International Journal of Applied Agricultural Research
ISSN 0973-2683 Volume 13, Number 1 (2018) pp. 1-8

http://www.ripublication.com

Comparison of Delayed Flood and Furrow Irrigation Regimes in Rice to Reduce Arsenic Accumulation

Michael Aide
Department of Agriculture
Southeast Missouri State University
Cape Girardeau, Missouri, USA

Abstract

Furrow irrigation of rice (*Oryza sativa* L.'indica') is an emerging practice in the Mid-South (USA). Initially the major concerns centered on weed management, nitrogen utilization and arsenic accumulation. Anticipated concerns that nitrification-denitrification reactions would limit rice productivity were proven partially valid; however, the soil moisture sensor-assisted scheduled frequency of furrow irrigation is becoming important to supporting comparatively high rice yields. In this research we investigated nutrient and arsenic rice tissue concentrations at various growth stages to infer whether the irrigation practice suitable for delayed flood were appropriate for furrow irrigated rice. Furrow irrigated and delayed flood irrigation regimes were imposed on field sized plots to monitor nutrient and arsenic accumulation along transect sampling points. The nitrogen, phosphorus, potassium and other nutrient rice tissue concentrations were deemed appropriate using commonly acknowledged rice tissue sufficiency levels. Harvest plant tissue analysis of seed and straw did not reveal substantial differences involving nitrogen, phosphorus potassium, calcium, magnesium and sulfur between furrow irrigated and delayed flood rice. Yield component analysis demonstrated no significant differences in the number of panicle bearing tillers per linear row length and panicle weight. The rough rice yields demonstrated that the delayed rice regime averaged 9,300 kg/ha (185 bushel/acre) for CL272, 11,950 kg/ha (237 bushel/acre) for Jupiter and 9,230 kg/ha (183 bushel/acre) for MM17, whereas for the furrow irrigated rice the yields were 7,310 kg/ha (145 bushel/acre) for CL272, 8,010 kg/ha (159 bushel/acre) for Jupiter and 6,300 kg/ha (125 bushel/acre) for MM17. Rough rice (seed) arsenic concentrations were substantially smaller for the furrow irrigated regime, illustrating that arsenic uptake is strongly influenced by water-induced suboxic to anoxic redoximorphic soil environments.

INTRODUCTION

Nitrogen is a critical element in rice (*Oryza sativa* L.) plant nutrition. Rice, being an aquatic plant, exists in soil environments having suboxic to anoxic soil oxidation-reduction regimes. Typically, the rice plant exists in a continuum of atmosphere, water, suboxic soil and anoxic soil layers. The boundary between suboxic and anoxic soil is pH dependent (pe 7 at pH 2 to pe of zero near pH 10 [1]. Nitrate and ammonium diffusion and water-percolation controlled flux between the suboxic and anoxic soil layers supports nitrification and denitrification reactions. Soil conditions that favor nitrification include molecular oxygen, carbon sources (electron acceptor), and soil moisture and temperature conditions suitable for vigorous microbial activity [1, 2, 3, 4 and 5]. Soil conditions favoring denitrification are an available carbon source, favorable soil temperatures and suboxic to anoxic reduction potentials [1, 4]. Aide et al [6] and Aide and Goldschmidt [7] repeatedly demonstrated, over multiple years, that furrow irrigated rice substantially reduced arsenic accumulation in both seed and vegetation.

MATERIALS AND METHODS

The Missouri Rice Research Farm (Dunklin County, Missouri)

The soils of the very deep, poorly-drained and very slowly permeable Overcup series (Fine, smectitic, thermic Vertic Albaqualfs) consist of Ap – E – Btg – C horizon sequences developed in fine-silty alluvium. Routine soil testing for the Overcup silt loam soils reveals an acidic soil; however, other soil characteristics affecting rice yield potential are appropriate for crop production.

