Increasing Adoption of Climate- & Water-Smart Irrigation Practices Among Tennessee Valley Farmers in Alabama & Tennessee: Findings and Lessons Learned

Project Funded by a Natural Resources Conservation Service (NRCS) Conservation Innovation Grant

Background

In recent years, farmers in the southeastern United States have increased irrigation adoption as a risk management strategy to mitigate the impact of frequent droughts, large summer rainfall variability, and to increase yield on soils with low water-holding capacity and fertility. In Alabama, irrigated land increased from 75,023 to 163,338 acres between 2008 and 2018. Through recent cost-share programs in the state, 1,600 acres were converted to irrigated land in 2021, and around 2,000 are expected to be added in 2022. Although there has been an increase in irrigation adoption across the Southeast (SE), few farms have reservoirs for winter rainfall storage for irrigation in the summer or use precision irrigation technologies to improve irrigation efficiency. Many farmers still have the preconceived idea that summer rainfall is enough to meet summer crop water demand and that irrigation is not needed; however, monthly rainfall varies between years, and rainfall distribution is poor, which increases the risk of water-related yield losses. For example, corn grown in Alabama experiences peak water demand in June and historic rainfall records in nearby Town Creek,

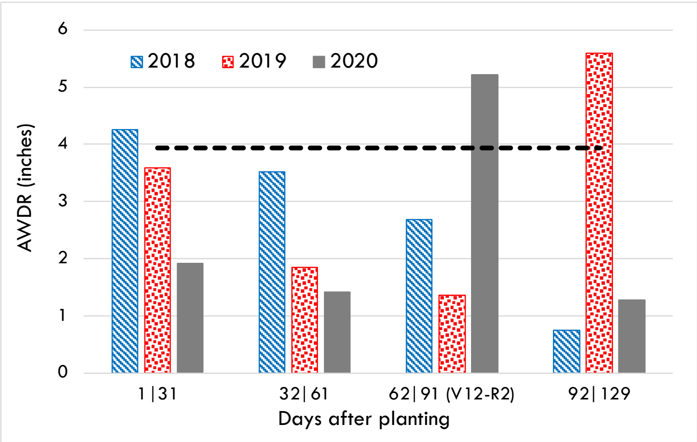


Figure 1. Last three years' rainfall in Town Creek, Alabama, represented using the Abundant and Well Distributed Rainfall Index (AWDR). Values lower than 3.9 indicate rare and spare rainfall and above indicate abundant and well-distributed rainfall.

Alabama, show that during the last three years, rainfall received during the reproductive period was deficient and poorly distributed (values lower than 3.9 in figure 1). The amount of rainfall received has not been sufficient to supply crop demand in 14 of the last 20 years (figure 2) suggesting the need for irrigation as well as irrigation scheduling methods.

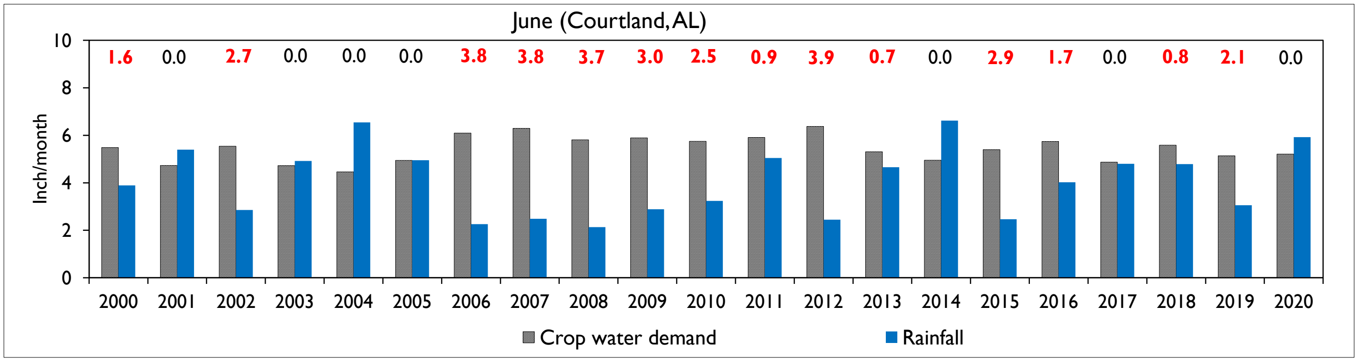


Figure 2. Historic June Corn Water Demand and Total Rainfall in Courtland, AL. Note: Numbers in red correspond to the June crop water demand not supplied by rainfall.

The net return map in figure 3 generated from 2012 corn yield data from a field in northwest Alabama demonstrates several aspects of irrigation use and management:

- Yield loss vulnerability in non-irrigated areas in a dry year.
- Net return variability under irrigation suggests potential for site-specific management: seed, water, and nutrients.
- Need for variable rate irrigation (VRI) and irrigation scheduling methods to reduce over- or under-irrigation and minimize yield loss or increase yield.
- Need for better maintenance of irrigation systems to increase efficiency and prevent yield loss.

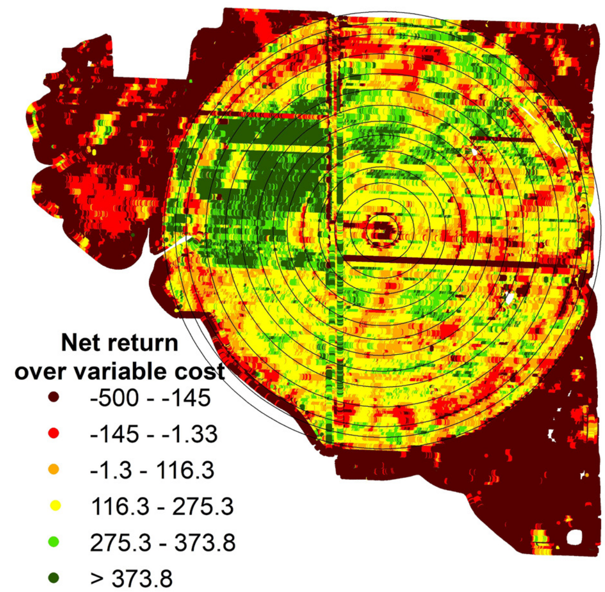


Figure 3. Variability in 2012 net return ($/acre) across irrigated and dryland areas.

