Considerations for Scheduling Irrigation in Agronomic Crops

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STAMP Smart Technologies for Agricultural Management and Production

Introduction:

Traditionally, irrigation of field crops was limited to arid regions of the United States. However, increasing rainfall variability and the associated short-term droughts occurring during critical growth stages within the crop season have led to the exploration of irrigation in hot, humid climates such as in Louisiana. Over time, the benefits of irrigation over dryland production systems in humid regions were realized and resulted in more than 54% of total acreage under irrigation as reported in 2019.

Adding irrigation capacity to any agronomic production system is a large financial investment that includes upfront costs for equipment and installation and ongoing costs, such as fuel, maintenance and labor. This investment has allowed farmers to diversify crop rotations. Sugarcane production continues to expand northward and westward into areas with less rainfall. Rice production has expanded into northeast Louisiana as a furrow-irrigated crop instead of being held under flood conditions. However, the return on irrigation investments can only be realized when water is applied efficiently and effectively.

It is critical to strive for high levels of irrigation efficiency to continue to have sustainable and profitable water resource applications. Scheduling irrigation to apply the crop water requirement determined using scientific principles and practices can improve application efficiency, which contributes to overall irrigation water use efficiency. Irrigation scheduling can be accomplished by using the soil water balance or through direct measurements of soil moisture.

What is Irrigation Scheduling?

Irrigation scheduling is the process of supplying water to crops at the right time and in the right amount to ensure minimal stress and yield loss due to tailwater runoff or deep percolation. Tailwater runoff occurs when excessive water flows over the surface of the soil, does not infiltrate and exits the edge of the field. Deep percolation occurs when the water infiltrates through the soil below the active root zone and is subsequently not available to the plants. Irrigation applications that produce runoff or deep percolation are inefficient and sometimes detrimental because the water was pumped to meet the crop water requirement but did not actually benefit the growth or yield of the crop.

Producers that manage large tracts of irrigated land without a scheduling plan are sometimes forced to irrigate on a calendar schedule regardless of soil moisture conditions or rainfall availability. These practices can lead to over-irrigation, production inefficiencies, and poor crop quality or yield declines. Furrow irrigation, the dominant irrigation system in Louisiana, is a gravity-led surface flow system that temporarily creates flooding conditions in the furrows, causing air to leave the soil profile while the soil moisture is over field capacity. Over-irrigating has the potential to decrease yields in most agronomic crops because of the prolonged nature of anaerobic or waterlogged soil conditions. Additionally, excessive irrigation can contribute to the loss of nitrogen due to denitrification and nutrient leaching. Even when over-irrigating does not decrease crop yields, it can reduce profits through unnecessary irrigation costs.

Studies have reported that using an irrigation scheduling tool has the potential to reduce water use by up to 50% without reducing yields. Profitability of irrigation is essential because of the average cost of $4 per acre-inch across water sources and fuel types, and each furrow-irrigated event averages 3 acre-inches of water. The costs of pumping certainly will increase as fuel prices rise and aquifers decline.

To enhance productivity and minimize water waste, it is important to fully consider each irrigation scheduling method to ensure the proper selection and use.

The following discussion relies on various technical concepts, terms or methodologies that are common to the irrigation industry but may not broadly apply to agricultural communities. The extension article "Speaking the Language of Irrigation: Glossary of Terms," publication No. 3552 on the LSU AgCenter website, may help in bridging this knowledge gap.

Soil Water Balance (Checkbook Method)

The soil water balance, also called the "checkbook method," is an irrigation scheduling tool that attempts to account for water moving in and out of the active root zone, resembling the balancing of a checkbook with deposits and withdrawals. This approach can be as simple or complicated as the manager desires.

Most soil water balances require the collection of crop evapotranspiration as the output and rainfall and irrigation as inputs. This method typically can get managers in the "ballpark" for needed irrigation events, which is an improvement over making an uninformed decision.

A weakness of the soil water balance strategy is that the components are estimated and not directly measured in the root zone. For example, if a 2-inch rainfall event were to occur, it is difficult to determine the amount of water that infiltrated from the event and can be considered usable to the crop and the amount of surface runoff that occurred. These deficiencies can be corrected by combining simple inputs and outputs with more sophisticated approaches that integrate soil-water status, wind speed, solar radiation, relative humidity, crop stages, canopy temperature and canopy coverage.

The soil water balance method also requires detailed record keeping throughout the growing season. In addition, managing the collected data to determine irrigation decisions can be tedious. There are existing tools to simplify the soil water balance method, such as the atmometer, Woodruff Chart or software programs that provide timely and precise irrigation recommendations. All these tools will allow for successful irrigation timing estimations. Although many universities have available programs, the program provided by University of Arkansas can be adapted to Louisiana conditions.