Field Protocols

At the Missouri Rice Research Farm (Dunklin County, Missouri, USA) three rice varieties (CL272, Jupiter, MM17) in 2017 were early-May drill-seeded in separate land-graded, paddocks. The two irrigation strategies included: (i) drill-seeded, delayed flood, and (ii) drill-seeded, furrow irrigation on 0.83 meter beds prepared using a field conditioner “hipper”. Irrigation water was supplied by wells having centrifugal pumps delivering 0.19 m^3/s (3,000 gallon / min).

Plot dimensions for each variety were two adjacent 1.95 meter (6.33 ft) by 100 meter (328 ft) plots The furrow irrigated plot was equally sectioned into R1 (row upper) (near the placement of the polypipe), R2 (row middle) and R3 (row lower is also tailwater accumulation). Planting seed intensity was 78.4 kg/ha (70 lbs/acre).

Flood was established at the fifth-leaf stage for the delayed flood treatment and 0.10 to 0.15 meters (4 to 6 inches) of paddy water was maintained until complete panicle development. Furrow irrigation was performed using poly-pipe, with each furrow receiving side-inlet water. Nitrogen fertilization consisted of broadcast urea at 134 kg N/ha (120 lbs N/acre) applied one day prior to initiation of flood for the delayed-flood treatment. Nitrogen was applied at internode elongation (34 kg N/ha, or 30 lbs N/acre) as urea.

Twenty panicles per treatment plot (row upper, row middle, row lower-tailwater accumulation, and delayed flood) were collected at harvest for panicle weight determination. Tillering was estimated as the number of tillers having panicles / 1.524 meters (number panicles / 5-ft row). Plot yields and moisture contents were obtained using a Quantum Wintersteiger Plot Combine. Plant tissue testing for nitrogen, phosphorus and potassium and other nutrient analysis was performed by Midwest laboratories (Omaha, NB, USA) using acid dissolution and inductively coupled plasma emission spectroscopy. Arsenic was analyzed using acid dissolution and atomic absorption with hydride generation. Mean separation and analysis of variance were performed to indicate significance.

RESULTS AND DISCUSSION

Soil Analysis

Prior to planting soil testing was performed. Soil pH for the furrow irrigated rice was slightly acid (6.2 to 6.7), whereas the delayed flood had a neutral pH reaction (6.7 to 6.9). Soil organic matter averaged near 2 percent (1.9 to 2.2 %) and the Bray1-P phosphorus values were appreciably greater than the 34 kg/ha (30 lbs P/acre) desired level, with the actual soil P concentrations ranging from 83 to 138 kg/ha. The cation exchange capacity (CEC) was low (8.3 to 9.4 cmol/kg). Exchangeable potassium ranged from 0.38 to 0.58 cmol/kg and are considered adequate to surplus and the ammonium and nitrate concentrations (data not shown) were considered low.

Plant Tissue Analysis at Mid-Tillering and Internode Elongation

Plant tissue analysis was performed near the end of tillering and again at internode elongation (data not shown). The mid-tillering plant tissue sampling demonstrated that nitrogen, phosphorus (0.33 to 0.53 % P), potassium (3.48 to 4.43 % K), magnesium (0.18 to 0.24 % Mg), calcium (0.28 to 0.39 % Ca), and sulfur (0.23 to 0.36 % S) were either at or above their respective sufficiency levels for both the furrow irrigated and delayed flood irrigated rice [8]. Nitrogen shows no analytical differences between the furrow irrigated treatments (3.33 to 4.33 % N) and the delayed flood treatment (3.49 to 4.88 % N). The micronutrients were either at or above their respective sufficiency levels for both the furrow irrigated and delayed flood irrigated rice [8]. The accumulation of arsenic (As) in the rice vegetation for each variety was substantially greater for R3 (tailwater accumulation) and the delayed flood treatments.