Project Summary

On-farm demonstrations were established in Alabama between 2017 and 2021 to increase awareness, knowledge, and skills of irrigation best management practices (BMPs). An irrigation learning network was initiated and four farms in three Alabama counties (Lawrence, Limestone, and Geneva) were selected as main learning nodes. Farmers, Extension personnel, faculty, graduate students, and industry representatives gathered at the learning nodes to exchange knowledge related to technology-based irrigation management strategies (figure 4). The learning nodes were also used to hold field days, small group meetings, and demonstrate and train farmers on innovative irrigation water management approaches. Workshops, webinars, Extension publications, newsletters, and presentations at regional and national conferences were also used for training and dissemination of results.

In addition to offering field days, small group meetings, and one-to-one training, the learning nodes were used to demonstrate the following:

- Use of El Niño Southern Oscillation (ENSO) Climate Forecast to support decisions of water withdrawal for irrigation
- Application of the right irrigation rate, at the right time, and at the right place using variable rate irrigation (VRI) along with soil moisture sensors and other irrigation scheduling tools
- Deficit irrigation strategies
- Impact of irrigation BMPs on soil nutrient availability and variability
- Offer an opportunity for peer-to-peer learning to support the adoption of climate- and water-smart irrigation practices

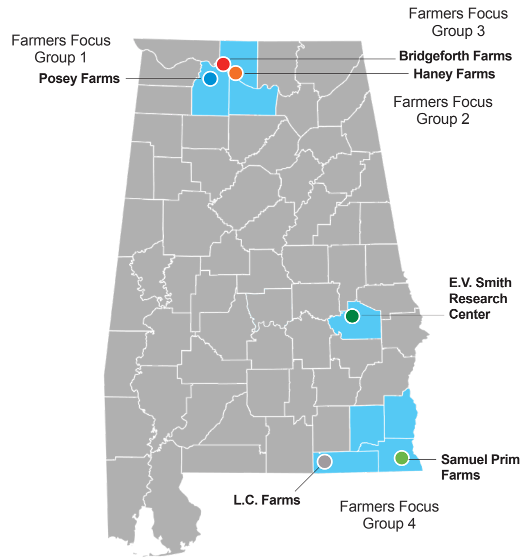


Figure 4. Locations of demonstration sites.

Project Impacts

Reservoir Winter Water Storage: A Solution to Summer Water Shortage

On average, Alabama receives approximately 56 inches of rainfall per year; however, 230 bu/ac corn planted in northern Alabama could use approximately 23 inches during March to August. Most annual rainfall occurs during the winter months, and many farmers with irrigation systems do not always have access to adequate water in the summer to meet crop water demand. The influence of El Niño Southern Oscillation (ENSO) on the southeastern climate, rainfall, and temperature might be useful for irrigation and even support planting decisions related to the type of crop and/or variety of crop. Farmers can use ENSO forecasts to plan water withdrawals from streams for irrigation in summer.

During this project in northern Alabama, the relationship was established at the watershed level between (1) ENSO and rainfall and (2) ENSO and streamflow. This relationship was used to determine how much water can be withdrawn from streams as a function of different ENSO phases without negatively affecting the ecological integrity of streams.

ENSO Forecast and Stream Flows. The impact of ENSO on rainfall patterns changes from southern Alabama to northwest Alabama. During the period January to March, if the climate is under the influence of the La Niña phase, northern Alabama may register rainfall above historic records while southern Alabama experiences below average rainfall. When the climate is influenced by the El Niño phase of ENSO, winters are wetter than normal in central and southern Alabama compared with the La Niña phase. However, during summer, rainfall is lower during the La Niña phase than during the El Niño phase. The La Niña phase has been linked to some of the most severe historic droughts in the southeast. In northern Alabama, regardless of ENSO phase, rainfall is higher in the winter months than in the summer months resulting in higher stream flows during January to April.

ENSO Forecast and Water Withdrawal Irrigation. If the summer climate is influenced by the La Niña phase of ENSO, farmers who rely on surface water for irrigation might not have enough water in the streams to make ecologically sustainable water withdrawals. However, if the winter climate is influenced by La Niña, higher rainfall and stream flows in the winter months of northern Alabama allow water harvesting from streams that can be stored in on-farm ponds or reservoirs. This water can be used later by the farmers in the summer months to irrigate their cropland fields. Simulation studies conducted in the Swan Creek watershed (37 square miles) in Limestone County, Alabama, demonstrated that when water is withdrawn sustainably at multiple locations within the watershed, approximately 40 percent of the watershed area could be irrigated.

If farmers plan water withdrawal in accordance with the ENSO phase, it would not only provide ample volume of water for irrigation during the crop growing season but would also help to maintain water quality and aquatic flora and fauna in the streams.

Right Irrigation @ Right Time @ Right Place: Resilience, Profitability, and Sustainability

Irrigation scheduling, the process to determine irrigation rate and timing, may prevent crop water stress as well as nutrient leaching and runoff that adversely affect crops and the environment. The use of irrigation technologies allows farmers to meet crop evapotranspiration demands that, in turn, avoids over- or under-irrigation. Irrigation scheduling methods (e.g., soil sensors, crop growth simulation models, and remote sensing) and variable rate irrigation (VRI) are irrigation BMPs available to increase irrigation efficiency.

Additional Information:

- Sangha, L., Lamba, J., Kumar, H., Srivastava, P., Dougherty, M., & Prasad, R. 2020. An innovative approach to rainwater harvesting for irrigation based on El Niño Southern Oscillation forecasts. Journal of Soil and Water Conservation, 75(5), 565-578.
- Sangha, L., Lamba, J., & Kumar, H. 2020. Effect of ENSO-based upstream water withdrawals for irrigation on downstream water withdrawals. Hydrology Research, 51(4), 602-620.