Direct Measurement:

The process of quantifying soil moisture availability can be used as an independent irrigation scheduling tool or included in the soil water balance strategy to overcome the challenges associated with estimating infiltration/runoff from irrigation and rainfall events. These systems will continue to evolve with new technologies and advancements. Soil moisture can be measured as gravimetric water content, soil water potential or volumetric water content.

Gravimetric Measurements

Soil moisture can be expressed as gravimetric water content (θ_g). Gravimetric water content is estimated as the ratio of the mass of water (m_{water}) within the soil to the mass of the soil (m_{soil}) using a soil sample collected from a field. Directly removing water from within a soil sample to weigh it on a scale is not reasonably possible. Instead, the mass of water is estimated by weighing the soil sample initially (m_{wet}) and then oven drying the sample for 24 hours to obtain the weight of the dried soil sample (m_{dry}). Then, m_{water} can be estimated as the water lost during oven drying and is calculated as the difference between m_{wet} and m_{dry}. In this case, m_{dry} equals m_{soil}. Thus, gravimetric water content can be calculated using a simple equation (1).

$$\theta_g = \frac{m_{water}}{m_{soil}} = \frac{m_{wet} - m_{dry}}{m_{dry}}$$

Equation 1: Gravimetric Water Content

The relationship between gravimetric water content and volume water content is driven by the bulk density (ρ_{bulk}), which is calculated as the ratio of mass to volume of the intact soil sample (Eqn. 2).

$$\rho_{bulk} = \frac{m_{dry}}{V_{Total}}$$

Equation 2: Bulk Density

Though gravimetric measurements are cheap and accurate for estimating soil moisture, it is unlikely that a producer will have the time and resources to collect soil samples throughout the crop season for making irrigation decisions. Instead, this process should be used to verify soil moisture measurements taken volumetrically. It can also be used to identify compaction by calculating ρ_{bulk}. Keeping ρ_{bulk} below 1.1 for clayey soils and below 1.4 for silty soils is important for allowing unrestricted root growth. Compacted soils generally produce more surface runoff by restricting infiltration from irrigation and rainfall.

Soil Water Potential

The soil water potential (θ_{SWP}) is an instantaneous measurement of the energy state of water in the soil. In more general terms, it is an estimate of the force that must be exerted by the plant to access soil water. This term is typically expressed in units of tension or pressure (i.e., cb, kPa) and is a negative value. The θ_{SWP} equals 0 kPa when the soil is at saturation and ranges from -10 to -33 kPa at field capacity depending on the soil structure. As the soil dries, the plant must provide more energy to remove the water, and the θ_{SWP} increases to reflect that effort. Permanent wilting point occurs at a θ_{SWP} of -1,500 kPa. Most Midsouth research considers irrigating agronomic crops at -50 kPa to -120 kPa with the most benefit falling in the -65 to -90 kPa range. The most popular products that measure θ_{SWP} for agronomic irrigation include tensiometers and gypsum-based electrical resistance sensors.

A tensiometer is a sealed, airtight tube filled with distilled water that can move between the soil and the tube through a semiporous ceramic tip buried in the soil (Figure 1). Each tensiometer utilizes a pressure gauge to indicate the θ_{SWP} at the time of the reading.

As the soil begins to dry, soil water potential is greater than it is within the tube and water exits through the ceramic tip. This creates a negative pressure (tension) within the tube that is viewed on the pressure gauge. As the soil becomes wet from rainfall or irrigation, the water potential within the tube becomes greater than the surrounding soil, forcing water to reenter the tensiometer and lowering the pressure.

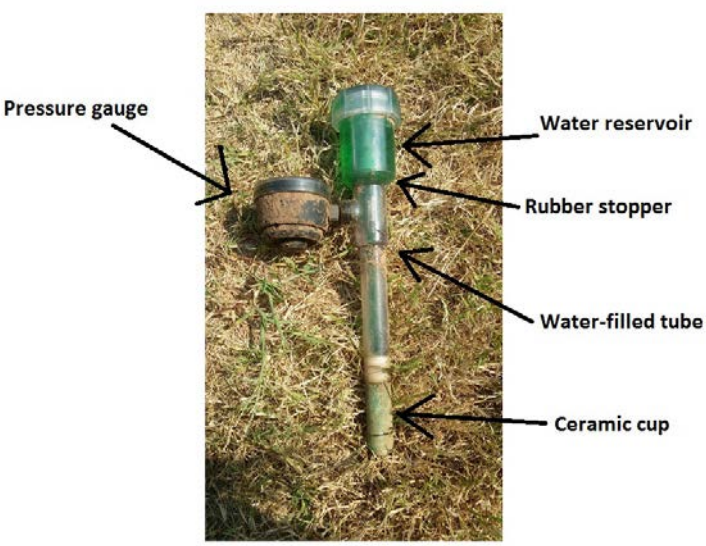

Figure 1: Diagram of a tensiometer.