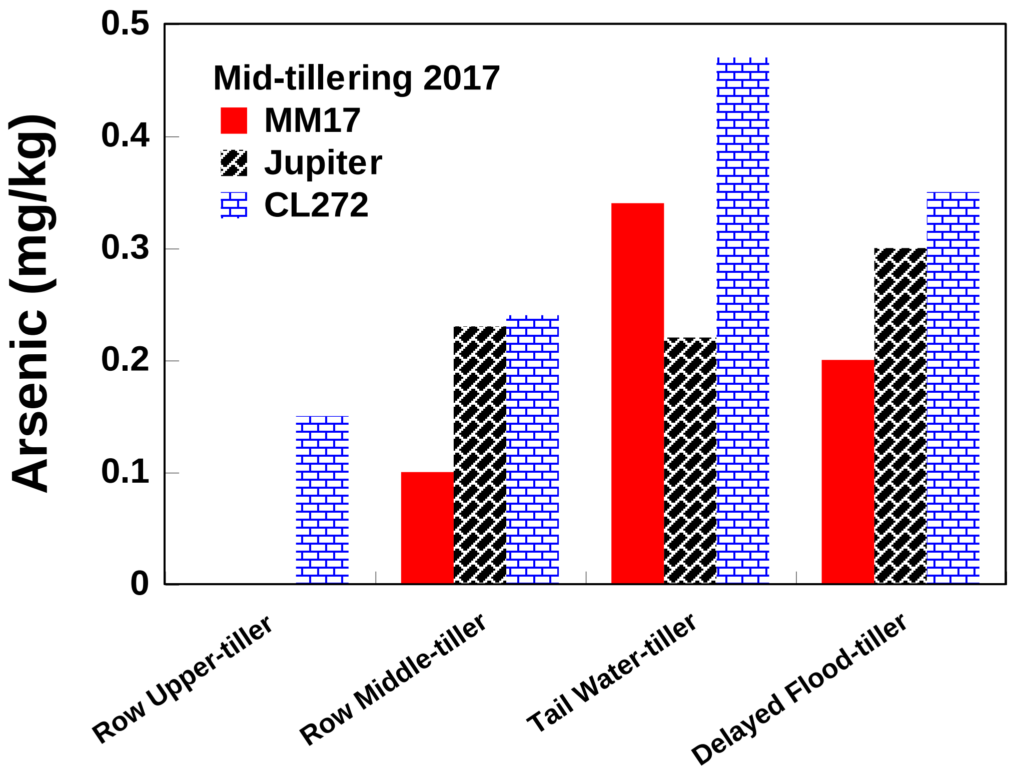

Figure 1. Arsenic concentration at mid-tillering for three cultivars with two irrigation regimes.

The plant tissue analysis at internode elongation (data not shown) was similar to the plant tissue nutrient concentrations at mid-tillering in terms demonstrating no apparent nutrient deficiencies for that growth stage.

Agronomic Yield Components

Analysis of variance ($\alpha = 0.05$) failed to show significant tillering differences among the furrow irrigated and delayed flood treatments; however, the number of panicles per row length was numerically greater for the furrow irrigated rice having accumulation of tail water and the delayed flood irrigation. Panicle weights were greatest for the R3 (tailwater accumulation in the furrow irrigated system); however, the differences were not significant.

Plant Tissue Analysis of Paddy Rice and Rice Vegetation (Straw)

At harvest, patty rice (rough rice seed) was collected to estimate nutrient and arsenic partitioning between the seed and crop residue (rice straw). Rough rice seed possessed between 1.25% to 1.74% nitrogen, 0.23 to 0.32 % phosphorus, 0.33 to 0.58 %

potassium, 0.09 to 0.14 % magnesium, 0.03 to 0.04 % calcium and 0.09 to 0.14 % sulfur. Similar statements may be proposed for the micronutrients, with iron ranging from 30 to 52 mg Fe/kg, manganese ranging from 66 to 191 mg Mn/kg, boron ranging from 2 to 5 mg B/kg, cupper ranging from 2 to 5 mg Cu/kg and zinc ranging from 17 to 40 mg Zn/kg. For these nutrients none of the varieties show any appreciable differences attributed to the irrigation treatments.

