Development of an Automated System to Incorporate Holes in Lay-Flat Irrigation Tubing During Initial Deployment in Mississippi Soybean Production Systems – Year 3, Project 27-2023 Annual Report

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Rationale/Justification for Research: The ability to irrigate row crops from the Mississippi River Valley Alluvial Aquifer (MRVAA) is crucial to the sustainability of soybean production in Mississippi and the Mid-South. However, groundwater is a limited resource; therefore, even in humid regions, groundwater must be prudently managed to ensure its continued viability and protect the ability to groundwater access for agricultural production. Declining aquifer levels, coupled with impending well monitoring, serve as a catalyst to improve water use efficiency. The RISER program has identified several technologies and management practices that have the potential to eliminate the 300,000 ac-ft/yr. overdraft on the Mississippi Alluvial Aquifer while ensuring that producers stay within permitted irrigation limits. However, the adoption of Best Management Practices (BMPs) by producers in the Mississippi Delta is minimal.

One technology that has been proven to reduce water usage and provide these positive economic impacts is the use of Computerized Hole Selection (CHS). CHS determines the correct hole size for each individual furrow in a lay-flat irrigation pipe system by accounting for row length, inlet and required individual furrow flow, pipeline pressure and hydraulics, and crown elevation. Two software programs exist for CHS: a research-based tool, Pipe Hole and Universal Crown Evaluation Tool (PHAUCET), (Burch, 2012), and a commercial product, Pipe Planner, developed and maintained by Delta Plastics (2020). From 2013 to 2017, the four irrigation water management practices were evaluated in the region using paired field comparisons (Bryant et al., 2017; Spencer et al., 2019). The paired field comparisons consisted of one field receiving the demonstration of irrigation water management practices while the other field was the producer-managed field, holding other management practices (e.g., cultivar selection) constant. Bryant et al. (2017) implemented these practices on 20 paired furrow-irrigated soybean fields and found no significant difference in yield between irrigation water management and the control ($p = 0.67$), while irrigation water management reduced water use by 21% ($p = 0.0198$) and increased irrigation water use efficiency by 36% ($p = 0.0194$).

Objective 1: Continue the assessment of lay-flat irrigation tubing at the farm-scale across a growing season.

Quarter 1: Virgin poly-pipe material (7, 9, & 10 mil.) has been preliminary tested in the automated hole insertion mechanism for functionality in feeding, hole size accuracy, and behavior in deployment through the mechanism after hole insertion with positive results. Further runs of poly-pipe are being prepared, allowing the mechanism to insert holes into field-scale lengths to further test system performance. This material will be connected to irrigation risers to assess flow characteristics by hole and as a whole, providing information to characterize insertion mechanism accuracy by monitoring riser discharge flow and pressure. Additionally, hole integrity will be monitored similarly by subjecting the poly-pipe to a series of irrigation events, alternating tubing inflation and deflation and monitoring for any changes in flow and pressure. After final use, holes from each run of tubing will be selected at defined intervals and evaluated on the poly-pipe test stand for differences in flow uniformity. This information, along with information obtained during previous poly-pipe material testing will serve as the basis for automated hole insertion mechanism operation and will also provide additional information necessary for producers for poly-pipe sizing and well operations. This material will be included in the grower recommendation guide for poly-pipe selection and use being created.

Quarter 2: Material testing is ongoing with the poly pipe test stand to assess material behavior when subjected to irrigation events and to evaluate the accuracy of the hole punch mechanism in dynamic operation utilizing varying thicknesses of poly pipe. As assessments continue, these data are being compiled and compared with previous data to identify potential material variability in both flow characteristics and in behavior/rigidity relative to pressure. These data will aid in better understanding poly pipe properties by material thickness and identify potential variances in material behavior between years to refine material recommendation methodologies.

Quarter 3: Data collection continues utilizing the poly pipe test stand. From initial observed variances in target to actual hole size differences, data suggests that the automated hole insertion mechanism is able to maintain a high level of hole accuracy relative to target size. The data from the recorded flows from these holes indicate that the actual hole size and subsequent flow is within ±2% of the expected flow and also the water discharge from the holes project as a smooth, solid stream with clean edges, observationally appearing to be a laminar flow as opposed to the semi-turbulent flow observed with holes created with the Poly Piranha. These characteristics appear to remain constant across all material thicknesses. Further observations will be continued with multiple outlets in longer runs of tubing as weather permits.