Variable Rate Irrigation

Variable rate irrigation (VRI) is an irrigation water management strategy that allows irrigation systems to apply different irrigation rates as the system is in operation. When center pivot sprinkler irrigation systems are equipped with VRI systems, it is possible to change the irrigation rate in the direction of travel and along the length of the irrigation system. The irrigation rate changes can be implemented by either changing the travel speed (speed control method) or by controlling the sprinkler water flow through changes in the duty cycle of an individual sprinkler or groups of sprinklers (zone control). The duty cycle is the ratio of “on” time to “on-off” time of a single solenoid valve. The amount of water applied decreases as the duty cycle decreases, and the sprinklers are completely turned off when the duty cycle is zero.

VRI – A Path to Strengthening Profitability and Environmental Stewardship.

Most fields where food and fiber are produced exhibit natural variability in soil type, topography, and/or depth of water table, which influences yield variability and final yield. Although most center pivot irrigation systems are designed and managed to apply a uniform amount of irrigation water, managing irrigation water with VRI systems allows farmers to address within-field variability by delivering water according to plant needs and soil water availability.

Right Rate @ Right Place of water application through VRI systems may result in the following:

- Less over- or under- irrigation that contributes to a decrease in yield variability, an increase in crop yield, and an increase in revenue.
- Lower risk of water and nutrient runoff or nutrient leaching.
- Water savings from less over-irrigation or avoidance of water application on noncropped areas under the irrigation system.
- Energy savings through fewer water pumping hours.
- Cost savings from less energy usage and/or time and machinery savings through the implementation of variable rate fertigation.
- Less weed or disease pressure by controlling irrigation water in terrain depression areas resulting in pesticide cost savings.
- Adoption of other site-specific management strategies such as variable rate seeding and fertilization.

> *"Posey Farms has been looking for a way to apply water on crops on the higher elevated soils on a field and cut back the flow on lower basin soil. Controlling the water in the basins will directly impact costs from using less water, less diesel to power the system, and less wear and tear on equipment, less maintenance, less manpower".*
>
> **Steve Posey**
> Posey Farms in Lawrence County, Alabama

Assessing the Impact of Precision Irrigation Practices.

On-farm evaluations and demonstrations of soil sensor–based irrigation scheduling along with VRI were conducted at four locations over three years. Before any field work was initiated, extensive characterization was conducted of field variability in terms of soil physical and chemical properties (e.g., soil texture, bulk density), terrain elevation, and historical yield. At each field, side-by-side comparisons of VRI supported by sensor-based irrigation scheduling (SS-VRI treatment) and the traditional uniform irrigation farmers' practice (UNIF treatment) were established. In year one, center pivot irrigation systems at each field site were retrofitted to control irrigation application by groups of three to four sprinklers (VRI zone control). Because VRI irrigation prescriptions were zone based, management zone maps were created for each field using yield maps, soil electrical conductivity, terrain elevation, and soil texture data. Soil water tension sensors were installed on each zone irrigation treatment area to monitor crop water uptake and soil water status and to prescribe irrigation. Irrigation scheduling based on soil water sensors (SWS) requires actual real time soil sensor data, estimated values of field capacity (FC) and permanent wilting point (PWP) as well as the maximum amount of water the irrigation operator allows the crop to extract from the active root zone or the managed allowable depletion (MAD). Soil sensor data allows the irrigation operator to track soil water and keep it above the irrigation threshold (MAD level) to prevent crop water stress and subsequent yield loss. Soil samples at soil depths of 6, 12, and 24 inches were collected from each demonstration field to estimate soil water retention curves to determine FC and PWP and convert soil water tension data into volumetric water content. Weather stations installed at each field site were used to monitor hourly weather conditions. Crop biomass, leaf area, soil water content, and yield were collected from each zone treatment for evaluation of irrigation practices in terms of yield, yield variability, and crop water use efficiency. These data were also used to conduct crop growth simulation studies for analyzing the impact of irrigation strategies on crop yield.

In addition to the demonstration of soil sensor–based irrigation scheduling and VRI, several irrigation scheduling tools were evaluated throughout this project. Two evapotranspiration-based soil water balance irrigation scheduling phone applications (Cotton and Corn smart irrigation app) were evaluated along with a crop growth model-based scheduling tool (FieldNet Advisor). Two different types of soil sensors, a capacitance sensor probe (AquaSpy) and a soil water tension sensor (Trellis) were also evaluated. These tools were evaluated for their accuracy in prescribing irrigation rate and timing as well as their complexity for use by farmers.

Operation and Maintenance of Irrigation Systems: Other Drives of Irrigation Efficiency and Crop Yield Losses

Figure 5. Steve Posey (Posey Farms), Brenda Ortiz, and Pierce McClendon discuss changes needed on irrigation sprinklers to improve the uniformity of water application.

Poor uniformity of water application of center pivot irrigation systems is usually related to pump operating pressure, incorrect nozzle size and placement, worn or clogged nozzles, and incorrect system panel setting. These issues not only reduce the efficiency of water application but also increase water pumping time, which increases energy use leading to higher irrigation costs. Each year all of the irrigation systems included in this project were evaluated for uniformity of water application. Maintenance of the systems was conducted in collaboration with each cooperating farmer. These activities identified the need for hands-on training among farmers and consultants and the need to raise awareness of the consequences of poor maintenance.

Figure 6. Hemendra Kumar, PhD student, collects soil samples to study the impact of irrigation and water movement on soil nutrient availability.

Irrigation and Soil Nutrient Availability.

Soil moisture variability can affect nutrient transport processes within a crop field. Therefore, as a first step, this project studied the spatial variability of soil moisture over a crop growing season. Soil phosphorus variability at different soil depth intervals was quantified with respect to different irrigation management zones previously delineated on the field located in Town Creek, Alabama, (figure 2). Significant within-field variability in phosphorus levels was found at different soil depth intervals. On the high crop yield areas (HY Zone), higher phosphorus concentrations were found compared to the low crop yield (LY zone), which had very low phosphorus levels. We found that spatial variability in topography and soil physical properties, mainly soil texture, affected surface runoff and soil erosion processes within the field, and those processes ultimately affected phosphorus levels and crop yield.