Rice vegetation (rice straw) was also assessed to determine the macronutrient, micronutrient and arsenic concentrations. Rice vegetation possessed between 0.68% to 1.33% nitrogen, 0.07 to 0.21% phosphorus, 2.15 to 3.42 % potassium, 0.10 to 0.21 % magnesium, 0.13 to 0.35 % calcium and 0.07 to 0.15 % sulfur. Magnesium and sulfur do demonstrate slightly greater plant tissue concentrations for furrow irrigated treatments; however, the differences are not statistically valid. The rice straw micronutrients concentrations range from 69 to 213 mg Fe/kg, 325 to1,226 mg Mn/kg, 3 to 7 mg B/kg, 1 to 6 mg Cu/kg and 15 to 30 mg Zn/kg. Manganese shows a significant difference within the irrigation treatments, with the R3 (tailwater accumulation) and delayed flood (460 to 1,226 mg Mn/kg) generally having greater Mn concentrations than the furrow irrigated rice (352 to 694 mg Mn/kg).

Total arsenic was also assessed in the rice vegetation to determine the influence of the irrigation treatments on arsenic uptake (Figure 2). All of the furrow irrigated treatments possessed total arsenic concentrations smaller than 0.3 mg As/kg, whereas the furrow irrigated rice that accumulated tailwater and the delayed flood irrigated rice showed straw arsenic concentrations ranging from 1.4 to 2.4 mg As/kg. Thus, significant differences were manifested based on the irrigation regime.

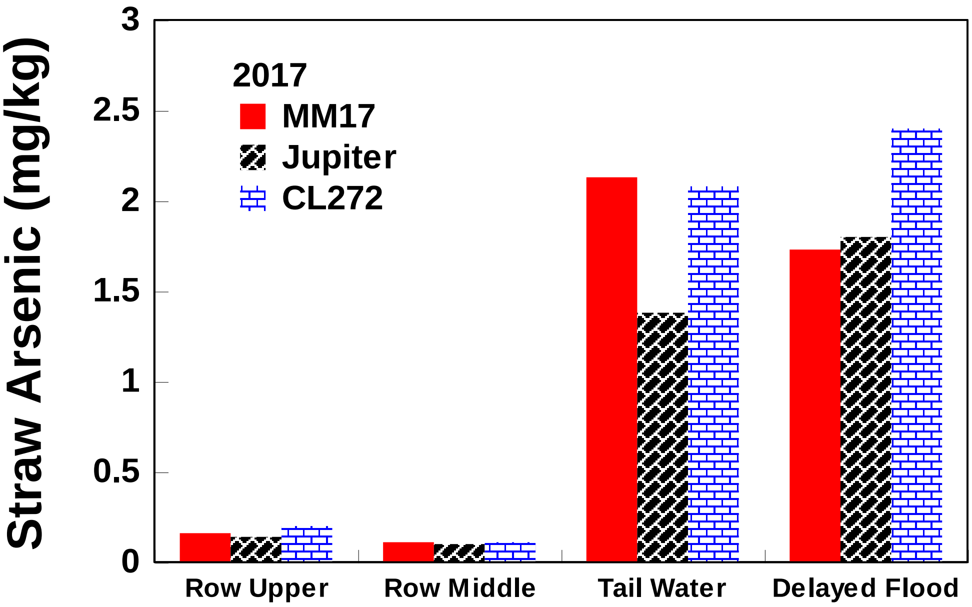

Figure 2. For three varieties the at harvest rice straw arsenic concentrations (mg/kg).

