suitable pending further investigation. The tool is a result of an analysis that showed as much as 1.9 million acres (9%) of agricultural land in the Midwest shows high potential suitability for subirrigation (Yu et al., 2020). In areas that are not suitable for subirrigation, other irrigation methods such as subsurface drip or sprinkler irrigation may be appropriate, and can also be used as part of a drainage water recycling system.

BOX 2: EXAMPLE OF A DRAINAGE WATER RECYCLING SYSTEM IN OHIO

Successful subirrigation requires soils that are sufficiently permeable to provide good drainage and allow water in the drains to raise the water table effectively.

Overview: Field experiments of drainage water recycling were implemented at sites in Defiance and Fulton counties in Northwest Ohio between 1997 and 2008. As part of the innovative Wetland Reservoir Subirrigation Systems (WRSIS) program, subsurface drainage and surface runoff was captured, filtered through a wetland, stored in a reservoir, and pumped back into the subsurface drainage network (subirrigation) during extended dry periods to meet crop water demands. Sites were located in flat topography with poorly to very poorly drained soils. Drain tile spacings were 8 to 16 ft for drainage water recycling and 20 to 40 ft for free drainage for the clay soil at Defiance, and 15 ft for drainage water recycling and 45 ft for free drainage at Fulton with a silty clay soil.

Soil characteristics: Subirrigation works best when soil hydraulic conductivity is high and there is an impermeable layer below the drains. Hydraulic conductivity at the Fulton site was adequate (2.4 to 14 in/day), but was very low in the clay soil at the Defiance site (0.2 to 0.7 in/day). An impermeable soil layer below the surface was located at approximately 2.5 feet (Defiance) and 4 feet (Fulton).

Drainage and subirrigation effectiveness: An example of the water table depth at Fulton and Defiance is shown in Figure 9, based on DRAINMOD simulations for seven months in 2015. At Fulton (top), drainage is good with a water table level that was 4 feet below the surface before subirrigation on June 9 raised it to 2 feet. Precipitation events in June raised the water table to the surface, but it quickly drained. At Defiance (bottom), drainage was poor in April and May (water table 0 to 2 feet deep) due to the very low hydraulic conductivity of the clay soil, and subirrigation in June raised the water table too slowly to provide adequate water.

Yield impacts: Drainage water recycling exhibited yield benefits every year at Fulton (blue squares in Figure 10, which are all above the 1 to 1 line, meaning that drainage water recycling always yielded higher than free drainage). However, there was a benefit in only about one out of every three years (33%) at Defiance (orange circles in Figure 10), which was probably due to the low soil hydraulic conductivity and shallow impermeable layer.

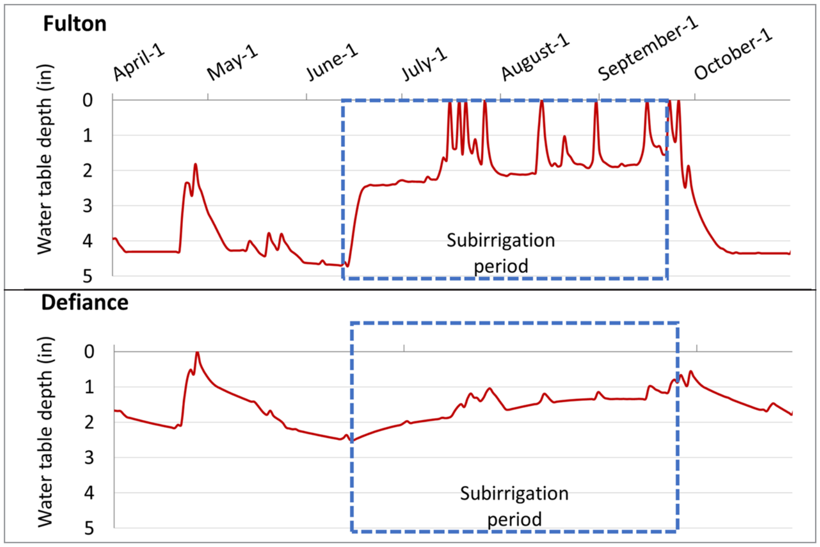


Figure 9: *Simulated water table depth for subirrigated fields at the Fulton (top) and Defiance (bottom) sites. Subirrigation, which was started in late June (blue dashed square), raised the water table immediately at Fulton, but very slowly at Defiance due to the slow hydraulic conductivity of the clay soil.*

