Mississippi Water Resources Research Institute (MWRRI)
Final Project Report

Water-Conserving Irrigation Systems for Furrow & Flood Irrigated Crops in the Mississippi Delta

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Abstract

The goal of this project was to improve irrigation water- and energy-use efficiency for one of the most economically important cropping rotations practiced in the Mississippi delta, the soybean-rice rotation. Combined economic activity for the two crops in the delta exceeds $600 million annually while combined irrigation water use approaches 2 million A-ft per season. As a result, a modest reduction in the amount of irrigation water used in the soybean-rice rotation could help reduce the current overdraft of the alluvial aquifer. Results from these 2010 on-farm trials indicate soybean irrigation savings using NRCS Phaucet optimization software ranged from 6 to 18% compared to non-optimized furrow irrigation while associated energy use reductions ranged from 32 to 20%, respectively. (It is important to note that in order to foster comparison, the soybean fields used in these studies were rectangular in shape; water savings are expected to be greater for more irregular (i.e., hard to irrigate) soybean fields.) Irrigation water used in rice grown using straight-levees with multiple inlets and intermittent flood management averaged 23.1 ± 2.4 A-in/A as compared to 32.4 A-in/A for straight-levee rice using multiple inlets without intermittent flood management. These results indicate that by overlaying an intermittent flood regime on practices that are already familiar to rice producers in Mississippi, rainfall capture is increased and over-pumping is decreased such that overall water use is reduced by ~40% over the standard rice irrigation practices. Field trials comparing rough rice yield and milling quality for 15 rice varieties grown on two soil series indicated that commercial rice varieties, grown using standard fertility and pest control programs, well-tolerated a carefully-controlled intermittent flooding regime. Each inch of water not pumped from the Alluvial aquifer onto an acre of rice or soybean saves the energy equivalent of ~0.7 gallon diesel fuel (with concomitant reduction in CO_2 emissions by ~200 lbs/A). Assuming a current off-road diesel price of $3.20/gallon, a 9 acre-inch (40%) reduction in rice irrigation translates to a savings of ~$20 per acre while a 1.5 acre-inch (18%) reduction in soybean irrigation represents a savings of ~$3 per acre. By reducing irrigation water and associated energy inputs in soybean and rice production, the producer reduces input costs while reliving pressure on the Alluvial aquifer and also reduces carbon emissions.

Critical Water Problem Addressed

The current rate of groundwater extraction from the Alluvial aquifer in the Grand Prairie region of Arkansas is unsustainable. Declines in groundwater availability are expected to reduce the region's crop production in coming years (1, 2). As a result, some producers have begun tapping into the underlying Sparta-Memphis aquifer for irrigation supplies. This is of great concern to cities such as Memphis (3) because the Sparta-Memphis aquifer is used primarily for domestic purposes and is not as productive as the Alluvial aquifer. The costly and controversial Grand Prairie Area Demonstration Project (4, 5) is being constructed to partially compensate for the region's anticipated loss in irrigation capacity.

The Mississippi delta is also experiencing groundwater decline, although less severe than that occurring in Arkansas (Figure 1). The decline in Mississippi has caught the attention of state regulators who have clearly indicated that water quantity, and the prevention of groundwater depletion in the Delta, are both important to the economic future of Mississippi (6).

