

Original Research Article

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Water Management and Planting Methods Influence Growth, Spikelet Sterility and Nutrient Acquisition in Aerobic Rice

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ABSTRACT

Aerobic rice (*Oryza sativa* L.) is widely grown in eastern India. Soil moisture stress and unscientific ways of sowing, limit its yield and grain quality. Thus, a field experiment was conducted at Central Rainfed Upland Rice Research Station, Hazaribagh, Jharkhand, India during rainy season of 2016, to study the effects of irrigation regimes, soil adjuvants and planting methods on growth, and uptake and partitioning of micro-nutrients in aerobic rice. The experiment was laid-out in a split-plot design replicated thrice. The treatments included 4-irrigation schedules, irrigation at 0.9, 1.2, 1.5 IW/CPE ratio and no-irrigation (rainfed), and 2-soil adjuvants (soil adjuvant applied and no-soil adjuvant) allotted to main-plots and 2-planting methods—conventional dry seeding at 20 cm row spacing and spot-sowing (dibbling of 4-seeds/hill at 20 × 15 cm interval) to the sub-plots. Irrigation at IW/CPE 1.5 exhibited the highest tiller count which was 4.2, 10.6 and 18.7% higher than IW/CPE, 1.2, IW/CPE 0.9 and rainfed treatment. The conversion of tillers to effective tillers was higher in IW/CPE 1.5 and 1.2 than water stressed crop (IW/CPE 0.9 and rainfed). Irrigation at IW/CPE ratio 0.9, 1.2 and 1.5 caused 16, 25 and 40% enhancement in filled-grain weight panicle⁻¹, respectively, over rainfed crop; the corresponding reduction in grain sterility was 21, 33 and 47%. Total uptake of Fe, Zn, Cu and Mn went up by 23.3, 24.6, 24.4 and 24.4%, respectively, in IW/CPE 1.5 over rainfed condition. Micro-nutrient harvest index and partial factor productivity of applied N, P and K also stood highest in IW/CPE 1.5. Spot-planting resulted in significantly larger tiller-count, higher number of panicles m⁻² with larger and heavier panicles compared to conventional planting. Micro-nutrient accumulation and harvest index were also higher with spot-planting. Soil adjuvant application did not express significant effect on any of the studied parameters. Hence for better crop growth and accumulation of micro-nutrients and their larger partitioning towards grains, aerobic rice should be spot-planted and irrigated at IW/CPE 1.5 under adequate water supply and at IW/CPE 1.2 when water is limited.

Keywords

Adjuvant, Aerobic rice, Irrigation, Nutrient harvest index, Partial factor productivity, Spot-planting, Sterility

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Introduction

Rice (*Oryza sativa* L.) constitutes staple food for more than half of the India's population

and plays an important role in country's food security. India should produce additional 50 mt of rice at growth rate of 3 m t annually to feed 1523 million population by 2030 (CRRI

2011; Dass *et al.*, 2016). However, the conventional transplanted puddled rice production system is labour, water and energy-intensive, and thus, less remunerative (Kumar and Ladha, 2011). The looming water crisis, climate change, global warming, and poor availability of labour are posing serious limitations to conventional rice cultivation (Sandhu *et al.*, 2017). Rice requires two to three times more water than other cereals and consumes about 70% of the available irrigation water in India (Biswas, 2010 and Dass and Chandra, 2013a). Humphreys *et al.*, (2010) found that continuous use of ground water for irrigation of rice led to declines in water table by 0.1–1.0 m per year in Northwest-Indo-Gangetic Plains. The situation is further worsening as the rainfall patterns in many areas are becoming more and more unreliable and erratic, with extremes of drought and flooding occurring regularly due to climate change.

