Reduced Water Use and Methane Emissions from Rice Grown Using Intermittent Irrigation

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Abstract

Current rice production techniques in the U.S. are water intensive and have led to groundwater depletion in some areas of the Mississippi Embayment aquifer system. Flooded rice culture also contributes to global climate change through the production of methane, a greenhouse gas. Our preliminary research indicates that intermittent rice irrigation techniques, where the height of floodwater cycles between 0 to 15 cm rather than being maintained at a constant height of about 15 cm, can reduce season-long water inputs by up to 50% over conventional (continuous flood) methods with only small reductions in yield. The production of methane gas was reduced by about 70% using intermittent irrigation compared to continuously flooded rice paddies. Future research needs to assess the utility of intermittent irrigation to maintain rice productivity while reducing water use and methane emissions across the various soil and climatic conditions in the Mississippi Embayment region.

Introduction

Demands placed on finite water resources will grow as the human population increases during the 21st century. In the US, irrigation is the single largest user of water. Most sources of freshwater have already been developed, and increased urban, thermoelectric, industrial and recreational water needs will largely be met through conservation and reallocation of existing irrigation water supplies (Gollehon and Quinby, 2000; Gollehon et al., 2002). As the amount of water dedicated to irrigation declines, *agriculture will have to use less water to meet increased global demands for food and fiber* (National Research Council, 1996). Thus, water savings through improved irrigation practices are essential to meeting the future water needs of both agriculture and other stakeholders (CAST, 1996).

Current U.S. rice production techniques are water intensive

Rice is unique among agronomic crops because it is typically grown in flooded paddies where floodwaters are maintained at a constant depth of ca. 8 to 15 cm. Flooding has traditionally been done to meet rice's relatively high water demand and to control broadleaf and grass weeds (Smith and Fox, 1973). Each of the roughly 1.26 million ha of rice harvested in the United States in 2000 required, on average, about 75 cm of water during the growing season, representing over 9.4 billion m^3 of fresh water. Most of this water was drawn from underground aquifers (Gollehon et al., 2002).

Irrigation practices have led to regional depletion of aquifers

More than 80% of the U.S. rice crop is grown in the Mississippi River alluvial plain. Underlying the fertile soils of this region is a series of six aquifers collectively known as the Mississippi Embayment aquifer system (USGS, 1998). The most intense rice production occurs in the Grand Prairie region of Mississippi River delta (Figure 1) where irrigation water is primarily derived from the Alluvial aquifer (ASWCC, 1997). However, due to groundwater overdraft, the Alluvial aquifer is not expected to sustain current extraction rates beyond 2015 (Scott et al., 1998; U.S. Corps of Army Engineers, 2000).

Increased pumping costs and lower water yields associated with declining water levels in the Alluvial aquifer have caused some farmers to install irrigation wells in the Sparta-Memphis aquifer which underlies the Alluvial aquifer. Currently, about 30 new agricultural irrigation wells per year are being drilled into the Sparta-Memphis aquifer (Charlier, 2002). This is of concern to regional municipalities since the Sparta-Memphis aquifer is the source of drinking water for over 350,000 people and, while it has purer water than the Alluvial aquifer, it has much less capacity to sustain heavy agricultural pumping rates (ASWCC, 1997). Thus, one of the consequences of intense rice production using current, water-intensive production practices is the potential for groundwater depletion and reduced agricultural sustainability over the long term.

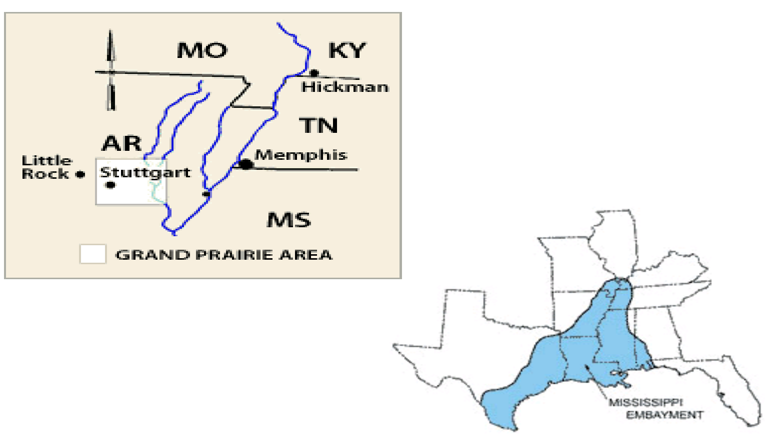

Figure 1. Over 80% of the nation's rice is grown using water from the Mississippi Embayment aquifer system. Depletion of the Alluvial aquifer in the Grand Prairie is a concern for producers, municipalities, and industries alike.