Site-Specific Nutrient Management

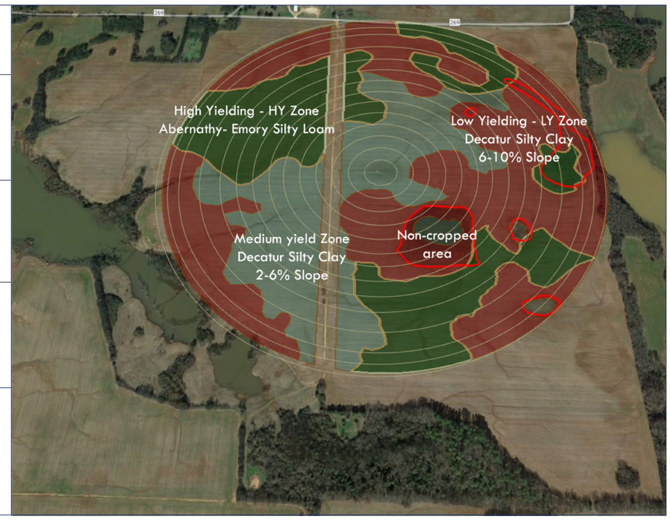
We concluded that in areas of the field where phosphorous was low, corn yield was also low. The spatial variability of phosphorous suggests the need for variable rate fertilization in combination with VRI to reduce phosphorus loss. Sediment-bound phosphorous loss through erosion or dissolved phosphorous through water could be minimized using VRI. Both practices, variable-rate fertilization and irrigation, could minimize nutrient loss and optimize crop yield and potentially increase the profitability of the operation.

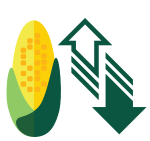
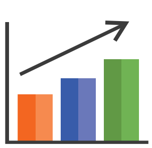
Results Highlights: On-Farm Demonstrations

Key findings from two of the on-farm demonstrations of soil-sensor-based irrigation scheduling and VRI are highlighted below. Those sites exhibited the greatest within-field variability in soil and terrain elevation and corresponded to contrasting row crop production areas in the state of Alabama. Data from a third location (central Alabama) is included where a deficit irrigation study was conducted. Additionally, highlights of various other aspects that could support the implementation of irrigation BMPs are included in this section. Overall and across on-farm sites, the use of soil sensors for irrigation scheduling and VRI resulted in water savings, a decrease in yield variability, and revenue increase.

Northwest Alabama Site

Location: Town Creek, Alabama	**Years of demonstrations:** 3
Crop: Corn	**Seeding rate:** 33,0000 seed/ac under irrigated area
Test area: 300 acres irrigated (results below correspond to 100 ac demonstration area)	**Row width:** 30 inches
Predominant Soil Types: Decatur Silty Clay & Abernathy-Emory Silt Loam	**Tillage:** No till
Center Pivot Irrigation Specifications: Reinke – 2043 foot length – 12 spans plus overhang	**Variable Rate System:** Advanced Ag Systems



<table>
<tr><td></td><td>2020
▪ Total rainfall growing season: 16 inches
▪ Irrigation: 5.6 inches to HY Zone (Abernathy-Emory silt loams soils; higher plant available water respect to whole field)
▪ Irrigation: 7.4 inches to LY Zone (Decatur Silty Clay, 6% to 10% slope; lower plant available water than Abernathy-Emory soil)</td></tr>
<tr><td></td><td>▪ 9.5 % water savings on HY Zone with respect to LY zone.
▪ Revenue impacts
▫ HY Zone: $ 21/ac-in increase respect to dryland area (6.2% revenue increase)
▫ LY Zone: $ 10.40/ac-in respect to dryland area (4.6% revenue increase)
▪ Better allocation of water to areas of low plant available water and high terrain elevation or slope where water infiltration is low.</td></tr>
<tr><td></td><td>▪ Less water applied did not affect corn yield or yield variability.
▪ Greater frequency of irrigation and higher irrigation rate on LY zone increased yield compared to historic zone yield average.
▪ Irrigation scheduling assisted by soil sensors:
▫ Minimized the risk for yield losses due to low frequency of rainfall June–July 2020
▫ Prevented over-irrigation on areas where soil water was available.</td></tr>
<tr><td></td><td>2020 Irrigated yield
▪ Zone HY (30% demonstration area): 249 bu/ac
▪ Zone LY (44% demonstration area): 238 bu/ac
▪ Dryland close to demonstration area: 219 bu/ac</td></tr>
</table>

Note: HY corresponds to high-yielding zone and LY is low-yielding zone

Southeast Alabama Site

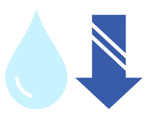
Location: Samson, Alabama (Geneva County)	**Years of demonstrations:** 3
Crop: Corn	**Seeding Rate:** 34,000 seed/ac
Test area: 70 acres	**Row Width:** 36 inches
Predominant Soil Types: Eunola Sandy Loam & Alpin Sand	**Tillage:** Conventional
Center Pivot Irrigation Brand: Zimmatic Center Pivot with a Lindsay Growsmart precision VRI system	**Irrigation system Length:** 1,298 ft. 6 spans plus overhang

2018

- Total rainfall (R) growing season: 24 inches (above historic average)
- Irrigation – 2.8 inches to HY Zone (Sandy loam soil with higher plant available water respect to whole field)
- Irrigation – 5.6 inches to Zone LY (Sandy soil with very low plant available water)

2019

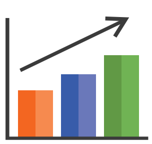
- Total rainfall growing season: 13 inches (below historic average)
- Irrigation – 6.3 inches to HY Zone (Sandy loam soil with high soil available water)
- Irrigation – 10 inches to LY Zone (Sandy soil with very low soil available water)



- **28 % water savings in 2018 – WET season.**
- **16% water savings in 2019 – DRY season.**

Compared to use of uniform irrigation and traditional irrigation scheduling method

- Less water applied did not affect corn yield or yield variability.
- Irrigation scheduling assisted by soil sensors minimized the risk for yield losses due to water stress in 2019 and overwatering in 2018.