Water scarcity for rice cultivation is felt not only in India, but world over too. In South and Southeast Asia, over 15 million hectare (mha) wetland irrigated rice may experience “physical water scarcity” whereas, 22 mha may experience “economic water scarcity” by 2025 (Tuong and Bouman 2003). Under such circumstances, aerobic rice (AR) can be a potential alternative to transplanted rice. Aerobic rice is a production system where rice is grown in well-drained, non-puddled, and non-saturated soils. The main advantage of AR is increasing water productivity through water saving during land preparation and limiting seepage, percolation, and evaporation and lesser use of labour as compared to transplanted puddle rice (Castaneda *et al.*, 2003; Belder *et al.*, 2004 Peng *et al.*, 2012). However, AR has been successful in cool temperate regions while for sub-tropic and tropic regions, a partial aerobic rice system (PARS) which includes alternate wetting and drying, keep soil at saturation and

irrigation at 1–5 days interval, may be more plausible alternative (Prasad, 2011). However, yield penalty also occurs in AR (Farooq *et al.*, 2009), which is mainly due to macro-and micronutrient deficiency or lesser uptake of these nutrients, weeds and root nematodes infestation (Prasad, 2011).

Thus, adequate soil moisture is pre-requisite for macro-and micro-nutrient uptake by plants. Soil water regimes facilitate the maximum micronutrient supply to the crop plants. Indirectly, soil moisture favourably enhances the physicochemical and microbial processes that enable soil to provide micro-nutrients in available form to the plant. Zn deficiency occurs under both flooded or anaerobic conditions (Fageria *et al.*, 2003) as well as under aerobic conditions (Prasad, 2011; Farooq *et al.*, 2011). Rainfed areas generally face drought like situations in between the vegetative and flowering stages of rice which is the main factor limiting grain yield. In drought like situations, application of soil adjuvants/surfactants can modify irrigation properties which will enhance water holding capacity (WHC) and allow soil to retain more water and supply to the crop plants in water scarce conditions. Adjuvants include a wide range of chemical compounds, such as surfactants, stickers, sun screen agents, humectants and anti-evaporation agents (Curran *et al.*, 1999). Under limited soil moisture conditions, a soil adjuvant improves the availability of nutrients in soil profile as they are chemically and biologically active compounds. Their mode of action allows water to penetrate and wet agricultural soils more easily, potentially improving water use efficiency (WUE) and crop quality (Karagunduz *et al.*, 2001; Krogh *et al.*, 2003).

Apart from irrigation management, proper spacing and method of planting can maintain the optimum plant population and favourably influence the growth, yield and nutrient

uptake of plants. Several workers have reported that maintenance of a critical level of rice plant population in field was essential to obtain adequate tiller-count with longer and heavier panicles, and higher yields and nutrient uptake (Shrirame *et al.*, 2000, Sultana *et al.*, 2012 and Dass *et al.*, 2017b). Thus, the objective of this study was to find the effects of irrigation regimes, soil adjuvant and planting methods on growth, and uptake and portioning of micro-nutrients in aerobic rice.

Materials and Methods

Study area, meteorological parameters

The field experiment was conducted at Central Rainfed Upland Rice Research Station, Hazaribagh (23°56'34" N and 85°21'46" E and 614 m above mean sea level.), Jharkhand. Soil of the experimental field was clay loam in texture, categorised as medium in organic C (0.62%), low in available N (153 kg ha⁻¹), medium in available P (11.3 kg ha⁻¹) and high in available K (380 kg ha⁻¹). The available Fe and Zn content was 13.42 and 2.79 ppm, respectively. Soil reaction was in neutral range (pH 6.8). Field capacity and permanent wilting point moisture content of soil was 28.7, 14.9%, respectively.

The climate of the experimental site is warm and humid with mean maximum and minimum temperature of 31.4°C and 13.7°C, respectively. South-west monsoon normally reaches Hazaribagh on and around 18th of June every year, with year to year deviation of 5–10 days. The normal rainfall of the district is 1083.9 mm, June to September are the usual rainy months accounting for 79% of the total rainfall. Total rainfall during experimentation period was 1237 mm. The mean maximum temperature was 31.7°C, while the mean minimum 13.5°C.