Objective 2: <u>Evaluate and refine the automated mechanism for hole insertion and increase performance capabilities to insert variable hole sizes.</u>

Quarter 1: Supply chain issues, parts availability, and shipping delays in the previous funding cycle slowed construction of the hole insertion mechanism. However, these delays allowed for additional time to refine the mechanism design before initial assembly. As such, the ability for variable hole sizing was included in the mechanism at initial assembly. Testing with this automated hole insertion mechanism has demonstrated positive results for inserting properly-sized holes into the folded edge of poly-pipe (Figure 1) in a continuous process. Initial testing has been conducted with manual operation of the hole insertion mechanism and at material speeds of less than 1 mph to more closely monitor system performance and to optimize the functionality of the hole insertion mechanism. Additional system refinement and testing is ongoing that addresses automating hole insertion timing and location relative to the desired hole spacing intervals. Near-term testing will focus on variable hole size accuracy and determining the optimum speed range at which to operate the system. The PI et al. have involved MSU's Office of Technology Management to provide protection to the intellectual property being developed with this mechanism and any other potential intellectual property developed for system control, prescription processing, etc.

Figure 1. Holes inserted into poly-pipe folded edge with Automated Hole Insertion Mechanism.

Quarter 2: Efforts to refine the hole insertion mechanism are progressing. Currently, the mechanism is capable of adjusting in steps similar to the Poly Piranha II die sizes with efforts focused on refining hole

size precision to fractional millimeter steps. Sensors have been installed to allow the hole insertion mechanism to track the poly pipe edge as it passes through the mechanism, improving the hole size accuracy relative to the desired hole size for each insertion trigger. Targets for refinement of the mechanism are to improve the overall hole size precision to sub-millimeter accuracy at speeds of up to 3 MPH. Further developments to the system include the ability to set hole position in correlation with row spacing to achieve optimum hole placement.

PI has continued meetings with MSU's Office of Technology Management and Patent attorneys to protect intellectual properties, providing technical materials for the development of a Patent application. Goals are to have a Provisional Patent in place in the near term to protect the technology prior to upcoming larger-scale field testing. Per advisement from MSU's Office of Technology Management, detailed information regarding the system, including pictures, graphics, specific operational parameters, etc., will not be disclosed until a Provisional Patent is secured and in place.

Quarter 3: A provisional patent (Serial No. 63/605,768) was filed on December 4, 2023 for a DEVICE AND SYSTEM FOR LAYING AND INSERTING VARIABLE HOLES IN IRRIGATION TUBING. The mechanism's control system has been refined to provide sub millimeter hole size accuracy, allowing for micro-adjustments in hole size and the subsequent flow. This level of precision will allow for fine-tuning of CHS prescriptions and can adjust to address performance variables not currently targeted such as soil type and texture, elevation changes, and other factors to provide a more precise and water conservation-friendly prescription that can be tailored to minimize over or under use of water during irrigation events.

With intellectual property protection now in place, discussions are ongoing with a company specializing in automated systems to further improve system operation and to make the system more user-friendly. These improvements will be under the direction of Dr. Lowe and will focus on refinements that tailor the system to grower needs. These improvements are slated to be performed in Q4 with testing to immediately follow.

Further efforts are ongoing to develop methodologies for hole insertion mechanism activation to deal with irregular field shapes, angles, and other field characteristics that necessitate hole insertion prior or post-row middle due to discharge water trajectory. These methodologies are projected to utilize GPS course headings and other precision ag data along with mathematical techniques to determine triggers for hole insertion.

Quarter 4: To improve the usability of the automated hole insertion mechanism, additional methodologies were developed to eliminate the need for manual integration of every desired hole size. Initial testing with the automated hole insertion mechanism demonstrated its ability to insert properly-sized holes into the folded edge of poly-pipe in a continuous process. Efforts focused on refining hole size precision to fractional millimeter steps, ensuring that the mechanism could adjust to sub-millimeter accuracy for variable hole sizes. Sensors were installed to track the poly pipe edge as it passed through the mechanism, enhancing hole size accuracy. These enhancements allow for micro-adjustments in hole size and flow, tailoring the system to grower needs and minimizing over or under use of water during irrigation events. With intellectual property protection secured, ongoing discussions with a company specializing in automated systems aim to further improve system operation and user-friendliness.