During the production season, tensiometers provide a quick means of determining actual soil water estimations compared to gravimetric water content. The installation and use of tensiometers in the field takes both time and planning. If they are installed incorrectly or do not maintain an adequate seal, they can produce inaccurate measurements. More specifically, tensiometers only function within a certain pressure range before the airtight seal is broken and integrity is lost. Although the device can be used across a range of soil water content and soil types, it is not recommended that tensiometers be used in soils where θSWP exceeds the range of the pressure gauge.

Tensiometers are easy to use and relatively inexpensive with prices reflecting intended depth of measurement and manufacturer. Therefore, they are a good tool for first-time irrigators or those new to soil moisture monitoring. These devices are typically sold as a manually read device, making it most effective when installed near a field edge for access. Some tensiometers have an electric switch with the ability to record pressure readings over time when connected to a logger or telemetric communication device. This feature would be ideal for more remote installations and also when the soil moisture at a midpoint in the field is more accurate for irrigation scheduling.

Gypsum-based electrical resistance sensors (Figure 2) measure the electrical resistance between two enclosed electrodes in a block of porous material. The electrodes attach to insulated wires that travel to the surface of the soil. These wires can be connected to a resistance meter with a voltage source, data logger or telemetric communication device to determine soil water potential based on resistance within the block. Similar to tensiometers, electrical resistance sensors measure soil water potential based on the water moving through a porous material. The gypsum located inside the sensor dries as the surrounding soil dries, subsequently decreasing electrical resistance.


Figure 2: The Irrometer Watermark is an example of an electrical resistance block.

Soil temperature affects the accuracy of soil moisture readings and results in the need for calibration. Similar to the tensiometers, these sensors are most beneficial in soils that create a sealed connection with the sensor, such as soils with high clay content, but are not recommended in sandy soils and shrink-swell soils (such as Sharkey clays) because of the potential for poor contact between the sensor and the soil.

In addition, electrical resistance sensors are highly affected by substances dissolved in the soil water. While not a widespread issue, water with a high salt content can be troublesome. Furthermore, these sensors should be replaced annually.

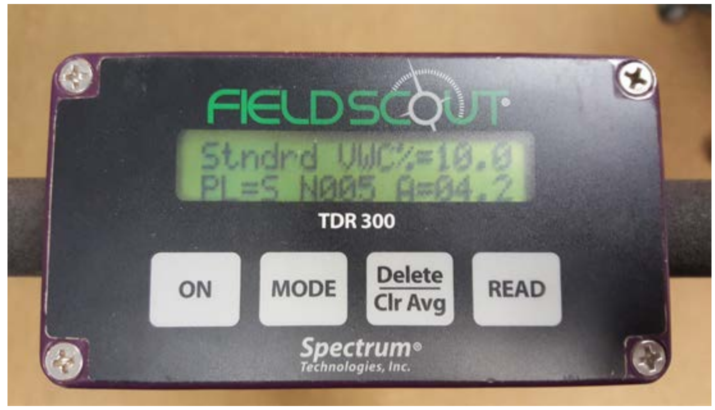

Figure 4: Example output of an instantaneous volumetric water content reading from the Spectrum Technologies TDR 300 (VWC%=10.0). Some sensors can also read temperature and electrical conductivity (not pictured).

Volumetric Measurements

Volumetric water content sensors (Figures 3 and 4) are the most advanced water sensors on the market. These sensors estimate soil moisture by measuring the permittivity, which is the time it takes for an electric pulse or electromagnetic wave to travel through a known volume of soil.