Experimental setup and crop management

The three-time replicated field experiment was conducted in a split-plot design. The treatments included 8-combinations of 4-irrigation schedules [irrigation at IW/ CPE 0.9, 1.2, 1.5 and no-irrigation (rainfed)] and 2-soil adjuvants (soil adjuvant applied and no-soil adjuvant) allotted to main-plots, and 2-planting methods—conventional dry seeding at 20 cm row spacing and spot-sowing (dibbling of 4-seeds/hill at 20 × 15 cm interval) to the sub-plots. Thus there were a total of 16 treatment combinations. Fifty milli-meter depth of irrigation water was applied when the cumulative pan evaporation (CPE) reached 56, 42, and 33 mm in order to get pre-determined IW/CPE ratio of 0.9, 1.2, and 1.5, respectively. Soil adjuvant (APSA 80TM) was applied on soil surface twice @ 450 ml ha⁻¹ dissolved in 500 litres of water, once at tillering stage and subsequently at panicle emergence stage.

A high yielding rice variety Sahabhazi Dhan suitable for direct sowing or transplanting in rainfed upland ecosystem was sown using pre-determined methods, namely, conventional planting and spot-sowing. In conventional planting, rice seeds were manually drilled in rows spaced 20 cm apart using 60 kg ha⁻¹ seed. In spot-sowing, 4 seeds were dibbled per hill at 20 × 15 cm spacing manually, using 30 kg seed ha⁻¹. All plots were equally fertilized with 120 kg N, 60 kg P₂O₅, and 30 kg K₂O. N was supplied through urea and di-ammonium phosphate (DAP). P was supplied through DAP and K from muriate of potash. Half of N and entire amounts of P and K were incorporated basally at the time of sowing. The remaining amount of N was top-dressed in 2-equal instalments, the first at active tillering and the second at panicle initiation stage. Weeds were controlled with pre-emergence application of pendimethalin @ 1.0 kg ha⁻¹ followed by

post-emergence application of bispyribac-Na @ 0.025 kg ha⁻¹.

Data collection and analysis

The number of tillers was counted from one square meter demarcated area at 45 days after sowing (DAS), 75 DAS and at harvest stage. Proportion of effective tillers (PEt, %) was computed by using the following expression.

$$PEt (\%) = \frac{\text{Effective tillers per square meter area at harvest}}{\text{Total number of tillers per square meter area at 75 DAS}} \times 100$$

Ten representative panicles were selected and number of grains (filled, unfilled) were counted and averaged out to arrive at filled, unfilled grains panicle⁻¹. The weights of filled and unfilled grains obtained from each of the 10 sampled panicles were recorded separately using a high precision electronic balance. Sterility percentage was calculated on the basis of number/weight of filled and unfilled grains by using the following expressions:

$$\text{Sterility (\%)} = \frac{\text{Number of un-filled grain or weight of un-filled grains}}{\text{Total number of grains (filled + unfilled) or their weight}} \times 100$$

The Fe, Zn, Mn and Cu in grain and straw of rice crop were determined by DTPA extractable method (Lindsay and Norvell, 1978). Uptake of Fe, Zn, Cu and Mn was computed by multiplying the values of their respective concentration in grains and straw with grain and straw yields. For computing grain and straw yields, the crop from the net profit area of 16.38 m² was harvested plot-wise dried, thrashed and weighed. All yields were determined at 14% moisture content. Partial factor productivity (PFP) and micro-nutrient harvest index (NHI) were determined using the following expressions:

$$PFP (\text{kg grain per kg nutrient applied}) = \frac{\text{Grain yield in kg/ha}}{\text{Amount of nutrient applied kg/ha}} \times 100$$

$$NHI(\%) = \frac{\text{Micro-nutrient uptake in grain, g/ha}}{\text{Total uptake of micro-nutrient (grain + straw), g/ha}} \times 100$$

Statistical analysis

The experimental data was subjected to statistical analysis by using the standard technique of analysis of variance (ANOVA). The significance of treatment means was tested using F-test (Rana *et al.*, 2014). The critical difference (P=0.05) were worked out to evaluate differences between treatment means.