2019 Irrigated yield (DRY Season)

- HY Zone: 186 bu/ac
- LY Zone: 98 bu/ac
- LY Zone - Dryland: 33 bu/ac

Additional information:

- Bondesan, L., B. V. Ortiz, F. Morlin, G. Morata, L. Duzy, E. van Santen, B. P. Lena, G. Vellidis. 2021. A Comparison of Precision and Conventional Irrigation in Corn Production in Southeast AL. *Journal of Precision Agriculture*. Manuscript accepted.
- Bondesan, L., B. V. Ortiz, G. T. Morata, D. Damianidis, A. F. Jimenez, G. Vellidis, F. Morari. 2019. Evaluating and improving soil sensor-based variable irrigation scheduling on farmers' fields in AL. In *Precision Agriculture '19*. Editor John V. Stafford. Pages 649-656. https://doi.org/10.3920/978-90-8686-888-9

Note: HY correspond to high-yielding zone and LY is low yielding zone

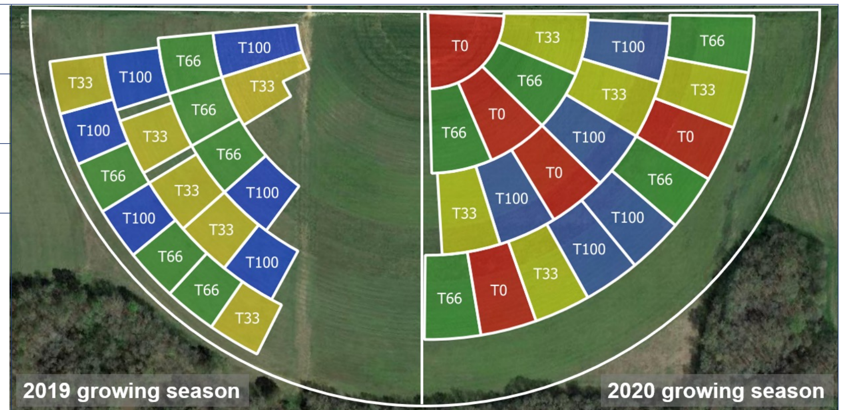
Central Alabama Site

Location: Shorter, Alabama	**Year:** 2020
Crop: Corn	**Seeding rate:** 36,000 seed/ac
Test area: 74 acres	**Row width:** 36 inches

Center Pivot Irrigation Specifications:
Valley – 700 Series

Length: 1,423 ft length
7 spans plus overhang

Variable Rate System: Valley



Predominant Soil Types (SSURGO soil survey):

In 2019 - 68% Altavista Silt Loam and 25% Cahaba sandy loam.

In 2020 - 100% Altavista Silt Loam/Clay loam soil texture determined on-site.

Irrigation Treatments:

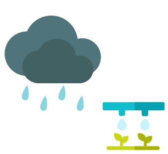
T100 - Full replenishment of water to field capacity in the top 24 inches of soil

T66 - 66% the amount applied at T100 (or 33% deficit)

T33 - 33% the amount applied at T100 (or 66% deficit)

T0 - Dryland

Note: Irrigation scheduling was done using soil sensors.



1998-2020:

- Total growing season historical rainfall - 16.6 in

In 2019:

- Total rainfall growing season: 16.4 inches. 70% of 2019 rainfall occurred in the first 40 days of the growing period. Rainfall was sparse and insufficient from silking to harvest.
- Irrigation
  - T100 (Fully irrigated to bring soil to field capacity: 8.1 inches
  - T 66 (33% deficit respect to fully irrigated): 5.2 inches
  - T 33 (66 % deficit respect to fully irrigated): 2.7 inches

In 2020:

- Total rainfall growing season: 17.5 inches. During the V7 to milking corn growth stages, rainfall was abundant and well distributed.
- Irrigation
  - T100: 7.4 inches
  - T 66: 5.2 inches
  - T 33: 3.1 inches

2019 Yield:

- T100: 216 bu/ac
- T66: 187 bu/ac
- T33: 166 bu/ac
- T0: 103 bu/ac (dryland)

Revenue estimated with respect to dryland:

- T100: $55.80/ac-in
- T66: $64.62/ac-in
- T33: $18.00/ac-in

Note: Yield adjusted to 15.5% grain moisture.
We assume the price of corn was $4/bu

2020 Yield:

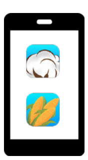
- T100: 249 bu/ac
- T66: 240 bu/ac
- T33: 207 bu/ac
- T0: 189 bu/ac (dryland)

Revenue estimated with respect to dryland:

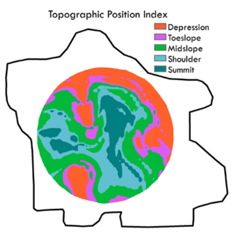
- T100: $32.54/ac-in
- T66: $39.30/ac-in
- T33: $23.62/ac-in

	▪ The results showed that when field corn was grown in a clay loam soil and under the rainfall patterns registered in 2019 and 2020, the yield was maximized when plants were fully irrigated (T100); however, greater net revenue was achieved when irrigation was reduced to 33% (T66). This suggests that deficit irrigation under these growing conditions could be a profitable and environmentally sound irrigation management strategy. Note that additional research is needed to provide a more accurate deficit irrigation recommendation. ▪ In 2019, revenue was greater than in 2020 because the timing of irrigation events minimized the risk for crop water stress yield losses. ▪ If rainfall is lacking during the reproductive period, as observed in 2019, yield losses up to 50% could be observed as compared to fully irrigated corn.
Additional information: ▪ Lena, B.P., B.V. Ortiz, L. Duzy, A.F. Jimenez, F. Morlin, G. Pate. 202X. Inter-annual corn yield response to consumptive water usage under a humid subtropical climate of the USA. *Irrigation Science*. Submitted	

