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Comparison of Delayed Flood and Furrow Irrigation Involving Rice for Nutrient and Arsenic Uptake

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Abstract

The purpose of this two-year (2015 to 2016) Missouri based rice research project was to estimate plant essential nutrient and arsenic uptake differences involving furrow and delayed flood irrigation. In 2015 paddy (rough) rice seed nitrogen, phosphorus, potassium, magnesium, calcium, sulfur, iron, boron, copper and zinc concentrations were not significantly different because of irrigation treatment; however, arsenic concentrations were significantly smaller in rough rice from the furrow irrigation system. Manganese seed concentrations were greater in the delayed flood regime. In 2016 paddy seed nitrogen, potassium, sulfur, calcium, iron, manganese, copper and zinc concentrations were greater in the furrow irrigation regime. Also in 2016, arsenic seed concentrations, with the exception of three varieties, were substantially smaller than the 0.05 mg As/kg detection limit and the three varieties that did demonstrate arsenic concentrations above the detection limit were at or less than 0.1 mg As/kg. All varieties sampled from the delayed flood irrigation regime in 2016 averaged 0.37 mg As/kg, with the smallest arsenic value at 0.25 mg As / kg.

INTRODUCTION TO FURROW IRRIGATED RICE

USA producer interest in furrow irrigation of rice (also called row rice) (*Oryza sativa* L.) is increasing, the increase in acreages largely attributed to the possibility of reduced costs associated with water pumping and field preparation. This study

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evaluates the plant essential nutrient and arsenic uptake rates of 12 varieties (2015) and 22 varieties (2016) cultured to furrow irrigated and to delayed flood irrigated rice. In 2015, yields of furrow irrigated rice were comparable to delayed flood rice, with approximately half of the varieties responding better to furrow irrigation. In 2016 delayed flood yields were higher than furrow irrigated rice yields; however, the date of planting was perceived as important in contributing to the yield differences.

Perceived advantages of furrow irrigated rice include: (i) the potential for smaller water usages, (ii) reduced labor, (iii) reduced energy usage, (iv) greater opportunity to use ground equipment instead of airplanes, (v) more rapid field drying towards harvest, and (vi) reduced levee construction. Disadvantages of furrow irrigated rice include: (i) requires graded land other than zero slope, (ii) possible delays in maturity, (iii) adjustments in the weed management program, (iv) greater potential of having yield-limiting water stress, (v) less information and producer experience, (vi) adjustments to the nitrogen management program, and (vii) crop insurance may not be available until underwriters provide risk assessments.

Codex Alimentarius Commission (United Nations Food Standards body) proposed that the maximum level for inorganic arsenic in polished rice (white rice) be set at 0.2 mg As/kg. If the total arsenic is less than 0.2 mg As/kg, then no further testing for arsenic is required [http://www.fao.org/news/story/en/item/238558/icode/] (verified October 2016). The United State Food and Drug Administration (April 2016) proposed an action level, or limit, of 100 parts per billion (ppb) (0.1 mg As/kg) for inorganic arsenic in infant rice cereal [http://www.fda.gov/Food/FoodborneIllness Contaminants/Metals/ucm319948.htm] (Verified October 2016).

Clayey sediments and soils generally have arsenic concentrations ranging from trace to 13 mg As/kg [1]. In Missouri, Aide et al. (2013) [2] discussed soil arsenic concentrations in 22 soil profiles having no history of arsenic contamination and reported that the surface horizons exhibited arsenic concentrations ranging from 2 to 12 mg As/kg. Subsurface horizons, particularly argillic horizons, possessed greater arsenic concentrations, ranging from 10 to 30 mg As/kg. Aide et al. (2005) [3] demonstrated that arsenic was strongly associated with Fe and Mn-oxyhydroxides. Aide et al (2016) [4] reviewed the soil chemistry of arsenic.

Arsenic uptake in rice is a global concern [5, 6, 7]. Recent research suggests that mitigating the soil's anaerobic status may reduce arsenic accumulation [8, 9]. In Missouri, Aide et al (2013) [2] observed that rice furrow irrigation did not increase seed cadmium concentrations because the soil resources were observed to have very low cadmium concentrations. In a pilot study Aide et al (2016) [8, 9] demonstrated that rice cultured under furrow irrigation did not accumulate arsenic or cadmium to the extent that delayed flood irrigated rice.