Results and Discussion

Growth and yield attributes

The irrigation regimes and planting methods revealed significant influences on all the yield attributing characters like tiller-count, filled grain weight panicle⁻¹, unfilled grain weight panicle⁻¹ and sterility percentage. The effect of soil adjuvant was non-significant. All characters were significantly affected by irrigation levels except tillers count at 45 DAS. At 75 DAS, maximum tillers count m⁻² was obtained with irrigations applied at IW/CPE ratio 1.5 which was, however, at par with IW/CPE ratio 0.9 and 1.2. At harvest, IW/CPE 1.5 exhibited the highest tiller count which was 4.2, 10.6 and 18.7% higher than IW/CPE, 1.2, IW/CPE 0.9 and rainfed treatment; the difference between IW/CPE 1.5 and 1.2 was non-significant. Moreover, the conversion of tillers to effective tillers (panicle bearing tillers) was higher in IW/CPE 1.5 and 1.2 than water stressed crop (IW/CPE 0.9 and rainfed).

A higher tiller mortality as a result of water deficit and resultant inadequate availability in the soil and low absorption of important nutrients (N, Fe, P and K) might be the reasons for lower tillers number and their conversion into effective panicles under

delayed irrigation (IW/CPE 0.9) and rainfed condition (Dass *et al.*, 2013b, 2016, 2017b).

Increasing frequency of irrigation as depicted by increasing values of IW/CPE ratios, significantly increased filled-grain weight panicle⁻¹ in aerobic rice. Irrigation at IW/CPE ratio 0.9, 1.2 and 1.5 led to 16, 25 and 40% enhancement in filled-grain weight panicle⁻¹, respectively, over rainfed crop. A reverse trend was, however, observed for unfilled-grain weight panicle⁻¹. Grain sterility was also significantly higher in rainfed crop. Grain sterility computed based on filled and unfilled grain number, was 21, 33, 47% lower with irrigations scheduled at IW/CPE 0.9, 1.2 and 1.5, respectively, compared to rainfed crop. The reduction in sterility percentage was significant with increase in irrigation frequency. The lower panicle weight and higher grain sterility under rainfed condition and stressed irrigation regime (IW/ CPE 0.9) could be due to soil moisture stress at most critical stages (grain-filling and flowering). Thomas *et al.*, (2014) also reported the reduction in yield attributing characters of upland rice in rainfed condition. Soil adjuvant application did not increase tiller count, and filled grain weight panicle⁻¹ significantly. Due to higher unfilled grain number and weight, sterility percentage was significantly higher in adjuvant excluded plots (Table 1).

Between two planting methods, spot-planting resulted in significantly larger tiller-count, and higher number of panicles m⁻² with larger and heavier panicles compared to conventional planting. The increase in filled grain weight panicle⁻¹ due to spot-planting was 10%. While sterile grain weight panicle⁻¹ was significantly higher in conventional drilling of seeds. The higher number of tillers, panicles m⁻² and filled grain weight panicle⁻¹ in spot sowing might be due to larger space, greater availability of light, moisture and nutrients and hence higher photosynthetic

rates in spot-planted rice plants (Bezbaruha *et al.*, 2011, Dass 2013a,b, Dass *et al.*, 2015).

Nutrient concentration

Increasing the irrigation frequency from IW/CPE 0.90 to 1.50 enhanced Fe, Zn, Cu and Mn concentrations in both rice grain and straw but the differences were non-significant. However, levels of irrigation exhibited significant variation in Fe, Zn, Cu and Mn uptake in both grain and straw. Applying irrigation at IW/CPE 1.50 increased total uptake of Fe, Zn, Cu and Mn by 23.3, 24.6, 24.4 and 24.4%, respectively, over rainfed condition (Table 2). The respective increase in total uptake of micronutrients (Fe, Zn, Cu and Mn) by irrigation at IW/CPE 1.2 was 9.1, 10.7, 13.6 and 9.7%. Availability of sufficient moisture in the plots irrigated at IW/CPE 1.5 and 1.2 facilitated the plants for higher nutrient uptake through better growth and yield attributes. Hazra and Chandra (2014); Dass and Chandra, 2012; Dass and Dhar, 2014 and Dass *et al.*, 2017b) reported that soil moisture regimes affected the availability and uptake of nutrients in rice significantly. Further, water play an important role in the mobilization of Fe, Cu and Zn, their uptake was significantly reduced due to water stress (Oktem, 2008). Soil adjuvant application did not influence concentration and uptake of any of the studied micro-nutrients significantly. Likewise, planting methods had meagre impact on nutrient concentration and uptake, except grain uptake of Fe, Zn, Cu and Mn that was significantly higher (5.8, 8.3, 10.4 and 6.3%) in spot-sowing over conventional planting. Higher grain yield led to higher uptake of micro-nutrients in grain in spot sowing, concentration of all micro-nutrients was alike between two planting methods. Beligar (1986) also noted that the differences in nutrient accumulation by plants are assumed to be depending on dry weight of plant.