Improved irrigation practices reduce water use while maintaining rice yields

Many of the improvements in rice irrigation were pioneered in Asia. Beginning in the mid-1980's, China has lead research and implementation of water conservation to balance agricultural, urban, and industrial demands for limited water resources (Bouman et al., 2002; Dong et al., 2001). As ca. 90 percent of the available freshwater in southern China was being used for rice production, limited fresh water supply was the primary obstacle for economic, domestic, and agricultural development (Li, 2001).

Driven by needs to conserve water resources for agricultural, industrial and urban development and protect the Alluvial and Sparta-Memphis aquifers, University of Arkansas researchers have been investigating a variety of water-saving irrigation practices. Research conducted in 13 Arkansas counties on 33 different fields demonstrated that multiple inlet irrigation offers significant savings in water, inputs, and labor to rice growers (Tacker et al., 2002; Table 1).

Arkansas County	*Soil Texture*	*Results*
Arkansas	silt loam	19% less pumping hours 21% less water
Chicot	clay	29% less electric power
Crittenden	clay silt loam	29% less water 17% less water
Cross	silt loam	15% less initial flood time 16% less water 29% less labor

Table 1. Results for 2001 multiple inlet rice irrigation studies conducted in Arkansas (Tacker et al., 2002).

Irrigation Terminology

Water Saving Irrigation: Any practice that reduces infield consumption of water while sustaining acceptable agronomic yields.

Intermittent or Alternating Wet-Dry Irrigation: Once initial flood depth of ca. 7 to 15cm is achieved, irrigation is halted and flood is allowed to subside until the soil moisture reaches ca. 85% saturation. This is equal to ca. 43% volumetric soil water content (θ_V). At this time, irrigation is resumed and flood returned to its initial height.

Multiple-Inlet or Side-Inlet Irrigation: Multiple-inlet irrigation pumps water through flexible polyethylene pipe ("poly-pipe") having numerous floodgates along its length rather than adding water into a rice paddy at only a few irrigation riser locations as with conventional practices. This allows the irrigation water to be distributed more quickly and evenly across the field, reducing pumping time, pumping costs and water losses from field edges.

Water savings using intermittent rice irrigation compared to continuous flooding have also been observed in field studies. The increased water use 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). In small plot studies, no loss of weed control were observed, however rice yields declined significantly when water inputs dropped below threshold levels (Table 2).

Volumetric Soil Water Content (θ_V)	*Total H_2O Use* **(cm/ha)**	*Barnyardgrass Control (%)*	*Rough Rice Yield* **(kg/ha)**
20% [A]	48 ± 18	96	5130
27%	53 ± 17	97	7110
34%	55 ± 20	96	7920
41% [B]	59 ± 16	95	7880
48% [B]	62 ± 19	96	7830
51% [C]	70 ± 21	96	8400

Notes: (A) Basing irrigation timing on 20% θ_V allows soil to dry between irrigation cycles.
(B) Irrigation water begins to puddle prior to reestablishment of flood.
(C). Continuous flood maintained on plots.

Table 2. Three-year averages from small-plot research assessing the effect of intermittent irrigation on weed control and rice yield. (Adapted from Scherder et al., 2003).

Intermittent irrigation reduces methane emissions from rice

When soils containing labile carbon are flooded for extend periods, methane gas is produced under highly anaerobic conditions (<-150 mV) by methanogenic bacteria (Bronson et al., 1997). Given that methane (CH_4) absorbs ca. 20-times more infrared radiation than CO_2 and has an atmospheric residence time of 5 to 10 yrs, there is international interest in reducing CH_4 emissions from rice and other anthropogenic sources. Current estimates indicate that global flooded rice culture contributes ca. 8 percent of total methane production (IRRI, 2001; Ramanujan and Keeler, 2002). In China, intermittent flooding has greatly reduced methane emissions within transplanted rice culture (IRRI, 2002; Ramanujan and Keeler, 2002). Similar reductions in direct-seeded rice in the U.S. have not been previously reported.

Objectives

In 2002 a collaborative effort between researchers at Mississippi State University, the University of Arkansas and the USDA's Southern Weed Science Research Unit, was begun to investigate the agronomic and environmental benefits associated with intermittent rice irrigation. The objectives of this research were to:

1. Compare continuously flooded (conventional) rice production to intermittent irrigation in terms of season-long water use and rice yield at the field scale.

