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Furrow Irrigated Rice Evaluation: Nutrient and Arsenic Uptake and Partitioning

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Abstract

Furrow irrigation of rice (*Oryza sativa* L.'indica') is an emerging irrigation management tool in the Mid-South (USA). In this research rice tissue nutrient and arsenic concentrations at various rice growth stages and different transect locations on graded-land field-dimension plots were assessed to infer whether the furrow irrigation was suitable for (i) high yield attainment and (ii) whether water-imposed soil redox conditions influenced nutrient and arsenic uptake. Six varieties were studied. Nitrogen, phosphorus, potassium and other nutrient rice tissue concentrations were deemed appropriate using commonly acknowledged rice tissue sufficiency levels. Harvest plant tissue analysis of straw reveals substantial differences involving nitrogen, magnesium, sulfur, manganese, boron, copper, zinc and arsenic because of field position, with manganese and arsenic showing greater straw concentrations in field positions having tailwater accumulation (wetter field portions). Nitrogen, sulfur, copper and zinc exhibited smaller seed concentrations and iron and arsenic exhibited greater seed concentrations in field positions receiving tail water accumulations. Yields were shown to increase along transects involving water gradients having drier to wetter soil conditions.

Keywords: Arsenic, nitrogen, furrow irrigation, plant tissue analysis, rice yields

INTRODUCTION

Furrow irrigated rice involves water application to furrows on graded soil, maintaining the soil near water saturation and avoiding unnecessary surface water ponding. Invariably, water ponding may occur on the downslope field portion, thus potentially imposing different oxic to suboxic to anoxic soil redox conditions across the field. The water application frequency for furrow irrigated rice is presumably greater than that for cotton [Gossypium hirsutum] or soybeans [*Glycine max* (L.) Merr.]). However, one perceived benefit of furrow irrigated rice is reduced total water application during the growing season

Arsenic (As) uptake is a major concern where rice is cultivated, with arsenic uptake influenced by the intrinsic soil arsenic content, water management and the water imposition of anoxic soil environments, variety selection, water quality and any previous usage of arsenical herbicides [1 - 7]. Aide et al [2] demonstrated that southeastern Missouri soils have a range of intrinsic arsenic concentrations, with fine-textured soils having somewhat greater arsenic concentrations; however, none of the sampled soil profiles have arsenic concentrations exceeding various literature citations for not arsenic impacted soils. Aide et al [7] further observed that southeastern Missouri soils have very limited soil cadmium concentrations, suggesting that Cd may not present any appreciable plant uptake concerns in limited water rice cultures. Aide et al [3 – 6] repeatedly demonstrated that furrow irrigated rice substantially reduced arsenic accumulation in both straw and rough rice when compared to adjacent rice plots having delayed flood irrigation.

The objective of this research was: (i) to assess field-sized plots for rice yields and their associated yield components, and (ii) to determine if furrow irrigation limits arsenic uptake as a function of plot position and its correlation with water-imposed suboxic/anoxic soil conditions

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) six rice varieties (CL172, Diamond, Roy J, CL272, 4534, 745) in 2018 were late-May drill-seeded in a land-graded, paddock. The irrigation strategy was 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). 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 near the 5th leaf stage. Additional internodal elongation application of nitrogen as urea was applied using a Mudmaster at 34 kg N/ha (30 lbs N/acre).

Plot dimensions were two adjacent 1.95-meter (6.33 ft) (total 3.9-meter (12.66 ft)) row-beds having a length of 358 meters (1,175 ft). The furrow irrigated plots were sectioned into R1 (row upper) (near the placement of the polypipe), R2 (row middle) and R3 (row lower is also tailwater accumulation). All non-hybrids were planted at a rate of 70 lb/acre (78.4 kg/ha), whereas the hybrids were planted at a seeding rate as suggested by the breeder.

Twenty panicles per plot were collected at harvest for panicle weight determination for each variety-zone. Plot yields and moisture contents were obtained using a Case Combine with weigh wagons. Analysis of variance and mean separation were performed to indicate significance.

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. The rice plant tissue sampling procedure at mid-tillering stage involved collecting the entire plant biomass 5 cm above the soil surface for approximately 20 plants. The rice plant tissue sampling procedure at pre-harvest involved collecting the entire plant biomass 5 cm above the soil surface for approximately 20 plants, followed by seed separation. The sufficiency levels for rice at mid-tillering, in units of g/kg for macronutrients and mg/kg for micronutrients [8] are: Macronutrients [N (28 to 36), P (1.4 to 2.7), K (15 to 27), Ca (1.6 to 3.9), Mg (1.2 to 2.1), and S(1.7+)] and Micronutrients [Fe (90 to 190), Mn (40 to 740), B (5 to 25), Cu (6 to 25) and Zn (20 to 160)].