Partial factor productivity

Partial factor productivity of N, P and K was maximum with irrigation at 1.5 IW/CPE ratio. Better irrigation regimes created favourable soil environment facilitating plant growth and yield that, in turn, resulted in higher partial factor productivity. Nayak *et al.*, (2015) reported that irrigation at 5- and 3- day intervals produced significantly higher value of partial factor productivity of N than other irrigation regimes at larger interval. The similar results have also been reported Rahman *et al.*, (2013). Between two planting methods, spot-sowing recorded higher partial factor productivity of all studied nutrients due to higher grain yields. Application of soil adjuvant did not alter the partial factor productivity.

Nutrient harvest index

Irrigation at IW/ CPE 1.2 and 1.5 improved micro-nutrient harvest index over rainfed crop significantly, barring Cu-harvest index that was similar between IW/CPE 1.2 and rainfed crop (Table 3). A higher moisture availability might have led to greater nutrient availability in soil, their higher uptake via higher grain yield and also increased translocation to grains, under favourable irrigation regimes mediated irrigations at shorter intervals (Dass *et al.*, 2017b). These processes could have culminated into higher nutrient harvest index. Spot-sowing resulted in higher grain yield which caused higher nutrient uptake and nutrient harvest index. The influence of soil adjuvant on nutrient harvest index was insignificant as was on crop growth and yield.

Table.1 Effect of irrigation regimes, soil adjuvant and planting methods on tiller count, grain weight/panicle and sterility in aerobic rice

Treatment	Tillers count m ⁻²			Proportion of effective tillers (%)	Filled grain weight panicle ⁻¹ (g)	Unfilled grain weight panicle ⁻¹ (g)	Sterility %	
	45 DAS	75 DAS	Harvest (Effective tillers)				Grain number based	Grain weight based
<i>Irrigation (IW/CPE ratio)</i>								
0.9	164	340	293	86.2	2.04	0.36	27.9	14.9
1.2	173	343	311	90.7	2.20	0.31	23.8	12.6
1.5	178	363	324	89.3	2.46	0.25	18.6	9.2
Rainfed	162	326	273	83.7	1.76	0.47	35.4	21.3
SEm±	4.97	7.94	7.75	-	0.056	0.01	0.68	0.47
CD (P=0.05)	NS	24.1	23.5	-	0.168	0.03	2.05	1.44
<i>Soil adjuvant</i>								
A ₁	172	346	304	87.9	2.16	0.34	25.5	13.9
A ₂	167	340	297	87.4	2.07	0.36	27.4	15.1
SEm±	3.52	5.61	5.48	-	0.04	0.007	0.48	0.33
CD (P=0.05)	NS	NS	NS	-	NS	NS	1.45	1.01
<i>Planting method</i>								
P ₁	165	337	292	86.6	2.02	0.36	28.0	15.5
P ₂	174	349	308	88.3	2.22	0.33	24.9	13.5
SEm±	2.9	3.9	5.1	-	0.04	0.01	0.47	0.31
CD (P=0.05)	8.6	11.6	15.4	-	0.12	0.014	1.41	0.91

Table.2 Effect of irrigation regimes, soil adjuvant and planting methods on nutrient concentration and uptake

