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Farmer adaptation of intermittent flooding using multiple-inlet rice irrigation in Mississippi

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ABSTRACT

Although intermittent flooding of rice (*Oryza sativa* L.) has been shown to significantly reduce irrigation demand, farmer adoption is limited in the United States where continuous flooding remains standard practice. This limited extent of adoption stems in part from a number of scalability and agronomic concerns. This study used replicated trials established in farmer-managed fields to determine if intermittent flooding can be successfully adapted to commercial-scale rice production in Mississippi. When intermittent flooding was coupled with multiple-inlet rice irrigation (MIRI), the quantities and qualities of yields were maintained or increased for five commercial rice varieties and one hybrid, relative to continuously-flooded controls. Only CL151 exhibited a decrease in total head rice when milled, this after being subjected to five or more wetting and drying cycles over ≈80 day flood periods. Water use over three years averaged 32% less than comparable MIRI systems not using intermittent flooding. These results demonstrate that intermittent flooding can be successfully adapted by producers to commercial-scale and that 600 mm irrigation is an achievable goal for rice grown on clay soils in Mississippi. The positive yield responses of CL162 to intermittent flooding and pre-flood urea-nitrogen support research showing that rice benefits from carefully managed wetting- and drying-periods when used in conjunction with effective pest management. The success of these producers at adapting intermittent rice flooding to commercial scale can be attributed in part to their having comprehensive weed and disease management programs, proficiency in using MIRI, and reliable irrigation systems with ample well capacities that allowed rapid flood establishment. Even partial adoption of intermittent rice flooding can increase rainfall capture and reduce demand for irrigation. In turn, this could help to alleviate overdraft of the Mississippi River Valley Alluvial aquifer, a resource of national and international significance.

1. Introduction

Approximately 65% of U.S. grown rice occurs in an 11,200 square kilometer area of intense agricultural activity along the Lower Mississippi River Valley. Irrigation water applied to rice and other crops is derived primarily from the Mississippi River Valley Alluvial (MRVA) aquifer (Arkansas Soil and Water Conservation Commission (ASWCC), 2010). The MRVA aquifer is second only to the High Plains aquifer in terms of irrigation withdrawals in the U.S. (Maupin and Barber, 2005). Portions of the aquifer in Mississippi are declining at rates 0.15 m or more per year (Yazoo Mississippi Delta Joint Water Management District (YMD), 2013). As a result, plans to address MRVA aquifer overdraft in Mississippi are being devised with initial efforts emphasizing improvements in irrigation efficiency of rice and other agronomic crops (Mississippi Department of Environmental Quality (MS DEQ), 2013).

Mississippi producers have worked steadily to reduce the amount of irrigation needed to produce rice. In the 1980s, they began precision-leveling fields to uniform slopes of 0.1 to 0.2%, built elevated roads around field perimeters, and installed slotted-board risers at field outlets. These improvements made irrigation management easier and allowed the use of straight levees rather than levees constructed along topographic contours. More than 60% of Mississippi's rice is grown in straight-levee fields which reduce water use by approximately 17% relative to contour-levee fields (Smith et al., 2007). In the 1990s, producers began using 'zero-grade' fields with no slope, reducing irrigation use by about 55% relative to contour fields (Smith et al., 2007). Although efficient,

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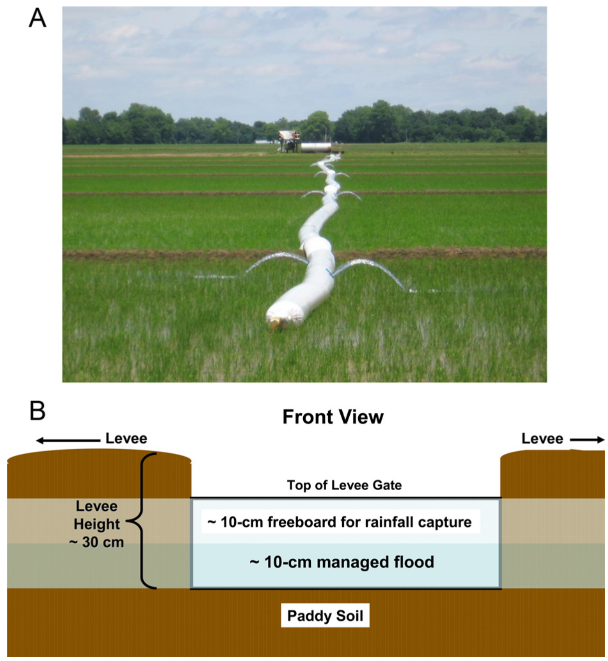

Fig. 1. (A) Use of multiple-inlet rice irrigation (MIRI) in a straight-levee field in Mississippi, and (B) example of a levee-gate system used to increase rainfall capture and reduce water movement between paddies when used in conjunction with MIRI.

zero-grade systems represent only approximately 5% of the rice growing area owing to potential water-logging of rotational crops such as soybeans [*Glycine max* L. (Merr.)] (Smith et al., 2007). Also during the 1990s, use of multiple-inlet rice irrigation (Vories et al., 2005; Thomas et al., 2004) began. In multiple-inlet rice irrigation (MIRI), plastic tubing is installed perpendicular to levees and used to distribute water to all paddies simultaneously (Mississippi State University (MSU) Extension Service, 2012). Fig. 1A shows MIRI use in a field with straight levees. MIRI is used on approximately 25% of the rice area and results in average water savings of about 30% relative to contoured-levees (Yazoo Mississippi Delta Joint Water Management District (YMD), 2013). The average seasonal amounts of irrigation applied to the different rice irrigation systems in Mississippi are 1117 ± 127, 965 ± 51, 783 ± 146, and 508 ± 152 mm for contour, straight-levee, straight-levee using MIRI, and zero-grade rice, respectively (Smith et al., 2007; Yazoo Mississippi Delta Joint Water Management District (YMD), 2013).