Tools for Irrigation Water Management: Highlights

Irrigation Scheduling	
	Soil sensor-based irrigation scheduling allows farmers to better determine when and how much to irrigate; however, sensor data is influenced by where the soil sensors are installed within a cropped field. We found that farmers and consultants should carefully choose locations within a field that provide temporal stability of soil sensor readings. Data of terrain elevation, slope, and soil texture could support decisions on the best location for soil sensor installation. **Additional information:** Kumar, H., P. Srivastava, B.V. Ortiz, G. Morata, B.S., Takhellambam, J. Lamba, L. Bondesan. 2021. Field-scale spatial and temporal soil water variability in irrigated croplands. *Transactions of ASABE.* Vol. 64(4): 1277-1294
	Irrigation initiation thresholds were identified to facilitate the implementation of sensor-based irrigation scheduling by farmers. Soil water tension (SWT) sensors and granular matrix sensors are an affordable soil-sensor solution to farmers, but data interpretation could be challenging. We developed a novel method that provide SWT thresholds for predefined irrigation rates commonly used by farmers. **Additional information:** Lena, B. P., L. Bondesan, E. A. R. Pinheiro, B. V. Ortiz, G. Morata, H. Kumar. 2022. Determination of irrigation scheduling thresholds based on HYDRUS-1D simulations of field capacity for multilayered agronomic soils in AL, USA. *Agricultural Water Management*. Vol 259, Jan 2022.
	Irrigation Scheduling Phone Apps, which are free and developed by the University of Georgia, can be used by farmers as entry-level tools for irrigation scheduling. Evaluations showed that both the Cotton and Corn Irrigation Scheduling Apps with the evapotranspiration-based soil water balance method embedded in adequately predicted crop water use during the peak of crop water need.
	Full implementation of VRI requires reliable irrigation scheduling methods that can determine crop water use and soil water depletion in approximate real time. Machine learning algorithms, specifically Recurrent Neural Networks, were found useful in learning behavior of soil moisture changes and then predicted irrigation events. These findings are useful in the development of irrigation scheduling decision-support tools. **Additional information:** Jimenez, A-F., B. V. Ortiz, L. Bondesan, G. Morata. D. Damianidis. 2020. Evaluation of two recurrent neural network methods for prediction of irrigation rate and timing. Transactions of the ASABE. 63(5): 1327-1348. (doi: 10.13031/trans.13765)

Variable Rate Irrigation



Delineation of irrigation management zones was improved with the incorporation of either Topographic Wetness Index (TWI) or Topographic Position Index (TPI) data layers in fields with rolling terrain. Both indices, along with the slope of the terrain and elevation, showed a correlation with the spatial variability of soil moisture, soil texture, and crop yield. These maps can also assist with the identification of the best locations for the installation of soil sensors for irrigation scheduling.

Additional information:

Morata, G., B. V. Ortiz, L. Bondesan, H. Kumar, F. O'Donnell, B. P. Lena, N. Billor. 202X. Evaluation of terrain attributes to characterize the spatial variability of soil water status with purposes of irrigation management zones delineation. *Journal of Precision Agriculture. Submitted for publication.*

Site-Specific Nutrient Management

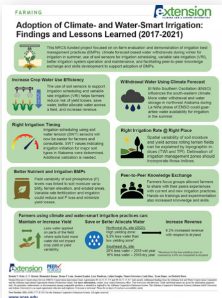
Within-field variability of soil phosphorus (P) levels could be linked to soil moisture variability, terrain elevation, and eroded areas. Variable rate fertilization and irrigation could reduce soil P loss and reduce the risk of soil P-related yield losses.

Additional resources:

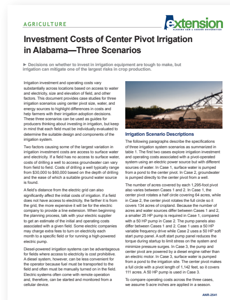
Kumar, H., Srivastava, P., Lamba, J., Ortiz, B.V., Way, T.R., Sangha, L., Takhellambam, B.S., and Morata, G. 202X. Field-scale spatiotemporal variability in soil phosphorus with response to crop growth and yield in delineated irrigated cropland. Journal of Precision Agriculture. Under-review.

Resources

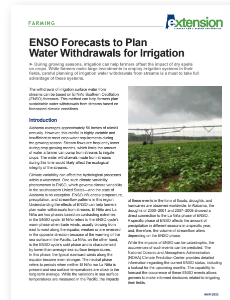
The Alabama Extension publications below were prepared to support stakeholders in the implementation of irrigation BMPs. Information and guidelines are provided to increase awareness and knowledge on the advantage and impact of climate-smart irrigation management practices and how to implement them. These are available on the Alabama Extension website.


Adoption of Climate- and Water-Smart Irrigation: Findings and Lessons Learned (2017-2021)

Adoption of Climate- & Water-Smart Irrigation Practices Among Tennessee Valley Farmers in Alabama & Tennessee: Findings & Lessons Learned (2017-2021)


Investment Costs of Center Pivot Irrigation in Alabama—Three Scenarios

Investment Cost of Center Pivot Irrigation in Alabama


ENSO Forecasts to Plan Water Withdrawals for Irrigation

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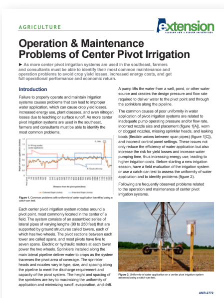
Operation & Maintenance Problems of Center Pivot Irrigation

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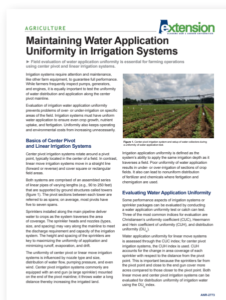
Maintaining Water Application Uniformity in Irrigation Systems

Maintaining Water Application Uniformity in Irrigation Systems


Alabama Irrigation Management Program

Alabama Irrigation Management Program Newsletter


Installation of Soil Sensors for Irrigation Scheduling

Installation of Soil Sensors for Irrigation Scheduling


Irrigation Scheduling Using Soil Water Tension Sensors

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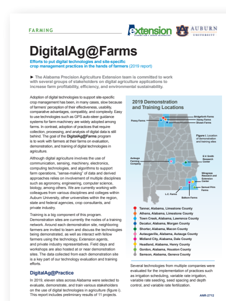
DigitalAg@Farms