Treatment	Fe-concentration (mg kg ⁻¹)		Fe-uptake (g ha ⁻¹)			Zn-concentration (mg kg ⁻¹)		Zn- uptake (g ha ⁻¹)			Cu-concentration (mg kg ⁻¹)		Cu- uptake (g ha ⁻¹)			Mn-concentration (mg kg ⁻¹)		Mn- uptake (g ha ⁻¹)		
	Grain	Straw	Grain	Straw	Total	Grain	Straw	Grain	Straw	Total	Grain	Straw	Grain	Straw	Total	Grain	Straw	Grain	Straw	Total
Irrigation (IW/CPE ratio)																				
0.9	75.3	132.3	241	804	1045	28.9	68.9	92	419	511	5.6	20.7	17.9	113	131	34.3	85.4	110	519	629
1.2	77.2	134.9	274	852	1126	30.2	70.7	107	445	552	6.1	21.6	21.7	125	147	36.0	87.2	128	551	678
1.5	79.2	137.8	332	1003	1335	31.2	71.9	131	523	654	6.4	21.9	26.3	142	168	37.3	89.7	157	653	810
Rainfed	74.9	131.4	232	792	1024	27.7	67.8	86	407	493	5.9	19.7	18.2	108	127	33.7	84.5	104	508	612
SEm±	1.85	2.75	7.1	23.7	30.5	0.81	0.81	2.8	12.5	15.2	0.2	0.2	1.0	6.2	6.9	0.9	2.2	3.5	15.5	18.8
CD (P=0.05)	NS	NS	21.65	71.9	92.6	NS	NS	8.5	38.0	45.9	NS	NS	2.94	18.9	20.9	NS	NS	10.7	47.0	56.9
Soil adjuvant																				
A₁	77.1	134.8	272	870	1142	29.8	70.1	107	452	557	6.0	21.2	21.1	124	145	36	87	127	564	690
A₂	76.2	133.4	268	856	1124	29.2	69.5	102	445	548	6.0	20.7	20.9	120	141	35	86	122	552	674
SEm±	1.31	1.94	5.1	16.8	21.6	0.58	1.142	2.0	8.9	10.7	0.14	0.41	0.69	4.4	4.9	0.7	1.5	2.5	11.0	13.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Planting method																				
P₁	76.5	133.9	262	851	1114	29.0	69.3	100	440	540	5.8	20.6	19.9	117	137	35.2	86.5	121	550	671
P₂	76.8	134.3	278	874	1152	30.0	70.3	109	457	565	6.2	21.3	22.2	127	149	35.4	86.9	129	565	694
SEm±	0.97	1.57	4.5	13.8	18.2	0.52	0.95	1.5	6.5	7.8	0.13	0.28	0.48	1.9	2.05	0.44	1.13	1.6	7.7	9.3
CD(P=0.05)	NS	NS	13.55	NS	NS	NS	NS	4.6	NS	23.3	NS	NS	1.44	5.7	6.2	NS	NS	4.8	NS	NS

Table.3 Effect of irrigation regimes, soil adjuvant and planting methods on partial factor productivity of applied nutrients and micro-nutrient harvest index

Treatment	Partial factor productivity (kg ha ⁻¹ kg ⁻¹ of applied nutrients)			Nutrient harvest index (%)			
	PF _N	PF _P	PF _K	Fe	Zn	Cu	Mn
<i>Irrigation (IW/CPE ratio)</i>							
0.9	27.9	55.9	111.8	23.1	18.1	13.7	17.4
1.2	30.2	60.5	120.9	24.4	19.4	14.8	18.8
1.5	34.3	68.7	137.3	24.8	20.0	15.8	19.4
Rainfed	25.0	50.0	100.1	22.7	17.5	14.4	17.1
SEm±	0.815	1.63	3.26	0.16	0.17	0.54	0.17
CD (P=0.05)	2.47	4.95	9.89	0.49	0.52	1.63	0.51
Soil adjuvant							
A₁	29.6	59.1	118.3	23.7	18.9	14.6	18.3
A₂	29.2	58.4	116.8	23.8	18.6	14.7	18.0
SEm±	0.58	1.15	2.31	0.11	0.12	0.38	0.12
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
<i>Planting method</i>							
P₁	28.4	56.8	113.6	23.5	18.4	14.5	17.9
P₂	30.4	60.7	121.4	24.0	19.1	14.8	18.4
SEm±	0.40	0.82	1.64	0.10	0.12	0.34	0.06
CD (P=0.05)	1.23	2.45	4.90	0.29	0.34	1.04	0.19