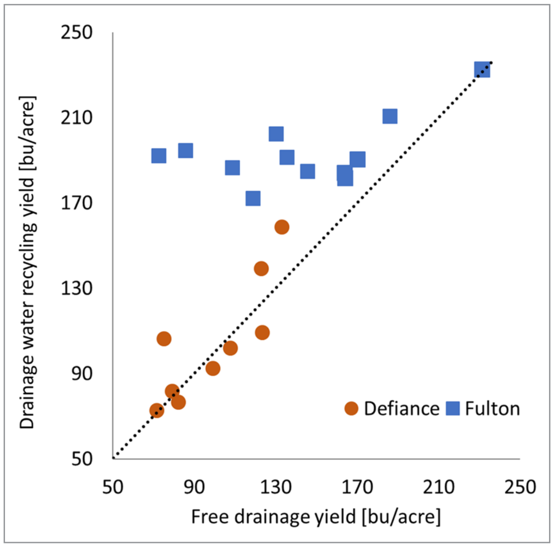


Figure 10: *Annual corn yield under drainage water recycling and free drainage at Defiance and Fulton sites. Years above the diagonal line show increased corn yield due to drainage water recycling.*

BOX 3: EXAMPLE OF A DRAINAGE WATER RECYCLING SYSTEM IN MISSOURI

Successful subirrigation is managed differently each year.

Overview: Drainage water recycling using subirrigation has been the focus of field experiments at the University of Missouri Drainage and Subirrigation (MUDS) sites in Shelby County, Missouri, for the past 17 years. The MUDS site has a shallow, poorly drained silt loam soil with an impermeable claypan layer 1.5 to 2 feet below the surface, a saturated hydraulic conductivity of approximately 1 inch per hour, and good conditions for implementing subirrigation.

Yield benefits depend on active water management. In order to maximize the potential benefits of subirrigation at this site, the subirrigation system was managed according to precipitation patterns throughout the year. Figure 11 shows three different examples.

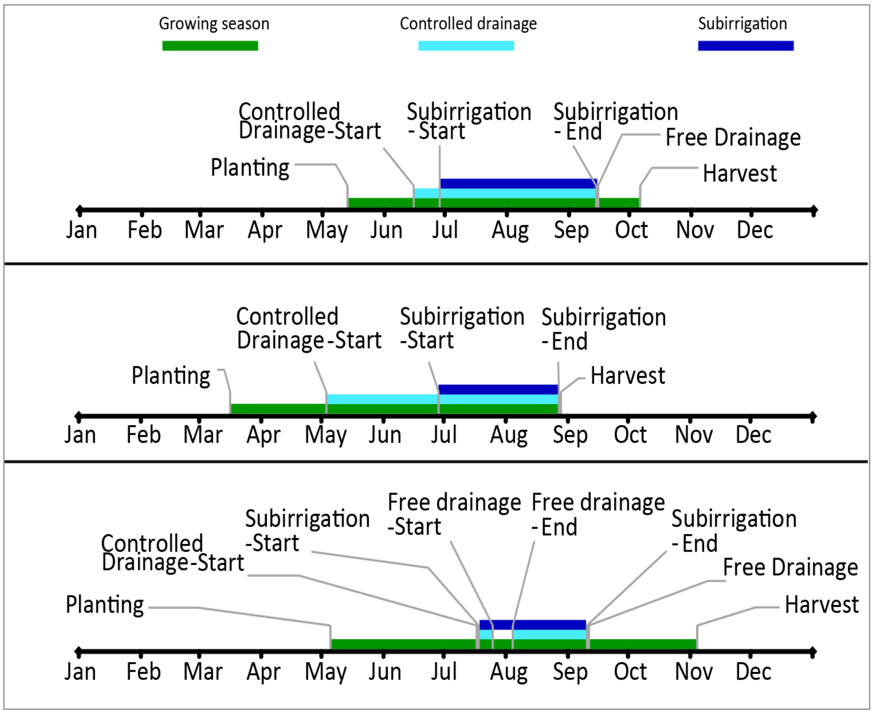


Figure 11*. Controlled drainage and subirrigation management in normal (top), dry (middle), and wet (bottom) conditions.*

Normal conditions (2007). The tile drainage system was put into controlled drainage mode following crop establishment, and subirrigation was initiated to maintain a target water table level throughout the summer. Once the crop had matured, the system was put into free drainage mode to prepare for harvest.