Putting Digital Technologies in the Hands of Farmers

Engaging with Stakeholders

As irrigation adoption increases in the southeast, the design of participatory Extension programs is key to identifying farmers' needs in knowledge and skills. Facilitating knowledge exchange activities among irrigation users, Extension, and industry will increase knowledge and skills development. These strategies contribute to empowering farmers and consultants to implement and adopt irrigation BMPs in Alabama and across the region. In year one of the project, four focus groups of farmers were created to identify needs and perceptions, facilitate peer-to-peer learning, and design Extension activities. Four on-farm demonstrations of irrigation BMPs were established as knowledge exchange and skills development hubs. Members of each focus group met three times a year to share their own experiences with irrigation at each of their farms. Besides exchanging their experiences in small group settings, other Extension strategies to increase awareness and exchange knowledge included field days centered on peer-to-peer exchange (farmers, industry, and Extension sharing and exchanging knowledge), workshops, one-to-one training, and the use of digital technologies for knowledge transfer (e.g., webinars, blogs, newsletters, Extension publications). Some of the topics addressed through these Extension events were current irrigation technologies available for implementation of irrigation BPMs, operation and maintenance of irrigation systems, use of drip irrigation, how to use different irrigation scheduling methods in row crops production, fertigation, and chemigation. Over 750 people took part in face-to-face meetings and up to 15,000 people were reached through digital platforms.

Extension Method	Number/People Reached
Irrigation Newsletter	16 issues (16,000 recipients)
Webinars	6 to 20 speakers (3,270 views)
Workshops	3 to 15 speakers (280 participants)
Field Days	4 to 25 speakers (250 participants)
Small meetings with focus groups of farmers	20 to 250 participants
Extension publications	8 (www.aces.edu)
Blogs	13 (www.aces.edu)
Abstracts & conference presentations	22
Student theses	3 MSc Theses/1 PhD dissertation

"After attending the farmers focus group for three years, I am ready to install a soil sensor to schedule irrigation on one of my corn fields… what is your opinion about the AquaSpy sensor?"

Question asked by **Gordon Fennel**, farmer in Lawrence County, to **Steve Posey**, farmer hosting an on-farm demonstration site

Paths to Adoption of Irrigation BMPs

The Extension approach and strategies used to engage farmers will influence the outputs and outcomes of a program or project. The adoption of a practice will be the result of a series of changes over time including perceptions, behavior, knowledge, skills development, farmer testing the practice on a small scale, and many others. Throughout this project, we used several Extension and engagement strategies. As a result, project participants increased their knowledge of crop water use and the use of tools for irrigation scheduling, especially soil sensors.

> *"I have a much better understanding of the importance of the timing of irrigating my crops and the importance of applying a correct amount of water at different areas in the field."*
>
> **Steve Posey**
> Posey Farms (7,000-acre operation)

Farmers and consultants also learned how to test center pivot irrigation systems for uniformity of water application and key aspects of the operation of the systems. Even though we documented the gain in farmer knowledge and skills, the farming community needs to continue learning about crop water use, the differences in water-holding capacity of major Alabama soils and the impact on irrigation scheduling, the impact of irrigation rates on runoff and water infiltration and the timing of the next irrigation event, and the impact of irrigation management (Right Rate @ Right Time @ Right Place) on crop water stress and final yield. Farmers and consultants must acquire new skills related to irrigation scheduling to minimize water stress-related yield losses and/or prevent water overuse. When it comes to irrigation scheduling tools, farmers look for accurate and easy-to-use solutions. Therefore, it is important to consider this when designing Extension programs. If soil sensors are used as the irrigation scheduling method, farmers and consultants still have questions related to the number of sensors that should be installed in a field and the best location to install a sensor. When it comes to VRI, several issues may prevent farmers from adopting this practice including the need to develop irrigation prescription maps. Crop water needs change in space and time across a field; therefore, farmers or consultants may have to install several soil sensors within a field to determine the right rate, the right time, and the right place for the application of crop water. Spatial variability of plant-available water potentially might cause the preparation of a different map each time the irrigation system traverses the field. Solutions to this problem are either under development or available in the market to address these issues. We tested the FieldNET Advisor developed by Lindsay Corporation. With a few improvements, this tool could be a good option for VRI on row crops planted in the southeast. The other issues related to VRI are the problems associated with the maintenance of the systems. Because electronics are used to control solenoid valves, damage by lightning or clogged solenoids becomes an issue and increases the maintenance costs. Farmers should be aware of these issues and regularly test the water application of the systems.

> *"This opportunity to learn and the knowledge we have gained so far has shown us that we can do more with less. This study has shown us several spots we were over-watering, which results in lower yields. The data and knowledge from these studies will change the way we manage 41 pivots and 5 hard hoses over 2,700 acres of irrigated land".*
>
> **Jim Lewey**
> L.C. Farms (7,000-acre operation)

There is also an urgent need for more training on center pivot irrigation system maintenance and operation. Farmers need to be more aware of the operational problems that might affect flow rate and final water application. The cost of irrigation and the risk of yield loss increases when the irrigation system is not operated at full capacity.

Empowering farmers with skills such as using irrigation scheduling, proper operation and troubleshooting of irrigation systems, and running tests to detect problems with uniformity of water application will increase irrigation efficiency, reduce variable irrigation costs, minimize production risk, and reduce negative environmental impacts.

> *"Variable rate irrigation allowed me to apply a more precise amount on higher elevations without excess runoff and not apply as much water in areas with lower elevation where less irrigation was needed."*
>
> **Steve Posey**

When it comes to the intersection between water and nutrient management, additional studies should be done to quantify the impact of water withdrawals on sediment and nutrient transportation at the watershed level. Water withdrawals may lead to the accumulation of sediment in streams when stream flows are lower. Furthermore, studies should investigate how smart irrigation practices can help increase irrigated acreage within a watershed. Finally, precision nutrient management strategies should be adopted to reduce nutrient loss from fields, thereby reducing variable costs related to nutrients. Modeling activities can help better understand nutrient cycling at the watershed level.