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.

RESULTS AND DISCUSSION

Plant Tissue Analysis at Mid-Tillering

Plant tissue sampling for CL172 during late-tillering for all zones demonstrated that elemental concentrations were either greater than the established sufficiency levels (nitrogen) or were within the lower and upper limits for nutrient sufficiency (phosphorus, potassium, magnesium, calcium, sulfur, iron, manganese, boron, copper and zinc) (Table 1). Interestingly, both iron and manganese demonstrated greater analytical plant accumulation upon transition from zone #1 to zone #3 (tailwater accumulation), reflecting a more anoxic soil environment. Arsenic plant tissue concentrations showed a progressive increase on transition from zone #1 to zone #3, further reflecting that the more anoxic soil environment in zone #3 supports enhanced arsenic uptake.

Table 1. Late-tillering rice tissue nutrient and arsenic uptake for CL172 (8 July 2018)

Zone	N	P	K	Mg	Ca	S	Fe	Mn	B	Cu	Zn	As
	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	4.1	0.29	2.9	0.27	0.39	0.31	101	592	15	11	35	0.13
2	4.5	0.30	2.9	0.23	0.36	0.32	113	807	8	9	39	0.29
3	4.1	0.33	2.9	0.22	0.44	0.29	284	1119	10	8	60	0.56

Note: all observations were duplicative observations.

Plant Tissue Analysis at Pre-Harvest (post physiologic maturity)

Vegetative (straw) elemental analysis across all varieties reveals consistently greater nitrogen (significance at 0.0046), magnesium (significance at 0.0018), sulfur (significance at 0.0006), boron (significance at 0.0026), copper (significance at 0.0001) and zinc (significance at 0.009) concentrations in zone #1 than zone #3, whereas manganese (significance at 0.0021) and arsenic (significance at 0.009) show appreciably greater concentrations in zone #3 (Table 2a). The straw element concentrations (mean, standard deviation) for phosphorus (0.13%, 0.02%), potassium (2.22%, 0.39%), calcium (0.38, 0.08%) and iron (113 mg/kg, 24 mg/kg) showed no significant differences because of zone location. The straw elemental concentrations (mean, standard deviation) for magnesium, boron, and copper are: magnesium (0.21%, 0.06%), boron (6 mg/kg, 2 mg/kg), and copper (3.1 mg/kg, 1.6 mg/kg).

Table 2a. Vegetation (straw) elemental analysis by variety for zones #1 and #3 (5 Oct 2018)

Variety	Zone	N	S	Mg	Mn	B	Cu	Zn	As
		%	%	%	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
CL272	1	1.41	0.15	0.17	498	6	5	31	<0.1
CL272	3	0.86	0.08	0.11	953	5	1	20	1.75
745	1	1.27	0.12	0.26	547	7	5	42	0.2
745	3	0.96	0.10	0.20	1056	6	2	28	1.48
Roy-J	1	0.89	0.12	0.28	638	9	3	28	0.11
Roy-J	3	0.79	0.08	0.20	974	5	1	26	1.02
Diamond	1	1.29	0.15	0.34	680	7	4	36	<0.1
Diamond	3	0.90	0.09	0.21	979	4	2	30	1.03
4534	1	1.15	0.12	0.20	686	7	5	53	0.13
4534	3	0.71	0.07	0.14	721	4	2	26	1.13
CL172	1	0.80	0.14	0.21	740	6	5	40	0.36
CL172	3	0.71	0.10	0.18	1119	4	2	28	1.04

element concentrations (mean, standard deviation), P (0.13%, 0.02%), K (2.22%, 0.39%), Ca (0.38, 0.08%) and Fe (113 mg/kg, 24 mg/kg) showed no significant differences because of zone location.

Paddy (rough) seed analysis demonstrates that for CL272, 745, Diamond, 4534 and CL172 the nitrogen content is greater for zone #1 than zone #3, whereas Roy-J has equivalent seed nitrogen concentrations (Table 3b). For all varieties, sulfur (significance of 0.00028), zinc (significance of 0.0069), and copper (significance of 2.74 E-05) rice seed concentrations are greater in zone #1 than zone #3. Conversely, rough rice iron concentrations (significance of 0.0064) are somewhat smaller in zone #1. For all varieties the rough (seed) rice phosphorus, potassium, magnesium, calcium, manganese and boron concentrations are not appreciably different as a function of zone location. The phosphorus, potassium, magnesium, calcium, manganese and boron concentrations (mean, standard deviation) are: phosphorus (0.32%, 0.02%), potassium (0.35%, 0.03%), magnesium (0.12%, 0.01%), calcium (0.028%, 0.004%), manganese (118 mg/kg, 31 mg/kg) and boron (1 mg/kg, 0 mg/kg). The nitrogen, sulfur, copper and zinc each show greater straw and seed elemental concentrations in zone #1, suggesting that (i) either soil conditions or plant growth characteristics influence the uptake of these nutrients and (ii) greater concentrations of these elements in stem and leaf tissue is conducive to transference to panicles. Seed arsenic concentrations are substantially greater in zone #3, supporting the premise that water ponding from tail water accumulation imposes sufficient anoxic soil conditions to increase plant uptake of arsenic.