Fig.1 Correlation between effective tillers and grain yield of aerobic rice

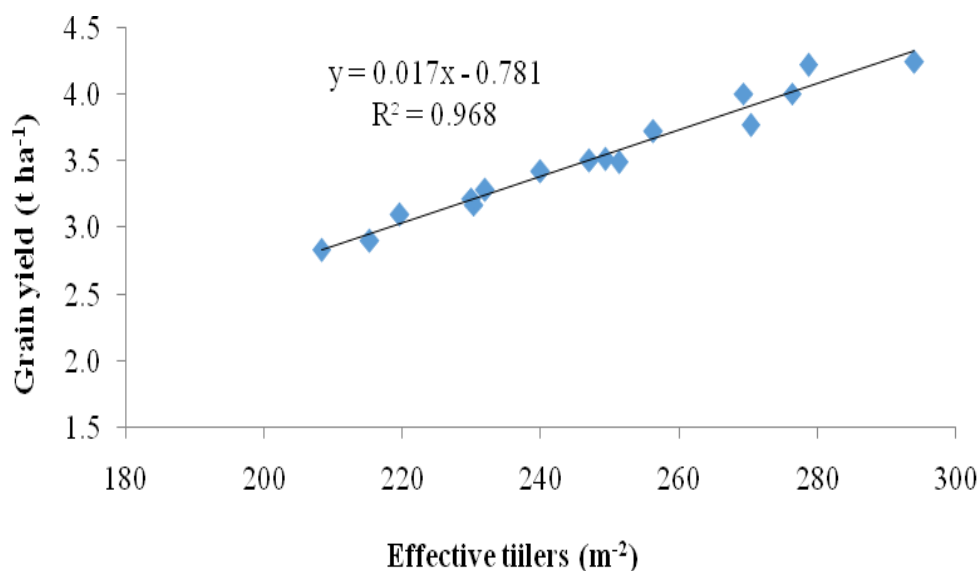


Fig.2 Correlation between dry matter accumulation and grain yield of aerobic rice