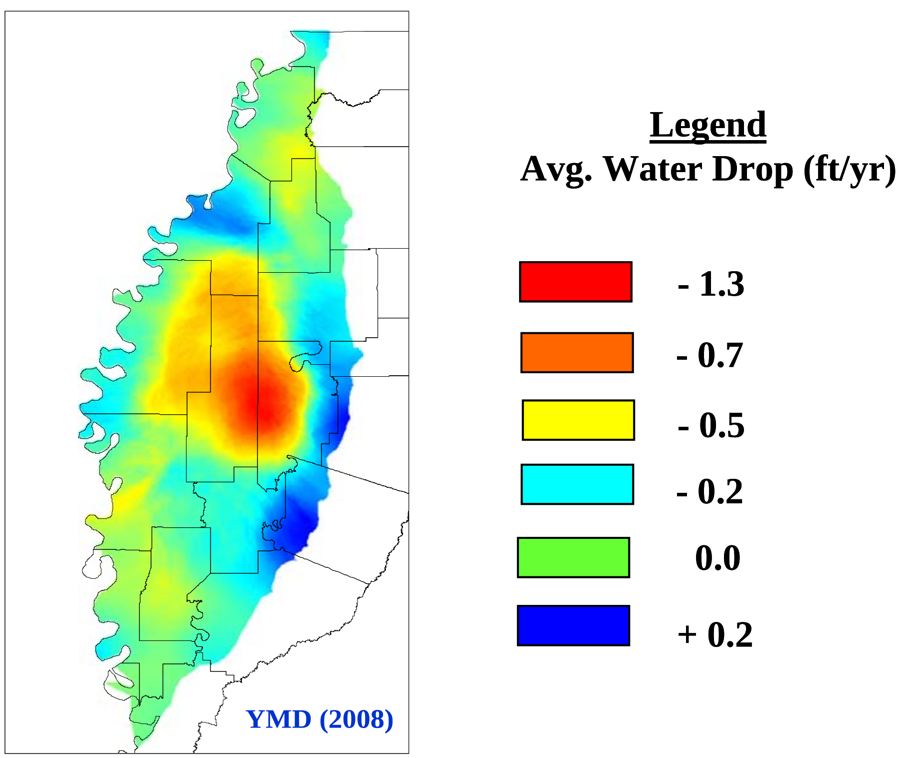

Figure 1. Average 20-yr decline in depth of alluvial aquifer in

Research Scope and Related Research

The 2:1 soybean-rice crop rotation is a three year rotation practiced on nearly one million acres across the Mississippi delta (Figure 2). This rotation has a combined economic activity that exceeds $600 million annually and uses approximately 2 million A-ft of irrigation water per season (Table 1). Thus, a modest reduction in the amount of irrigation water used in the soybean-rice rotation could help to reduce overdraft of the alluvial aquifer.

Table 1. Estimated water use in Mississippi agriculture (7, 8).

Crop	2009 Acres (thousands)	Avg. H_2O Use (Ac-ft/Ac)	Seasonal Water Use (Ac-ft)
Rice	250*	3	750,000
Corn	900	0.8	720,000
Soybeans	2,500* (Delta only: 1,750)	0.7	1,750,000 (Delta only: 1,225,000)
Cotton	270	0.5	135,000
Fish	70	1.9	133,000

* 100% of the rice and ~70% of the soybeans grown in MS occur in the Mississippi delta.

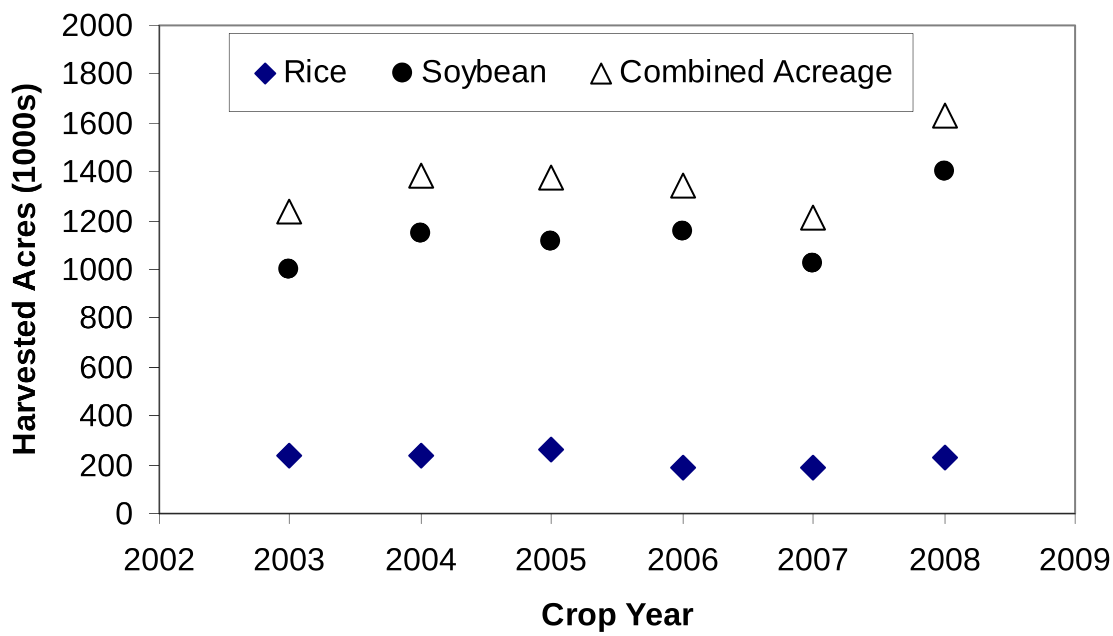

Figure 2. Rice and soybean acreages in the Mississippi Delta (2003-2008). (8).