An Automation Direct PLC system was integrated to coordinate the controls of the entire assembly. Ladder logic is utilized to manage hole size insertion, leveraging sensors for edge position detection of the poly-pipe material. By employing greater-than functions, the system dynamically moves the table in response to the ever-changing edge of the poly-pipe material, reducing the margin of error in hole size to within 0.1 mm. This adaptive control allows the system to adjust to varying speeds of material travel

automatically, eliminating the need for the user to set a specific speed for correct operation. The system calculates the material speed in real-time and adjusts its processes accordingly.

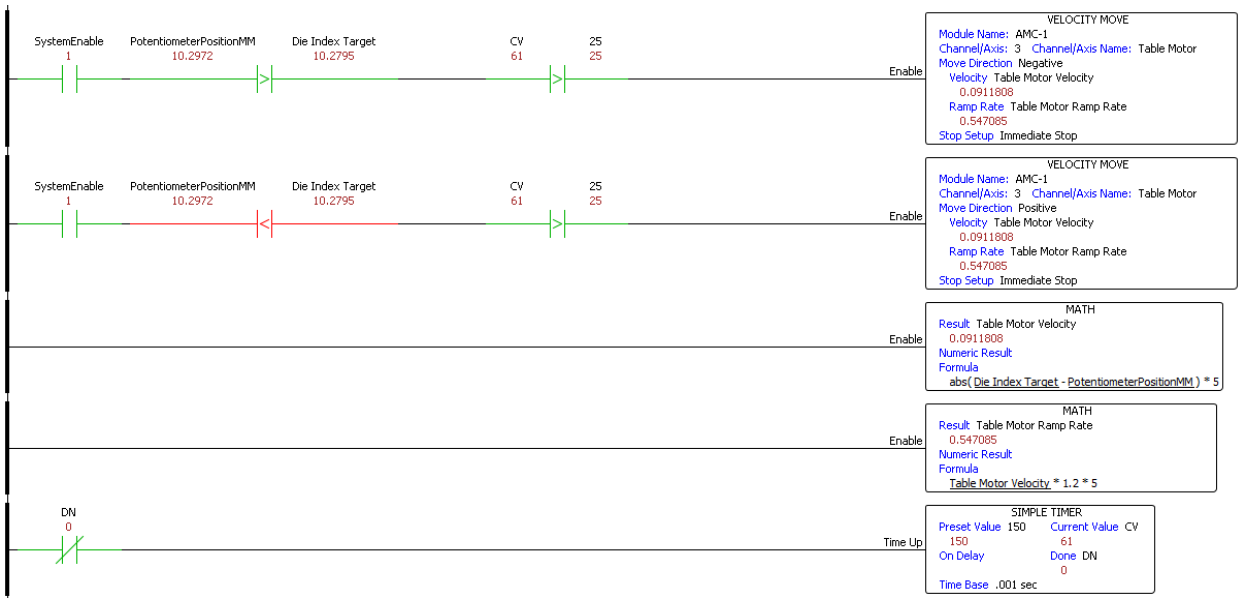

Figure 2. Ladder logic using 'greater than' functions controls hole size insertion. The system, guided by edge position sensors, adjusts dynamically to maintain a 0.1 mm margin of error without requiring preset speeds.

Objective 3: <u>Incorporate the automated hole insertion mechanism onto a poly-pipe laying implement.</u>

Quarter 1: Initial work has started to incorporate the hole insertion mechanism onto a poly-pipe laying implement. A commercially-available poly-pipe implement has been acquired and modifications are ongoing to provide a mounting location for the mechanism. Modifications are also being made to hold and control the feed of the rolled poly-pipe into the mechanism in a controlled manner. These modifications are expected to be completed in the near-term to facilitate overall system functionality testing and evaluation.