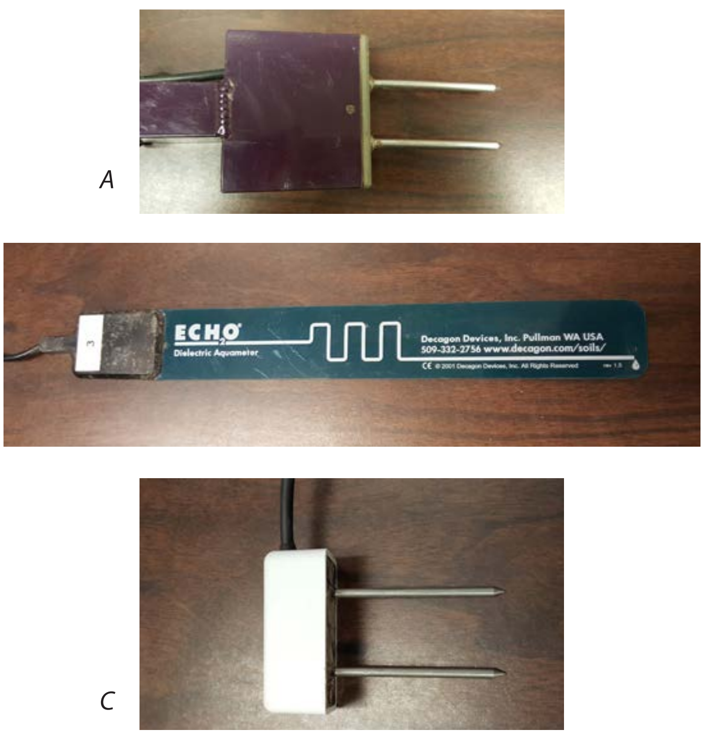

Figure 3: Three examples of sensors that estimate volumetric water content: A) Spectrum Technologies TDR 300, B) Decagon Devices ECH2O, and C) Decagon Devices GS1.

While many soil components (minerals, nutrients and air) contribute to soil permittivity, the permittivity of water is substantially higher than that of any other component. Therefore, it can be assumed the major shifts in these numbers are due to fluctuations in soil water. For this reason, the permittivity is related to the volume of water in the soil and thus indirectly measures the volumetric water content.

There is a variety of commercially available volumetric water content sensors, and each uses a specific technology like time domain reflectometry (TDR), time domain transmissometry (TDT), or frequency domain reflectometry (FDR) as the main types. The TDR and TDT sensors send electrical pulses along metal rods in varying configurations for estimating permittivity based on transmission time. The FDR releases a frequency instead of a pulse.

These sensors work consistently across many soil types and textures, with less need for calibration compared to gravimetric methods when scheduling irrigation based on trends in changing soil moisture. Caution should be used on shrink-swell clays because the loss of contact between the sensor and the soil can produce inaccurate readings. In addition to soil moisture, additional measurements such as soil temperature and electrical conductivity are commonly incorporated into these sensor technologies.

One of the biggest decisions for selecting a specific sensor product is whether the soil moisture is estimated at one depth or multiple depths. Some sensors are purchased as point measurements only, similar to the electrical resistance sensors where measurements at multiple depths require multiple sensors to be installed. The TDR and TDT sensors typically require multiple sensors for estimating soil moisture across the entire soil profile. These sensors are typically selected for quick irrigation decisions without much need for interpretation. Other products, such as FDR sensors, have multiple sensors at specific depths inside a tube or device for ease of installation. These sensors capture water movement throughout the entire root zone and can be advantageous when moving beyond just irrigation scheduling. Other uses include observing root growth based on water movement, compaction and estimating infiltration from irrigation and rainfall.

Another big decision for selecting sensors is the type of communication, listed in order of increasing cost: 1) walk up to sensor site and take an instantaneous reading (all trends over time would be manually tracked), 2) logger keeps subdaily data stored, but it must be downloaded directly to a personal computer, shuttle or phone (no annual fees but must regularly access and process data manually), 3) radio communication through a sensor/node network back to a centralized base station or personal computer for access (no annual fees, but communication distance is short and can be obstructed by plant canopies, buildings, etc.), and 4) cellular communication to the cloud (cell fees required, but you never have to visit the site unless something goes wrong).

Many sensor products must use a proprietary communication system. This means that the datalogger or communication device used to access the data is specific to the sensor brand/model. It also means that the datalogger or communication device cannot be used with any other sensor brand. If flexibility is needed, the ability to use a third-party product should be considered in sensor selection.

Conclusions

There are many instruments and tools that can aid with proper irrigation scheduling. The variety of available technologies can make it difficult to choose the best and most cost-effective methods. Tools that are flexible and provide more detailed information often are more costly, while tools that may be more economical initially often have limited utility and accuracy. When selecting any combination of irrigation scheduling tools, it is essential that the tools and technology are compatible with the intended goals of the production system and the producer.

Author:
Stacia L. Davis Conger, Ph.D., E.I.T.
LSU AgCenter

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William B. Richardson, LSU Vice President for Agriculture, Louisiana State University Agricultural Center, Louisiana Agricultural Experiment Station
Louisiana Cooperative Extension Service, LSU College of Agriculture

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