Total arsenic was also assessed for the rough rice seed to assess the influence of the irrigation treatments on arsenic uptake (Figure 3). All of the furrow irrigated treatments possess total arsenic concentrations near or smaller than the established detection limit of 0.05 mg As/kg. The furrow irrigated rice that accumulated tailwater and the delayed flood irrigated rice shows appreciably greater arsenic concentrations ranging from 0.56 to 0.82 mg As/kg. Thus, significant differences were manifested based on the irrigation regime.

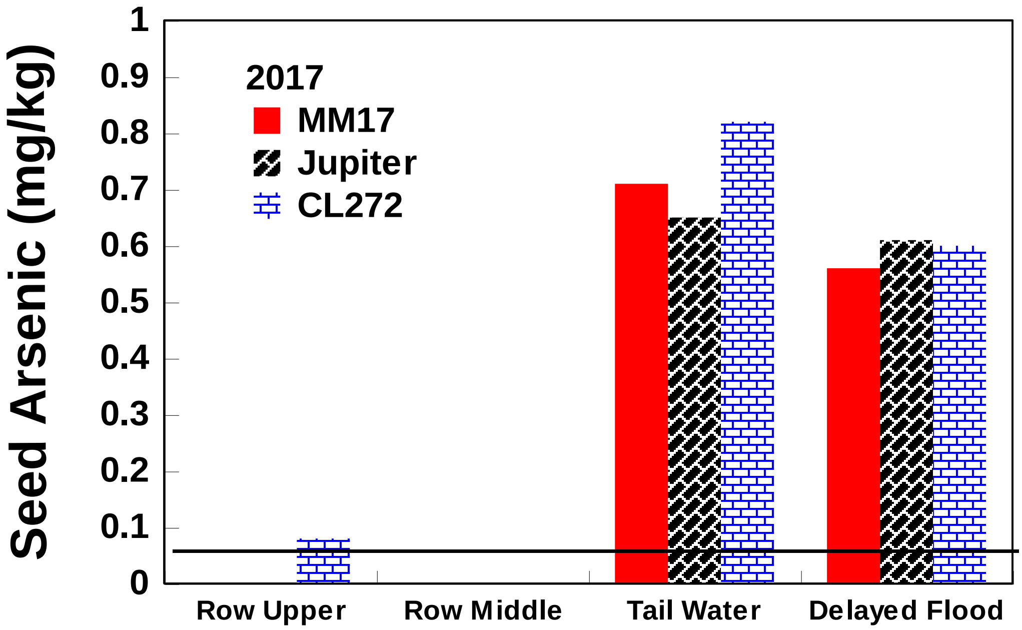

Figure 3. For three varieties the paddy rice arsenic concentrations (mg/kg). The lack of a column implies the value was smaller than the established detection limit of 0.05 mg As/kg.

Yield

Significant and substantial yield differences exist between the furrow irrigated rice and the delayed flood rice regimes. Yields for the furrow irrigated rice are least near the water inlet and increase to greater yields in the middle portion of the gently slope field and are greatest when tail water accumulated in the farthest and lowest portion of the field (Figure 4). The delayed flood rice showed a slightly smaller rice yield at the upper portion of the field (likely attributed to cold water effects) and was rather consistent in the other field portions. For all varieties the delayed flood regime yields better than the furrow irrigated rice, with Jupiter yielding a field average of 236 bu/acre (11,894 kg/ha) for the delayed flood regime and 159 bu/acre (8,014 kg/ha) for the furrow irrigation regime.