2. Compare methane emissions from conventional vs. intermittent rice irrigation systems.

3. Assess changes in soil microbial communities occurring in these two irrigation regimes.

Materials & Methods

The most promising irrigation levels observed in small plot research by Scherder et al. (41 and 48% θv) were combined and used in field-scale trials in 2002 at the University of Arkansas' Pine Tree Experiment Station. Season-long water use, rough rice yield and methane emissions from rice produced using either intermittent irrigation (44% θv) or conventional (continuous flood) irrigation (51% θv). Yield and water use, but not methane, were also measured in a multiple inlet irrigation system. Each field was about 8 ha in size and arranged in the manner shown in Figure 2. The fields were cropped with the rice cultivar 'Ahrent' and received identical pesticide and fertilizer inputs.

Season-long water use for each field was measured using a McCrometer odometer-type water meter. Irrigation timings were based on volumetric soil water content, θ_V. Basing timing of intermittent irrigation inputs upon θ_V instead of time since last irrigation will allow rice producers to manage irrigation inputs according to their prevailing soil and climatic conditions.

Methane emissions were determined using closed chamber techniques (Hutchinson and Moiser, 1981). Eight 18 cm x 25 cm PVC chambers were positioned along transects in the conventional and intermittent irrigation treatments. Gas samples were collected at 2 hr intervals from 10 am to 4 pm. Methane was quantified by gas chromatography and flame ionization detection with a limit of quantification of ca. 10 parts per million.

Soil samples were collected from the surface 2.5 cm of soil inside the PVC chambers and placed on ice until they could be stored at –80^oC. Fatty acids were extracted from 4 g subsamples and esterified in the method of Shutter and Dick (2000). Resulting fatty acid methyl esters (FAMEs) were separated by gas chromatography using the EUKARY method and the Sherlock Microbial Identification System (MIDI, Inc., Newark, DE). Comparisons in FAME profiles were made by Principle Component Analysis and used to assess changes in microbial community structure as impacted by irrigation regime.

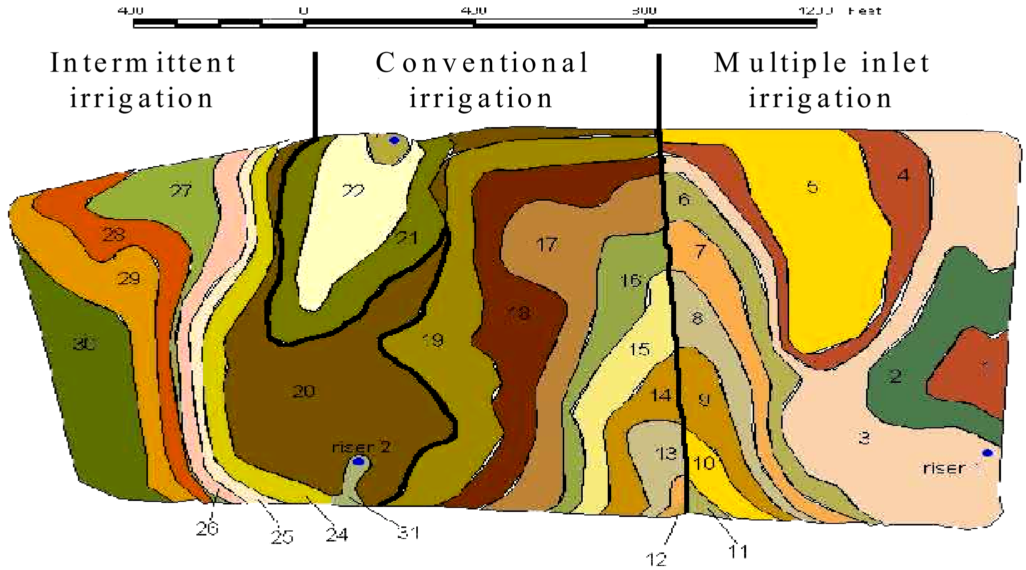

Figure 2. 2002 field layout at Pine Tree, Arkansas, used to compare three irrigation systems.

Results & Discussion

Preliminary results from the one-year production-scale fields are given in Table 3. A 51% water savings over conventional (continuous flood) rice irrigation was observed using intermittent irrigation. Rice yield was reduced by about 4% using intermittent irrigation. These results support previous reports that intermittent rice irrigation has the potential to significantly reduce water use and pumping costs while maintaining acceptable rice yields (Bouman and Tuong, 2001; Dong et al., 2001; Li, 2001). Maintaining economically acceptable yields is key to the success of any water-saving irrigation practice.

Irrigation Treatment	Water Use (cm/ha)	Water Savings (%)	Rough Rice Yield (t/ha)	Pumping Cost ($ /ha)
Conventional	95	---	9.7	133
Multiple Inlet	72	24	10.6	100
Intermittent	47	51	9.4	66

Table 3. Economic comparison of in-field water savings and rough rice yields for three irrigation systems.