Soybean (*Glycine max*) are often grown on beds and irrigated using lay-flat plastic tubing (Figure 3). The USDA NRCS *Phaucet* irrigation computer program[1] optimizes hole size and number in plastic tubing, improving irrigation efficiency by 25% or more according to research conducted in Arkansas(9). Phaucet requires that the overall field dimensions (row lengths and widths) and slope of the field (total head pressure, in feet) and flow rate of the irrigation pump (gallons per minute) be determined. Coupling this information with the dimensions of the plastic tubing, the program provides the optimal hole sizes and numbers to distribute water more evenly across irregularly-shaped fields.

Figure 3. Irrigation using lay-flat tubing can be improved using the NRCS Phaucet program that determines optimal hole size and number for furrow-irrigated crops.

For rice (*Oryza sativa*), this project will build upon research conducted at Mississippi State University (10) that has found that coupling multiple-inlet (MI) irrigation with intermittent (Int) flood management may reduce water use by as much as 50% relative to conventional irrigation practices. Unlike conventional flooding where the rice flood is maintained at a nearly constant depth throughout the growing season, intermittent irrigation allows the flood to naturally cycle over time (Figure 5-a). This reduces water use by (a) reducing over-pumping and associated tail-water runoff, and (b) by increasing rainfall capture. The Mississippi delta receives approximately 10 to 14-inches per season. In practice, as many as 8 drying cycles have been achieved by Mississippi rice growers, resulting in paddies being maintained at "less-than-full" throughout the entire growing season (Figure 5-b), and significantly improving rainfall capture. Rice yield and grain milling quality have been unchanged relative to that of control fields. Moreover, farmers have found that simple depth gauges installed in their rice paddies (Figure 6) and spring-wound timers (Figure 7) can aid in managing the rice flood.

[1] NRCS Phaucet program available at link:
(http://www.wsi.nrcs.usda.gov/products/w2q/water_mgt/irrigation/irrig-mgt-models.html)