This report documents nutrient and arsenic uptake by rice (Oryza sativa L. 'indica') involving two irrigation regimes to compare the arsenic uptake risk and rice seed quality.

MATERIALS AND METHODS

Field Protocols

The Missouri Rice Research Farm (Dunklin County, Missouri)

At the Missouri Rice Research Farm (Dunklin County) 12 rice varieties in 2015 and 22 rice varieties in 2016 were mid-May plot planted in separate paddocks having (i) furrow irrigated rice, and (ii) delayed-flood irrigation regimes. Each variety was replicated at least four times. Plot dimensions in 2015 were 1.52 meter (5 ft) by 3.66 meter (12 ft) and in 2016 for the delayed flood were 1.95 meter (6.33 ft) by 5.54 meter (18 ft) and for the furrow irrigation were 1.95 meter (6.33 ft) by 6.15 meter (20 ft). Flood was established at the fifth-leaf stage for the drill seeded-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 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. For the furrow irrigated rice treatment, irrigation scheduling was based on a Pessl Instrument platform employing Decagon soil moisture probes at selected soil depths.

The soils of the somewhat poorly-drained Crowley series (Fine, smectitic, thermic Typic Albaqualfs) consist of Ap – E – Btg – C horizon sequences developed in fine-silty alluvium. Routine soil testing for the Crowley silt loam soils reveal a slightly acidic to acidic soil (pH 5.5 to 6.3); however, other soil characteristics affecting rice yield potential were appropriate with routine N, P and K fertilization based on soil test and yield goal.

Rice Cultured in Two Irrigation Regimes

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). As a note: water analysis showed irrigation water arsenic concentrations to be less than 30 µg As/ L.

At the fifth leaf stage (2015) and just prior to internode elongation (2016) and again for both years at harvest the entire aerial plant from each plot were collected and subsequently separated into leaf-stem and rough rice, dried at 70ºC, and analyzed for nitrogen, phosphorus, potassium, magnesium, calcium, sulfur, iron, manganese, boron, copper, zinc and arsenic using acid dissolution coupled with ICP-MS for the routine nutrients and atomic absorption spectroscopy – hydride generation for arsenic. The plant tissue analysis was performed by Midwest Laboratories (Omaha, NE), using USEPA method 6020.

Statistics

All statistical analysis was accomplished using Microsoft Excel.

RESULTS AND DISCUSSION

Mid-season Tissue Analysis

In 2015 nutrient uptake patterns at the fifth leaf stage demonstrated that the traditional delayed flood irrigation regime had greater nitrogen, phosphorus, manganese and zinc tissue concentrations (Table 1), whereas the furrow irrigated rice regime showed greater copper tissue concentrations (Table 2). The greater phosphorus, manganese and zinc tissue concentrations in the delayed flood regime may be partially attributed to a more anaerobic soil condition with the partial dissolution of manganese and iron oxyhydroxides. The greater nitrogen tissue concentrations in the delayed flood regime may be partially attributed to a more stable soil environment that restricts alternating nitrification-denitrification reaction episodes.

In 2016 midseason tissue concentrations of nitrogen, potassium, sulfur, copper and zinc were greater from the furrow irrigation regime, whereas rice tissue concentrations of phosphorus, calcium, manganese and boron tissue concentrations were greater in the delayed flood regime. Routine visual observations appear to show a greater degree of tillering in the delayed flood regime, suggesting the enhanced tillering provided more phytomass for the effectively diluting the nutrient concentrations. In 2016 arsenic was also assessed in rice tissues collected at mid-season. The arsenic tissues concentrations from the delayed flood regime averaged 1.31 mg As/kg (standard deviation of 0.42 mg As/kg), whereas arsenic tissues concentrations from the furrow irrigated regime were all less than 0.1 mg As/kg, with the exception of the CL111 variety which had a tissue concentration of 0.13 mg As/kg.

Table 1. Mean nitrogen, phosphorus, potassium, magnesium, calcium and sulfur concentrations for rice varieties cultured as delayed flood and furrow irrigation.