In terms of methane emissions, our preliminary results agree with accounts published by IRRI (2002) and Ramanujan and Keeler (2002) that indicate that intermittent rice irrigation produces significantly less methane than continuously-flooded systems. Initial (zero-time) methane concentrations observed in chambers installed in continuously flooded rice soil were ca two-fold higher than those measured in intermittently irrigated soil (Figure 3). We observed little or no methane evolution under intermittent irrigation (< 25   moles/ cm^2 / h) compared to an approximately six-fold greater methane flux under flooded soil at 65-d after initial flooding (Figure 3). Similar results were observed from small-plot studies we conducted at Stuttgart, AR in 2002 (data not shown). Results from FAME analysis suggest that the observed differences in methane production may be due to changes in microbial community structure resulting from water management and concomitant changes in redox potential (Figure 4).

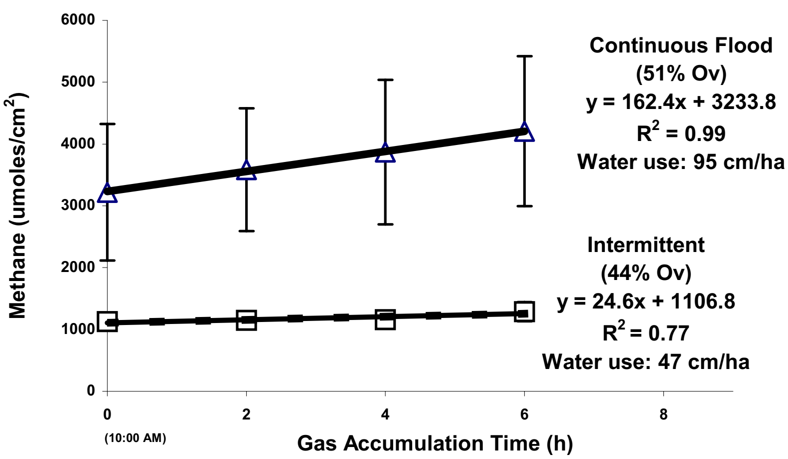

Figure 3. Comparison of methane flux from rice paddies under conventional (continuous flood) and intermittent irrigation at Pine Tree, AR (August, 2002).

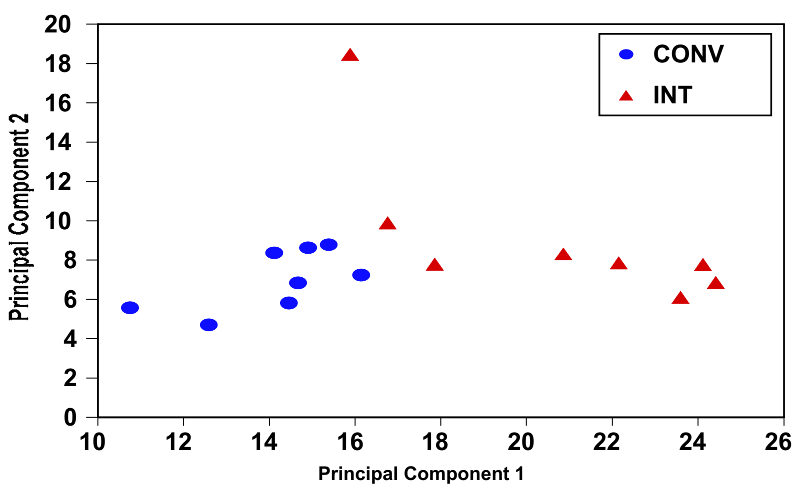

Figure 4. Principal component analysis of fatty acid methyl ester (FAME) composition reflects changes in microbial community structure under conventional (CONV) and intermittent (INT) irrigation regimes.

Conclusions

Our preliminary research indicates that direct-seeded rice grown using intermittent rice irrigation techniques may reduce season-long water use by up to 50% over conventional (continuous flood) methods with small reductions in yield. In addition, late-season methane flux may be significantly less than that of continuously flooded rice paddies. These findings agree with those reported from Asia involving transplanted rice. Given the potential agronomic and environmental benefits of intermittent rice irrigation, it should be further evaluated for use in rice growing areas of the Mississippi River Embayment region.

Future Research

A key concern surrounding intermittent irrigation is the potential for increased soil denitrification losses. This must be thoroughly investigated as it may have serious, negative agronomic and environmental implications. Additional research is needed to ascertain potential reductions in non-point source runoff of pesticides and nutrients, as well as altered pest infestations and control in rice resulting from intermittent irrigation practices. Future research should also investigate the potential for combining multiple inlet irrigation with intermittent rice irrigation techniques. This research should be conducted across a variety of soil and climatic settings and include thorough economic comparisons with conventional rice production practices.

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