Rice in Mississippi is grown using a direct-seed, delayed-flood culture (Miller, 2008). The flood is initiated at the five-leaf or V5 (Counce et al., 2000) growth stage and maintained at a nearly constant 8- to 15-cm depth to meet evaporation-transpiration (ET) demand and to suppress weeds (Smith and Fox, 1973; Gealy, 1998). Pringle (1994) found that rice grown in Mississippi using an 80-d flood requires from between 355 to 635 mm water (rainfall plus irrigation), depending on cultivar, soil texture, and weather. Thus while producers have significantly reduced water use, all systems but zero-grade routinely receive more irrigation than is generally considered necessary for rice production in Mississippi.

Intermittent flooding uses up to 50% less irrigation compared to continuous rice flooding (Bouman et al., 2002; Dong et al., 2001). The increased efficiency is attributed to decreased water loss from percolation, field-edge seepage, and floodwater runoff (Bouman and Tuong, 2001; Dong et al., 2001; Li, 2001). The lower average flood depth also results in increased rainfall capture as compared to continuously-flooded rice (Li, 2001). Mississippi receives approximately 300 mm rainfall during the May through August rice irrigation season (Silva, 2013), indicating potential to reduce irrigation inputs by optimizing rainfall capture. For every 2.5 cm rainfall captured, approximately 9 L diesel fuel per ha are saved when irrigating from the MRVA aquifer (Hogan et al., 2007).

In spite of these possible savings, producers have expressed concerns regarding the potential negative impacts of intermittent flooding on grain yield and quality. The risk of not being able to reestablish a flood in a timely manner is of particular concern, as most published research has been conducted in plots or fields considerably smaller than those used for commercial production in Mississippi. Moreover, large fields serviced by wells having capacities less than the recommended 140 L min^{-1} ha^{-1} for rice irrigation (Miller, 2008) can be difficult to manage even under the best of circumstances. Because MIRI distributes water to all paddies simultaneously, it allows more rapid flood establishment in large fields. For this reason, MIRI was deemed essential to adapting intermittent flood management to commercial-sized rice fields.

Other producer concerns relate to potential negative impacts on nitrogen dynamics and pest management. Alternating between anaerobic and aerobic soil environments can result in reduced yields and increased environmental loading via nitrification and denitrification losses. For example, Wang et al. (1998) reported that nitrogen recovery efficiency was only 29% in early-planted and 5% in late-planted rice grown using alternating wet–dry irrigation. It is uncertain how intermittent irrigation will affect nitrogen management in drill-seeded, delayed-flood rice culture used in Mississippi. However, the preponderance of research suggests that intermittent flooding will be more susceptible to nitrogen losses through nitrous and nitric oxide emissions (Bronson et al., 1997; Phillips, 1999). Moreover, a permanent flood has traditionally been used to reduce competition from weeds (Baldwin and Slaton, 2001) and injury from rice blast (*Pyricularia grisea*) (Cartwright and Lee, 2001). In order for intermittent flooding to be adopted by producers, they must be convinced that these issues will not result in significant reductions in grain yield or quality.

The overall objective of this research was to devise rice irrigation practices that reduce irrigation demand, while maintaining rice yield and quality, as a means to help reduce overdraft of the MRVA aquifer. The specific objectives were to determine if intermittent rice flooding (1) can be successfully adapted and managed by commercial rice producers using MIRI in straight-levee fields, the most common rice levee system used in Mississippi, (2) impacts the quantity and quality of rough rice yield for commercial varieties and hybrids grown in Mississippi, and (3) impacts the yield response of drill-seeded rice to pre-flood urea-nitrogen applications as compared to continuous flooding. To our knowledge, this is the first study to report successful adaptation of intermittent rice flooding to commercial-scale production in the United States.

2. Materials and methods

Studies were conducted in straight-levee rice production fields located in Bolivar (years 2010, 2011) and Coahoma (year 2012) counties in the LMRV rice growing region of western Mississippi. Field locations and sizes along with soil series and taxonomic descriptions are given in Table 1. All fields were managed by cooperating producers using agronomic and pest control practices common to their particular operations. The rice growth staging system of Counce et al. (2000) is used when describing irrigation or pest control timings used by the cooperating producers.

Each year, replicated trials were established at the top and bottom of one paddy in one rice production field. Owing to the ≈0.15% slope of the field, a shallower flood always covered the upper portion of the test paddy relative to the lower portion of the paddy. During the dry-down phase of an intermittent flood cycle, mud with no standing water was exposed in the upper third of the paddy while the bottom-third of the paddy remained submerged.