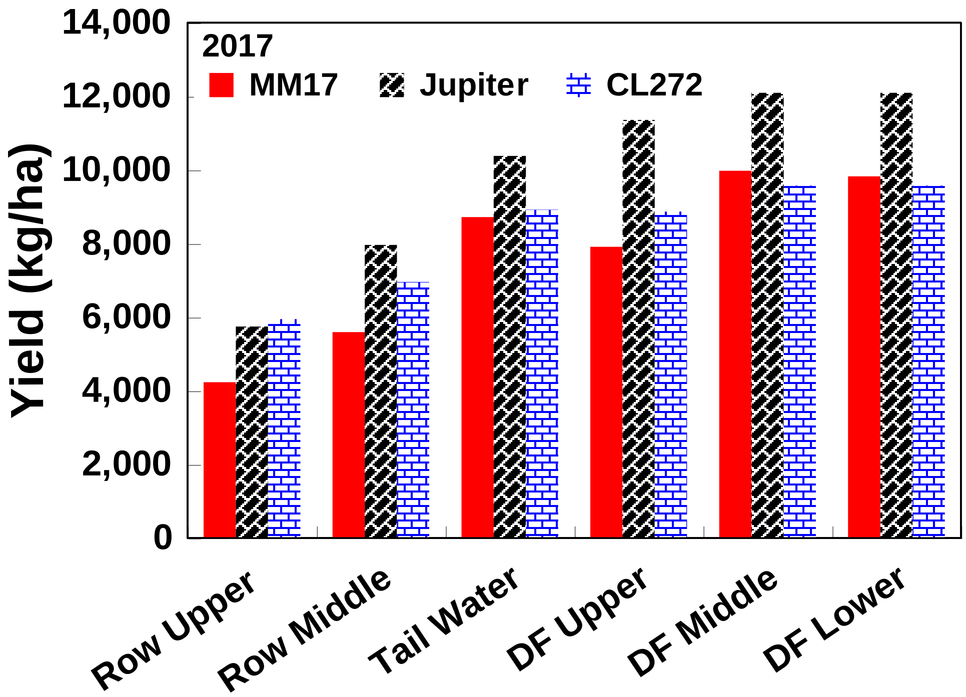

Figure 4. Yield of rough rice for three varieties by field position having delayed flood (DF) and furrow irrigation (Row upper, Row middle and Row lower (Tail water))..

CONCLUSION AND SUGGESTIONS FOR FUTURE RESEARCH

(1) Furrow irrigated rice requires a new nitrogen timing paradigm. One possibility includes a split application beginning at the 5th leaf stage and the remainder applied three weeks later to promote normal tillering.

(2) Furrow irrigated rice substantially reduces arsenic uptake, thus new production and marketing processes need to be implemented.

REFERENCES

[1] Essington, Michael. 2004. Soil and water chemistry: An integrative approach. CRC Press. Boca Raton, FL.

[2] Dobermann, A. and Fairhurst, T. 2000. Rice: Nutrient Disorders and nutrient management. PPI/PPIC and IRRI.

[3] Norman, R.J., Guido, D., Wels, B.R., and Wilson, C.E. 1992. Seasonal accumulation and partitioning of nitrogen-15 in rice. Soil Sci. Soc. Am. J. 56:1521-1527.

[4] Reddy, K.R., Patrick, W.H., and Lindau, C.W. 1989. Nitrification-denitrification at the plant root-sediment interface in wetlands. Limnol. Oceangr. 34:1004-1013.

[5] Schepers, J.S., and Raun, W.R. 2008. Nitrogen in agricultural systems. Agron. Monog. 49. American Society Agronomy, Madison, WI, USA.

[6] Aide, MT., Beighley, D., Dunn, D. 2016. Arsenic uptake by rice (Oryza sativa L.) having different irrigation regimes involving two different soils. International J. Appl. Agric. Research 11:71-81.

[7] Aide, M.T. and Goldschmidt, N. 2017. Comparison of delayed flood and furrow irrigation involving rice for nutrient and arsenic uptake. International Journal of Applied Agricultural Research 12:129-136.

[8] Bell, P.F., and Kovar, J.L. 2013. Rice. *In* (C. Ray Campbell, Ed.) Reference sufficiency ranges for plant analysis in the southern region of the United States. Southern Cooperative Series Bulletin #394. URL. North Carolina Department of Agriculture and Consumer Services Agronomic Division, Raleigh, NC. www.ncagr.gov/agronomi/saaesd/scsb394.pdf.