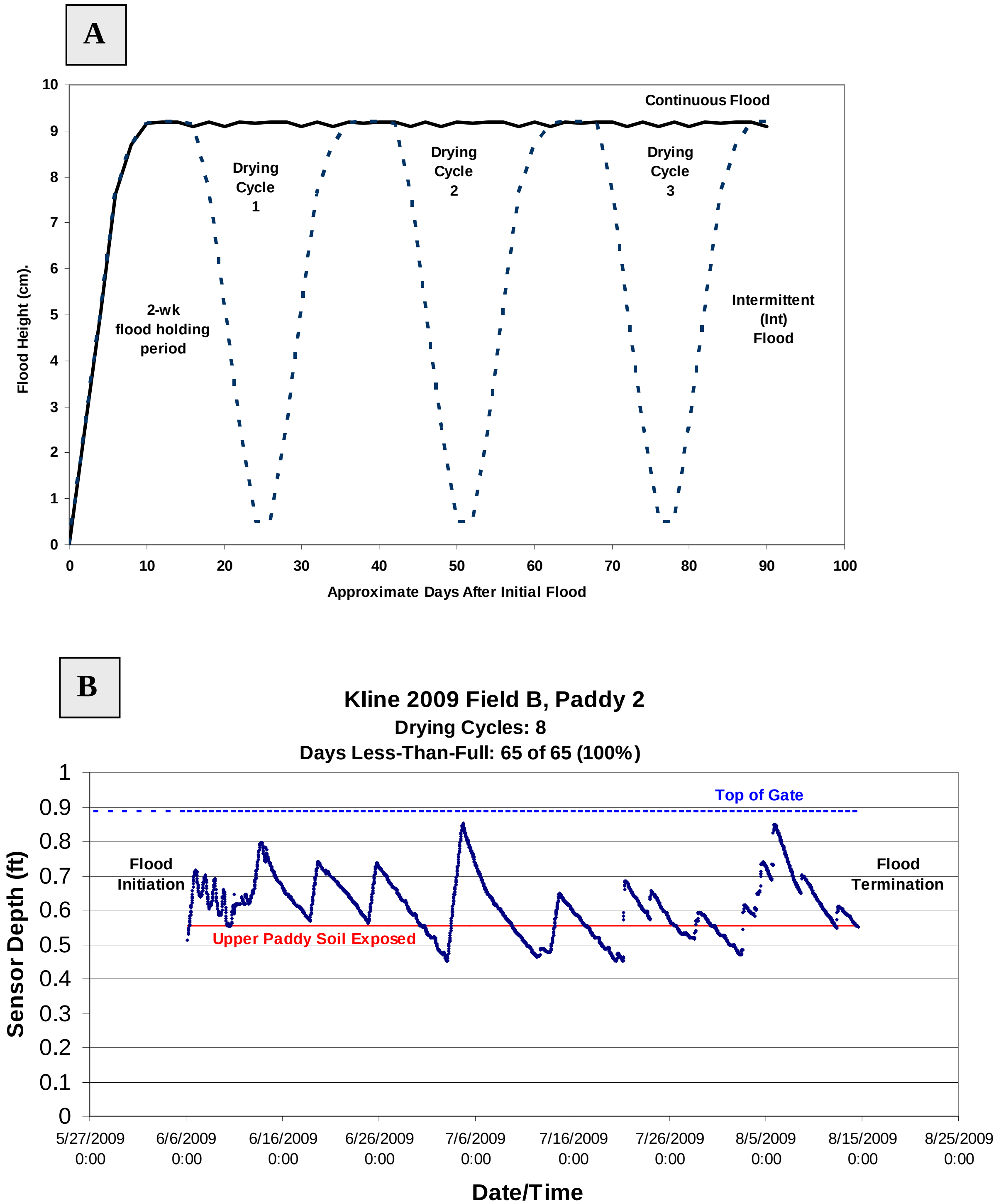

Figure 5. Diagram demonstrating flood depths in rice paddies maintained using continuous or intermittent flooding (A), and actual flood management that resulted in 8 drying cycles and 100% of days where paddy was maintained at a 'less-than-full' status (B). The water use in Field B was 1.22 Ac-ft/A.

Figure 6. Low-cost depth gauges may assist in the careful management of rice flood.

Figure 7. Manual timers installed to control irrigation pumps can save additional water and energy in soybean and rice production.

Objectives

The overall goal of this project was to collaborate with producers to develop water-conserving irrigation practices for soybean and rice so as to reduce overall withdrawals from the alluvial aquifer while also reducing input costs related to irrigation. To reach this goal, the following objectives were pursued:

Objective 1: Compare season-long water and energy use, grain yield, and grain quality for soybean grown using furrow irrigation systems optimized using the NRCS Phaucet and pump timers to that of non-optimized furrow irrigated soybean.

Objective 2: Compare season-long water and energy use, grain yield, and grain quality for rice grown using intermittent flood plus multiple inlet irrigation, pump timers, and depth gauges to rice grown using only multiple inlet irrigation.

Objective 3: Using input from producers and crop consultants, refine approaches developed in Objectives 1 and 2 to create systems that can be readily adopted across the delta.

Research Design

Soybean

Ten fields at five commercial farms located in Bolivar, Leflore, and Washington counties were fitted with McCrometer flowmeters for season-long water use and arranged to allow side-by-side comparisons of water and energy use with and without *Phaucet* furrow irrigation optimization.

Rice

Twelve fields at four commercial farms located in Bolivar, Coahoma, and Leflore counties were fitted with McCrometer flowmeters for season-long water use and Global Water depth loggers for determining flooding pattern. The water use and flood management practices were monitored from flood initiation (~mid-May) to flood termination (~mid-August). Weather stations and/or electronic tipping bucket rain gauges were installed at each producer site.

Two variety trials were conducted in Bolivar County to determine the effects of variety, soil type, and intermittent flooding on rice yield and milling quality. Fifteen rice varieties using four replications each were planted in the top and bottom of a paddy near the top of a field. The top of the paddy underwent intermittent flooding while the bottom of the paddy was to remain continuously flooded. This allowed direct comparison of the effect of intermittent flooding on rice yield and milling quality. This study was conducted on a clay and silt loam soil.

Data Collection and Analysis

Seasonal water use (A-ft/A), water depth profile (rice only), electrical energy use (soybean), grain yield (bu/A), and milling quality (rice only) were collected for each field included in the study. Simple descriptive statistics were used to report these values.