Table 2b. Seed elemental analysis by variety for zones #1 and #3 (5 Oct 2018)

Variety	Zone	N	S	Fe	Zn	Cu	As
CL272	1	1.66	0.11	43	30	5	<0.05
CL272	3	1.07	0.09	49	19	2	0.54
745	1	1.48	0.10	38	23	5	0.09
745	3	1.02	0.08	44	16	2	0.36
Roy-J	1	1.25	0.10	29	26	4	<0.05
Roy-J	3	1.25	0.08	39	19	2	0.32
Diamond	1	1.58	0.11	36	43	5	<0.05
Diamond	3	0.96	0.08	58	21	3	0.34
4534	1	1.41	0.10	53	23	5	0.07
4534	3	1.15	0.08	59	18	2	0.24
CL172	1	1.36	0.10	33	27	5	0.09
CL172	3	1.26	0.09	54	21	2	0.34
Mean	1	1.46	0.10	39	29	5	0.08
Mean	3	1.11	0.08	51	19	2	0.36

Note: element (mean, standard deviation), P (0.32%, 0.02%), K (0.35, 0.03%), Mg (0.12, 0.01%), Ca (0.03, 0.0%), Mn (117 mg/kg, 31 mg/kg), B (1 mg/kg, 0 mg/kg), and Cu (3.5 mg/kg, 1.5 mg/kg) showed no significant differences by zone location.

Agronomic Yield Components

Panicle weights show significant differences based on field location, with panicle weight located in zone #3 substantially greater than for panicles selected from zone #1 (Table 3). The variety 745 had the highest panicle weight in zone #3, whereas Roy J had the smallest panicle weight in zone #1.

Table 3. Mean panicle weights from zones #1 and #3.

Variety	Zone #1	Zone #3
CL172	3.7	4.2
Diamond	3.8	4.8
745	3.7	5.1
Roy-J	2.4	4.5
4534	4.0	4.5
Cl272	2.6	4.4

Paired t-test for mean separation was 0.0025
Each value the mean of 20 panicles

Yield

Rough rice yields (adjusted to 12.5 % seed moisture) for all varieties were greatest in zone #3 and least in zone #1 (Table 4). The highest yielding variety was 4534 (mean of 10,540 kg/ha, followed by 745 (9,460 kg/ha), CL172 (7,940 kg/ha), CL272 (7,920 kg/ha), Diamond (7,600 kg/ha), and then Roy J (6,130 kg/ha).

Table 4. Mean rice yield (kg/ha) by zone

Variety	Zone #1	Zone #2	Zone #3	Mean
Diamond	6250	7265	9289	7601
Roy J	4879	5750	7757	6128
CL272	6575	7507	9689	7924
4534	9369	10347	11902	10540
745	8228	9609	10551	9462
CL172	7149	7633	9042	7941

Each value for each zone is the average of two replications, each plot 3.86 m by 120 m (12.6 ft by 392 ft) involving zones #1, #2 and #3. The mean is the average of six values across three zones.

Regression of yield (kg/ha) with panicle weight was significant, with [Yield (kg/ha) = 2166 (panicle weight) – 320] and $r^2 = 0.70$. Thus, the panicle weight (proxy for the number of seed per panicle and mean seed weight) likely influenced the harvestable yield.

CONCLUSION

Yields in 2018 on furrow irrigated rice vary because of variety. However, for each variety position within the furrow irrigated field influenced yield attainment, with field portions having accumulated tailwater exhibiting greater rice yield. Tailwater accumulation mimicked the more traditional delayed flood irrigation regime. Presumably furrow irrigation supports a more intensive nitrification reaction of ammonium to nitrate and then subsequent nitrate denitrification with furrow water application. With water ponding because of tailwater accumulation, a more anoxic soil regime was imposed which increased the soil arsenic availability and its subsequent uptake and transference to both vegetation and seed. Clearly, variety selection and suitability for furrow irrigated rice needs more research.

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