Treatment	Year	N	P	K	Mg	Ca	S
		--------------------g/kg---------------------					
		Fifth leaf stage					
Delayed Flood	2015	**42.9**	**3.5**	28.4	2.2	4.7	2.7
Furrow Irrigation	2015	**35.2**	**2.3**	29.6	2.3	5.2	2.6
		Just prior to internode elongation					
Delayed Flood	2016	**32.5**	**3.4**	**24.7**	2.5	**4.2**	**2.1**
Furrow Irrigation	2016	**40.1**	**2.8**	**30.4**	2.3	**3.4**	**2.9**

Boldface indicates highly significant ($P < 0.01$) differences by pair t-test within a year.

Table 2. Mean iron, manganese, boron, copper, and zinc concentrations for rice varieties cultured as delayed flood and furrow irrigation.

Treatment	Year	Fe	Mn	B	Cu	Zn
		----------------------mg/kg------------------				
		Fifth leaf stage				
Delayed Flood	2015	95	**753**	5.1	**6.8**	**31.5**
Furrow Irrigation	2015	104	**136**	5.9	**10.0**	**24.4**
		Just prior to internode elongation				
Delayed Flood	2016	87	**742**	**6.1**	**3.4**	**26.9**
Furrow Irrigation	2016	129	**168**	**5.0**	**10.3**	**34.7**

Boldface indicates highly significant ($P < 0.01$) differences by pair t-test within a year.

Harvest Plant Tissue Analysis

In 2015 rough rice seed nitrogen concentrations were largely equivalent among the respective selected varieties. Rough rice seed phosphorus, potassium, magnesium, calcium, sulfur, iron, boron, copper and zinc also demonstrated little differences between the furrow and delayed flood irrigation regimes (Table 3 and 4). Manganese seed tissue concentrations were significantly greater from the delayed flood irrigation regime. In 2016, seed tissue concentrations from the furrow irrigated regime showed greater nitrogen, potassium, calcium, sulfur, iron, manganese, copper and zinc concentrations. Seed tissue concentrations of phosphorus, magnesium and boron were not significantly different.

Table 3. Mean nitrogen, phosphorus, potassium, magnesium, calcium and sulfur concentrations for paddy rice seed from varieties cultured as delayed flood and furrow irrigation rice.

Treatment	Year	N	P	K	Mg	Ca	S
			----------------------g/kg----------------------				
Delayed Flood	2015	10.4	2.3	3.1	0.9	0.2	0.8
Furrow Irrigation	2015	10.1	2.2	3.4	0.9	0.3	0.8
Delayed Flood	2016	**11.8**	2.9	**4.6**	1.2	**0.3**	**1.0**
Furrow Irrigation	2016	**13.7**	2.6	**6.4**	1.4	**0.6**	**1.2**

Boldface indicates highly significant ($P < 0.01$) differences by pair t-test within a year.

Table 4. Mean iron, manganese, boron, copper, zinc and arsenic concentrations for paddy rice seed from varieties cultured as delayed flood and furrow irrigation rice.

Treatment	Year	Fe	Mn	B	Cu	Zn	As
			---------------------mg/kg---------------------				
Delayed Flood	2015	19.5	**94.5**	2.8	6.0	38	**0.25**
Furrow Irrigation	2015	20.6	**59.7**	3.1	7.2	44	**<0.05**
Delayed Flood	2016	**59.9**	**114**	2.3	**1.6**	**24**	**0.37**
Furrow Irrigation	2016	**76.2**	**202**	3.0	**5.8**	**37**	**<0.01**

Boldface indicates highly significant (P < 0.01) differences by pair t-test within a year.

In 2015, arsenic seed concentrations significantly between the two irrigation regimes were significantly different. With a detection limit of 0.05 mg As / kg, eight varieties selected from the furrow irrigated rice were below the detection limit, whereas all twelve varieties from the delayed flood irrigation regime demonstrated arsenic concentrations above the detection limit and averaged 0.25 mg As / kg. For all twelve varieties, seed arsenic concentrations were smaller for the furrow irrigated rice regime than the corresponding delayed flood regime (Figure 1).

In 2016, twenty rice varieties were assessed for total arsenic in their rough rice seed. The rough rice seed arsenic concentrations from the delayed flood regime ranged from 0.25 mg As/kg to 0.51 mg As/kg with a mean of 0.37 mg As/kg (standard deviation of 0.07 mg As/kg). The rough rice seed arsenic concentrations from the furrow irrigated regime had three varieties with arsenic concentrations above 0.05 mg As/kg, with the remainder of the varieties below the 0.05 mg As/kg detection limit (Figure 2).