Results and Benefits

Soybean

Owing to circumstances beyond our control, side-by-side field comparisons of conventional furrow irrigation versus furrow irrigation optimized using the NRCS *Phaucet* program were made at only two farm locations in Washington Co. At one location, *Phaucet* reduced water use by approximately 18% (15.6 vs. 13.3 A-in/A) and energy use by approximately 20% (313 vs. 260 gallons per 29 A fields). At the second location, water used was reduce by only 6% (20.3 vs. 19.1 A-in/A), but energy use was reduced by ~32% (3202 vs. 2431 kWh). This latter result reflects that overall water use was not significantly different, but the total run time for the pump was less as the *Phaucet* optimization program allowed the water to distribute across the field in a more efficient manner, saving considerable energy. Soybean yields at both locations were not significantly different between irrigation treatments. These results are summarized in Table 2.

Table 2. Results from two soybean irrigation trials comparing water and energy use with and without Phaucet furrow irrigation optimization.

Parameter	**Conventional Design**	**Phaucet Design**	**Savings (%)**
Trial A Field Size (A)	16	15	
Water Use (A-in/A)	20	19	5
No. of Irrigations	5	6	---
Energy Use (kWh/A)	200	162	23
Total Pumping Time (hrs)	153	116	32
Soybean Yield (bu/A)	62.2	62.2	---
Trial B Field Size (A)	29	30	
Water Use (A-in/A)	16	13	23
No. of Irrigations	3	3	---
Energy Use (kWh/A)	11	9	22
Total Pumping Time (hrs)	123	105	17
Soybean Yield (bu/A)	48.2	48.6	---

Rice

Irrigation water used in rice grown using straight-levees with multiple inlets and intermittent flood management averaged 23.1 ± 2.4 A-in/A as compared to 32.4 A-in/A for straight-levee rice using multiple inlets without intermittent flood management. These results indicate that by overlaying an intermittent flood regime on practices that are already familiar to rice producers in Mississippi, rainfall capture is increased and over-pumping is decreased such that overall water use was reduced by ~40% over the standard rice irrigation practices. These results are summarized in Table 3.

Table 3. Summary of rice irrigation results for 2010 at various field locations.

Field Location	**Field Size (A)**	**Soil Type**	**Irrigation System**	**Irrigation Added (A-in/A)**
Coahoma Co.	32	clay	SL + MI + Int.	19.3
	30	clay	SL + MI + Int.	26.9
Bolivar Co.	34	clay	SL + MI + Int.	22.9
	73	clay	SL + MI + Int.	23.2
	64	clay	SL + MI + Int.	29.3*
	36	clay	SL + Conv. Flood	29.9
	35	clay	SL + MI + Int.	23.2
Leflore Co.	40	clay	SL + MI	23.3
	40	clay	SL + MI	28.8
	40	clay	SL + MI	27.8

(*) water use increased owing to field having lost its precision level, necessitating the need to keep flood depth higher in middle sections of field with the result of increased runoff.

In the rice variety trials conducted on the clay soil, the top-of-the-paddy treatments underwent five wetting-drying cycles while the bottom plots remained flooded except for two wetting-drying cycles. Water use on this field was approximately 23 A-in/A irrigation water as compared to the delta-wide average of 32 A-in/A for straight-levee with side inlets (YMD, 2010). Pair wise comparisons (top vs. bottom paddy) for each variety suggests that yields (Table 4) and milling quality (data not shown) of the different rice varieties were unaffected by these wetting-drying cycles, except for 6004 where top of the paddy yield was higher than that of the bottom paddy ($p = 0.0326$). When analyzed across all varieties, the statistics indicated that there significant (~5%) increase in yield ($p < 0.05$) in favor of the intermittent (top of paddy) plots. It has been reported that rice grown under intermittent irrigation often yields higher than when it is continuously flooded (11).

In the rice variety trials conducted on the silt loam soil, the producer had difficulty keeping this field irrigated due to recent sub-soiling, dry weather, and weak irrigation well. As a result, the top of paddy plots underwent 10 wetting-drying cycles and the bottom underwent 8 cycles. Water use on this field was nearly 6 A-ft/A, reflecting the harsh conditions of this test. Thus, this test does not realistically allow for valid comparisons of intermittent flood impacts on yield and milling because both top and bottom plots underwent wetting-drying cycles. As shown in Table 5, pair wise comparisons of top vs. bottom paddy yields were not different ($p > 0.05$) except for CL181 ($p = 0.0123$) which had higher yield for the bottom paddy plot as compared to the top plots. Similar results were observed for milling quality whereby no differences ($p > 0.05$) between top and bottom plots were detected (data not shown).