Quarter 2: The hole insertion mechanism and control system has been successfully installed onto a poly-pipe laying implement. Modifications were performed on the implement to reposition and hold the rolls of poly-pipe in alignment with the mechanism and to provide dynamic braking to prevent material free-spooling off the roll. Additional work is ongoing to design and construct a mechanism to regulate the delivery of the punched poly-pipe onto the ground with the desired hole orientation and to cast loose soil onto it to prevent its' movement until it is initially charged with water during the first irrigation event.

Quarter 3: An initial design of the ground delivery component has been finalized and construction of the mechanism is ongoing to conclude early Q4 with preliminary testing and refinement to follow. Further testing to evaluate the ability of the mechanism to cast loose soil onto the deployed tubing will be carried out as soon as field conditions are favorable. During this period, data about tubing behavior will be collected in order to establish a methodology for charging with water and maintaining desired hole alignment relative to the row middle.

Quarter 4: Efforts to refine the accuracy of hole size insertion have continued with the addition of new components to the device. These improvements are aimed at enhancing the precision of the hole insertion mechanism. Concurrently, a system is being developed to manage the transition of poly-pipe material

from the device to the ground. This system will be crucial in ensuring the correct alignment and orientation of the tubing upon deployment, thus maintaining the integrity of the inserted holes.

Objective 4: Modify the poly-pipe laying implement by adding a rotary ditcher to create a "trough": deposit loose soil onto the tubing during deployment for correct hole orientation and alignment; field evaluations.

Quarter 1: Initial work has been started to add the rotary ditcher head onto the poly-pipe implement beginning with the acquisition of components to assemble the head assembly, construct an adjustable support structure for the head for depth adjustment, hydraulic components for powering the cutter head and depth control, and associated electronic control components to regulate the system. Additionally, design parameters for laying and covering the deployed poly-pipe to hold it in place until initial charging are being formulated and will be constructed once all components are mounted onto the poly-pipe implement. Testing and evaluation of this part of the system will run concurrently with overall system testing as all components must work in tandem to achieve the overall goals of this project. Testing should begin within Q2 with any adaptations or modifications to occur as design deficiencies or functionality issues are identified.

Quarter 2: Rotary ditcher components have been acquired along with the parts to construct the cutting head positioning mechanism. Currently, the mechanism is in the final stages of construction and fitting to the poly-pipe laying implement to follow in the near term. The mechanism was designed to control cutting head depth and side-to-side positioning to match with poly-pipe diameters in use. The cutting head is powered hydraulically, with speed control incorporated to allow for fine-tuning relative to varying soil conditions to produce a clean, curved bottom trough for the poly pipe material to rest in. Evaluation of the mechanism's mechanical function appears to operate favorably and will be further evaluated for performance in field conditions in the near term.

Quarter 3: The rotary ditcher assembly is complete and preliminary installation onto the laying implement has been performed. Additional components necessary to control the head depth are being purchased and installed. Primarily, this system is integrated into the control system and relies on GPS elevation data to determine the target depth for the cutting head. This system features electrically-controlled hydraulic valves that adjust head to regulate the trough depth where the tubing is deposited. This system will also index horizontally to change trough position relative to tubing diameter at inflation with water.

Quarter 4: The cutting head has been successfully implemented onto the rotary ditcher assembly, marking a significant milestone in the project's progression. Electrically-controlled hydraulic valves, which adjust the cutting head to regulate trough depth and position relative to the tubing diameter, have been procured and initially installed. These components require further integration to be fully operational in field conditions. A potentiometer system has been incorporated into the assembly to ensure the accurate depth and position of the trough, enhancing the precision of the cutting process. The preliminary installation of the GPS system has been completed, with initial testing demonstrating favorable results. This system utilizes elevation data to determine the target depth for the cutting head, with further testing scheduled for Q5. During this phase, the rotary ditcher's performance in creating a clean, curved bottom trough for the poly-pipe material will be thoroughly evaluated, ensuring correct hole orientation and alignment during deployment in actual field conditions.

Figure 3. The rotary ditcher lower assembly (cutting head not installed) with steel skid and hydraulic drive motor.

Figure 4. The rotary ditcher assembly (cutting head removed) installed on the poly-pipe punch and laying implement. Hydraulic cylinder attaches in the rear to raise/lower the assembly to control depth.

Figure 5. Cutting head assembly mounted on the rotary ditcher.