Challenges and Lessons Learned

On-farm demonstration of irrigation practices poses challenges. Demonstration and evaluation of irrigation scheduling are challenging because a lot of factors, such as availability of water for irrigation or even the frequency and amount of rainfall received over a growing period, may affect the operation of the irrigation system. Before on-farm demonstrations are established it is important to know if the source of irrigation water can supply the water demand for the crop. At some of the demonstration sites in this project, the irrigation pond that supplied water for irrigation was not big enough to store winter rainfall, and the dry conditions in the summer limited the availability of surface water for irrigation. Weather patterns, especially frequent rainfall, might reduce the opportunities of conducting proper irrigation scheduling evaluations.

Extension approach and expectations. The adoption of a practice cannot be perceived as the result of a unidirectional process where the farmers are just recipients of information. The design of Extension programs rooted in the Roger's Diffusion of Innovation Model has traditionally conceived adoption as the ultimate indicator of success. One of the main pitfalls of this approach is the "snapshot" conceptualization of practice change that does not place much emphasis on the dynamic processes of learning and self-experimentation. We recommend that NRCS and other funding agencies update the requirements of Extension-related funding programs and even review their expectations regarding the type of changes that are possible within the time frame of a project. The transformation of behavior and knowledge into action takes time. It is influenced by processes and practices that affect the intrinsic motivation to engage, perceived behavioral control changes (e.g., skills gained, beliefs of being capable of performing tasks, assessment of the complexity of practice implementation), and coproduction of knowledge. Successful Extension programs today are participatory in nature, bottom-up, and focused on farmers' empowerment, knowledge codevelopment, learning processes, problem solving, and capacity-building processes.

On-farm research with boundaries. Although the evaluation of a new practice under farmers' field conditions will yield important benefits, "uncontrolled" factors that might arise at the farm could affect the implementation and development of the research study. It may be wise to consider reducing the scope of the study, either by selecting only a portion of the field that represents the degree of variability needed or an area most representative of the average conditions. The other aspect could be reducing the number of treatments to evaluate. This might allow more resources to be used in a smaller area. In the case of this project, frequent sampling for soil nutrient analysis across a 200-acre test area located four hours from the main campus was time-consuming and required substantial resources in terms of time and funding. However, it is important to study nutrient cycling in fields as a function of irrigation to develop robust precision agriculture management strategies. Combined water and nutrient management strategies can help farmers increase crop production and reduce nutrient loss to surface and groundwater systems.

Start small and increase complexity over time. Assuring farmers are active members of the project ensures that there is a gradual increase in the complexity of the new techniques and tools introduced to them and that they fit their operation. If too many complex techniques and tools (e.g, equipment, topics) are introduced early in the project, participants may perceive the project as too complex and costly and could lose interest or disengage because they cannot relate to the topics and ideas being discussed. Incremental changes or increasing complexity over time may yield better results. Farmers are busy with crop production and other farming activities and they will be more engaged if we introduce solutions that solve current problems and address more complex topics over a longer time.

Figure 7. Guilherme Morata, *Regional Extension Agent,* discusses with Greg Bridgeforth (Bridgeforth Farms) aspects of yield variability and possible impact of rolling terrain on water movement.

Estimation of economic benefits of VRI. In this project, we demonstrated that the use of soil sensors along with VRI reduces the amount of water applied to the field over the production year; however, since farmers in Alabama do not typically pay for water, one of the challenges of VRI is calculating the economic costs and benefits associated with the practice. While an acre-inch of water could be used on another field or remain in the aquifer or stream for another use, it is difficult to put a dollar value on an acre-inch of water. The primary costs, aside from the investment cost in VRI and soil sensors, is the cost of electricity or diesel fuel, management time, and repair and maintenance.

When VRI is used, the irrigation pivot will traverse the field based on the speed required to apply the highest irrigation rate. If the highest irrigation rate is similar to or greater than the flat rate typically used by the grower, there will potentially be minimal savings related to electricity or fuel. Additionally, with VRI, farmers may be able to more efficiently allocate water to all of their irrigation pivots if they are faced with limited surface water for irrigation.

Additional benefits of VRI are difficult to quantify, not because they are not real or important but because, as discussed above, they are directly related to environmental or societal benefits. More efficient use of water reduces soil erosion thereby reducing sedimentation into ditches, rivers, and streams; reduces water withdrawals from surface waters that are habitats for aquatic species; and allows more farmers to irrigate from the same water source without having to regulate water use between farmers.

Investing in expensive equipment that might get lost. Streamflow measuring gauges were installed at one of the farmers' fields within the study watershed. The gauges disappeared either because they were stolen or an extreme rainfall event increased streamflow causing the equipment to be washed out from the site. This unexpected event resulted in a redirection of one of the project objectives. Data from a United States Geological Survey streamflow gauge was used to calibrate and validate the hydrological model used in this study.

Needs

- Additional work is needed on deficit irrigation strategies as well as yield losses and revenue losses from poor irrigation scheduling. Sometimes, farmers do not irrigate on time because they want to save money on fuel used to run the irrigation pumps. Some farmers might wait for a rainfall event before irrigation is initiated; however, this could cause crop water stress and depletion of soil moisture at deeper depths. Additional economic analyses of the cost-benefit of irrigation timing versus the cost of diesel are needed.
- It is important to raise awareness of rainfall amounts and frequency versus crop water use. People usually talk about monthly rainfall amounts but these numbers might be misleading if the frequency is not considered. Few and sparse large rainfall events might not be enough to meet crop water demand.
- Demonstrations of best irrigation practices should not only include irrigation scheduling and VRI but also operation, maintenance, and upgrade or irrigation systems.
- Participatory Extension programs where the farmers are active members in the project and not just recipients of the information are highly recommended. Extension programs that are participatory in nature place emphasis on co-construction of knowledge, knowledge exchange, peer-to-peer exchange, and group facilitation. Besides targeting changes in management practices, Extension programs should work on strengthening learning processes, resilience capacity, relationship building among project participants, and documenting changes in group dynamic processes and progress.

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