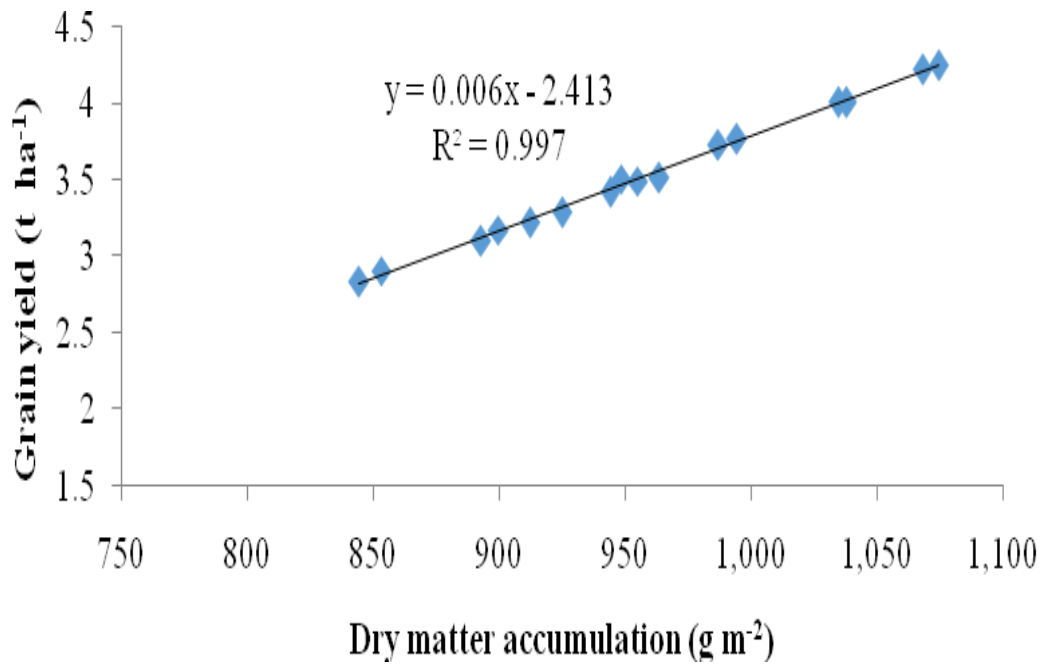
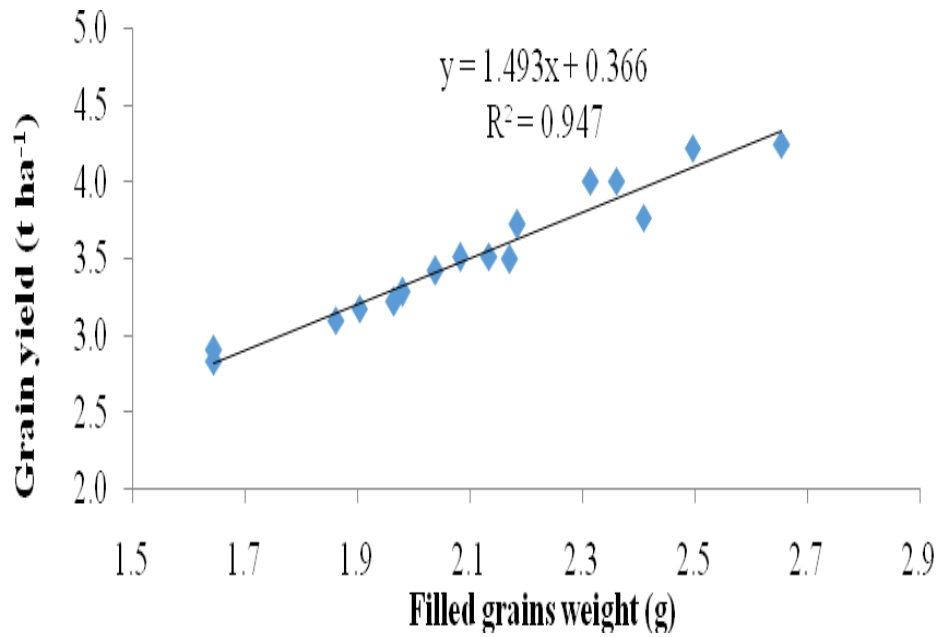


Fig.3 Correlation between filled-grains weight and grain yield of aerobic rice



Correlation of growth with yield

Effective tillers, dry matter accumulation and filled grain weight, were positively correlated with rice grain yield (Figs. 1, 2, 3). Yield formation in rice largely depends upon tiller production, more than 80% rice yield is contributed by tillers/ m² (Baloch *et al.*, 2002; Dass *et al.*, 2013a,b). Thus, a positive and significant correlation between tiller count and grain yield of aerobic rice could also be expected. Similarly, a higher overall dry matter production, which is accumulation of carbohydrates, makes possible the higher transport to and accumulation of dry matter in grain finally resulting in larger yield attributes and grain yield. Thus, both drymatter accumulation and panicle weight were positively and significantly correlated with grain yield in the current study also (Dass *et al.*, 2013b).

In conclusion, the current study clearly demonstrates that for better crop growth and higher accumulation of micro-nutrients and their larger portioning towards grains, aerobic rice should be spot-planted. Irrigations should be applied at IW/CPE 1.5 under adequate water supply and at IW/CPE 1.2 when water is limited. These findings are applicable in sub-humid eastern India and other similar agro-ecologies of South-Asian rice production systems.

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