Dry conditions (2012). The system was put into controlled drainage mode earlier and remained in subirrigation mode all the way until harvest in an effort to maintain a constant water table throughout the growing season.

Wet conditions (2008). The system was put into controlled drainage later and required a period of free drainage during the growing season to avoid crop stress due to excess soil water.

CONCLUSIONS

Drainage water recycling is the practice of capturing and storing agricultural drainage water, and then reusing that water as supplemental irrigation. This publication synthesizes the impact of this practice on corn yield and yield variability from 53 site-years at seven sites across the Midwest. Key findings include:

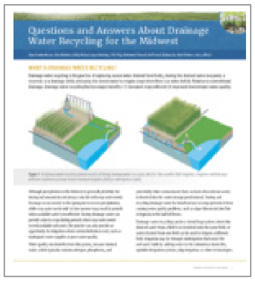
- Drainage water recycling adds resilience and increases yield stability. The practice increased yield compared to free drainage in 64% of the site-years by an average of 19 bu/acre, and reduced the yield variability by 28%.
- Precipitation during the V9 to R2 development period is critical, influencing the response of corn to drainage water recycling. Modeling showed that when precipitation was 5 inches or less during this period, drainage water recycling consistently increased yield over free drainage. During particularly dry years (3.4 inches or less during the V9 to R2 period), the average yield increase was 43 bu/acre.
- Active management of drainage water recycling systems using subirrigation, such as allowing for drainage of excess water to avoid waterlogging during the V9 to R2 period, is necessary to fully realize the potential yield benefits from the practice.
- Across much of the Midwest, precipitation analysis suggests potential for drainage water recycling to improve corn yields in at least 50% of the years (see Figure 8). Subirrigation, which is one possible irrigation method, may be suitable on as much as 1.9 million acres (9%) of agricultural land, although site-specific analysis is needed.

RESOURCES FOR LEARNING MORE ABOUT DRAINAGE WATER RECYCLING SYSTEMS

Evaluating Drainage Water Recycling Decisions (EDWRD) is a tool to estimate the potential water quality and irrigation benefits from drainage water recycling given various sizes of water storage. Based on user input about soil properties, field and reservoir sizes, and management, it uses a water balance approach to estimate how much drainage water can be captured, stored, and utilized for supplemental irrigation. (https://transformingdrainage.org/tools/edwrd/)

The **Subirrigation Site Suitability Tool** is an online mapping application that identifies the potential suitability for subirrigation of land in the U.S. Midwest based on criteria for soil hydraulic conductivity, presence of an impermeable layer, topography, and drainage class. The tool can also be used to identify the most limiting criteria for subirrigation.(https://transformingdrainage.org/tools/subirrigation-suitability-tool/)

Questions and Answers about Drainage Water Recycling for the Midwest provides an introduction to the practice and what is currently known about drainage water recycling. (https://transformingdrainage.org/practices/drainage-water-recycling/)



Storing Drainage Water – A Win for Crop Production and Water Quality, 3-min. video, (https://transformingdrainage.org/videos/storing-drainage-water/)

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AUTHORS

Kelly Nelson, Plant Sciences, University of Missouri

Jeppe Kjaersgaard, Division of Pesticide and Fertilizer Management, Minnesota Department of Agriculture

Benjamin Reinhart, Agricultural and Biological Engineering, Purdue University

Jane Frankenberger, Agricultural and Biological Engineering, Purdue University

Rebecca Willison, Statistics, University of Missouri

Kpoti Gunn, Environmental Engineering, University of Wisconsin-Green Bay

Charlotte Lee, Agronomy, Purdue University

Lori Abendroth, Cropping Systems and Water Quality Research Unit, USDA-ARS

Laura Bowling, Agronomy, Purdue University

Ali Rashid Niaghi, Benson Hill

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