Significant Research Findings

These data support the premise that readily-available technologies and management strategies such as the NRCS *Phaucet* furrow irrigation optimization program, improved crop genetics, pump timers, flood depth gauges, and intermittent irrigation practices can be combined within cropping rotations to significantly reduce water and energy use while maintaining economically-viable yields. Each inch of water not pumped from the Alluvial aquifer onto an acre of rice or soybean saves the energy equivalent of ~0.7 gallon diesel fuel and reduces CO_2 emissions by ~200 lbs per A. Given a current off-road diesel price of $3.20/gallon, the 9 acre-inch (40%) reduction in rice irrigation demonstrated in this study translates to a savings of ~$20 per acre while a 1.5 acre-inch (18%) reduction in soybean irrigation represents a savings of ~$3 per acre. By reducing irrigation water and associated energy inputs in the soybean-rice rotation, the producer can reduce input costs, relieve pressure on the Alluvial aquifer, and also reduce carbon emissions.

Table 4. P-values for comparison of yields at top versus bottom paddy on clay soil.

	Avg. Rice Yield (lb/A) dry		
Variety	**Top of Paddy (int flood)**	**Bottom of Paddy (cont flood)**	**Type III Pr > F***
6004	10,548	9,067	**0.0326**
Bowman	9,838	9,905	0.9004
CL111	10,850	11,380	0.5048
CL131	9,142	9,762	0.2304
CL142	11,605	10,489	0.0643
CL151	11,428	10,852	0.2763
CL181	9,588	9,278	0.6637
CLX745	12,386	11,698	0.1889
Cheniere	10,576	10,124	0.1017
Cocodrie	10,796	10,528	0.2154
Neptune	10,396	9,452	0.0756
Rex	10,481	9,899	0.1846
Taggart	11,486	10,961	0.3535
Templeton	11,083	9,933	0.0618
XL723	12,809	12,808	0.9986

(*)Values less than 0.05 indicate difference in yield between top and bottom of paddy for that variety.

Table 5. P-values for comparison of yields at top versus bottom paddy on silt loam soil.

	Avg. Rice Yield (bu/A) dry		
Variety	**Top of Paddy (int flood)**	**Bottom of Paddy (cont flood)**	**Type III Pr > F***
6004	8,108	8,697	0.3636
Bowman	7,578	7,139	0.5650
CL111	9,637	10,398	0.1592
CL131	7,986	8,522	0.1948
CL142	9,084	9,482	0.7100
CL151	7,957	8,815	0.2325
CL181	8,033	8,759	**0.0123**
CLX745	13,506	13,981	0.3847
Cheniere	7,697	8,173	0.0857
Cocodrie	8,846	9,085	0.5360
Neptune	8,651	9,633	0.3829
Rex	8,034	9,222	0.1178
Taggart	8,607	8,981	0.3871
Templeton	8,384	8,691	0.4008
XL723	12,445	13,788	0.0987

(*)Values less than 0.05 indicate difference in yield between top and bottom of paddy for that variety.

Technology and/or information transfer and dissemination

Presentations

Earth Day week talk MSU April 19, 2010. Water and Agriculture in the Mississippi Delta. Mississippi State, MS.

YMD Board of Directors Meeting.. Reducing Water Use in Mississippi Rice Production: Opportunities and Challenges. Leland, MS. 21 April 2010

Professional Soil Classifiers Association of Mississippi. Management of Risk and Agricultural Resources in the 21st Century. Crystal Springs, MS. 15 July 2010.

Agriculture and the Mississippi Delta. PSS Departmental Seminar, 04 Oct 2010. Mississippi State

University.

Water-Conserving Irrigation Systems for Furrow & Flood Irrigated Crops in the Mississippi Delta. Mississippi Water Resources Research Institute Annual Conference, Bay St. Louis, MS. 03 November 2010.

Mississippi Water Resources Research Institute Advisory Board meeting. Water-Conserving Irrigation Systems for Furrow & Flood Irrigated Crops in the Mississippi Delta status report. Mississippi State, MS. 9 November 2010.

Yazoo Water Management District Water Meeting. Efficient Irrigation Systems Overview. Stoneville, MS. 10 Nov 2010.

Training potential

To date, one undergraduate student was involved in this research.

Future research

Additional research that investigates technological advances in crop breeding and pump monitoring and irrigation system control electronics should be conducted to derive water- and energy-efficient production systems that provide the grower options and increased resilience for 21st century cropping conditions.

References

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