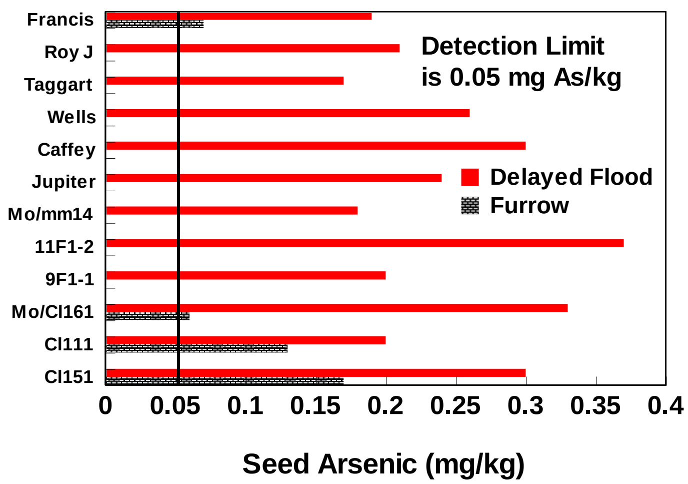

Figure 1. Seed arsenic contents (2015) for twelve selected varieties having furrow and delayed flood irrigation regimes. The absence of horizontal bars indicates As concentrations smaller than the detection limit.

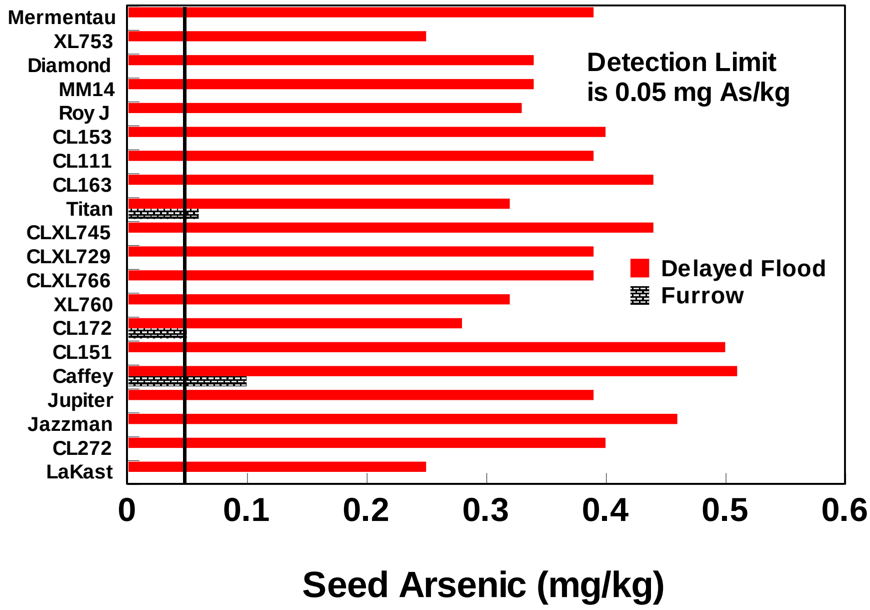

Figure 2. Seed arsenic contents (2016) for twenty selected varieties having furrow and delayed flood irrigation regimes. The absence of horizontal bars indicates As concentrations smaller than the detection limit.

CONCLUSION

In 2015, seed nitrogen, phosphorus, potassium, magnesium, calcium, sulfur, iron, boron, copper and zinc rough rice concentrations were not significantly different because of irrigation treatment; however, arsenic concentrations were significantly smaller in rough rice from the furrow irrigation system. Manganese rough rice concentrations were greater in rough rice from the delayed flood regime.

In 2016, the seed concentrations of nitrogen, potassium, calcium, sulfur, iron, manganese, cupper, and zinc were greater for the furrow irrigated regime. In 2016 arsenic seed concentrations were, with the exception of three varieties, were smaller than 0.05 mg As/kg threshold and the three varieties that demonstrated arsenic concentrations above the 0.05 mg As/kg threshold were at or less than 0.1 mg As/kg. All varieties sampled from the delayed flood irrigation regime in 2016 averaged 0.37 mg As/kg and all varieties were greater than 0.05 mg As/kg.

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