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Influence of field capacity vis-à-vis submerged water regime on growth and yield of rice in a Typic Haplustalf soil of Red and Laterite zone of West Bengal

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ABSTRACT

An experiment was conducted for two consecutive boro seasons in the farmers' field at Jhargram, West Midnapore, to quantify the extent of possible reduction in grain yield of seven varieties of rice grown under field capacity water regime (FC) in comparison to continuous submergence (CF). While highest grain yield (3.46tha^{-1}) was recorded under CF, in FC the extent of decrease in rice grain yield was 38.1% compared to that in CF. Rice genotypes exhibited differential response to water management practices. Though UPLRi -7 produced the highest grain yield (4.52 t ha^{-1}) under CF, under decreased water supply in FC water regime, IR -36 was still the best variety producing the highest average grain yield (3.16 t ha^{-1}). Compared to CF, FC water regime also resulted in shorter plant height and decreased number of tillers as well as panicles but higher straw yield of rice. The present research work pointed out that without ensuring adequate supply of irrigation water, rice cultivation during boro season may not be profitable in the Red and Laterite Zone of West Bengal. Differential varietal response to field capacity (FC) water regime vis-à-vis continuously submerged (CF) water regime also pointed out to the necessity of selection of varieties that could adopt itself to decreased supply of irrigation water.

Keywords : Alfisol, *boro* rice, deficit irrigation, red and laterite zone

Rice is considered the main food staple for more than 50 per cent of the world's population (Childs, 2004). Consumed by about 3 billion people it feeds more people than any other crop (Maclean *et al*., 2002). It is the grain that has shaped the cultures, diets, and economies of billions of people in the world (Farooq *et al*., 2009). Ninety percent of the world's rice is produced and consumed in Asia and in the foreseeable future; rice will continue to be the main staple food of Asia (Rosegrant *et al*., 2001; Sombilla *et al*., 2002). With 43.7 million ha under rice, India produces about 140 million Mg of rice annually. Demand for rice in South Asia is expected to grow at 2.02 per cent per year during the next couple of decades (Rosegrant *et al*., 2002) and our ability to achieve a trend of growth towards productivity and profitability of rice farming systems on an ecologically sustainable basis will dictate the future of the food security system, not only in India but the whole of Asia (Swaminathan, 1993). While rice production under flooded conditions in the irrigated ecosystem is highly sustainable (Bouman *et al*., 2007), the rainfed rice ecosystem, which is subjected to different water regimes - from submerged to water stress, also contribute significantly to food security in many countries including India. To fight poverty and provide food security, rice production must increase from the present level to at least 760 Mt by the year 2020 (Kundu and Ladha, 1995) from same or even shrinking land due to increasing competition for land and declining water availability. A major challenge in rice (*Oryza sativa* L.) production now is to achieve the dual goal of increasing food production and saving water. Exploring ways to produce more rice with less water is essential for food security and in this direction water-saving rice production systems, such as aerobic rice culture, system of rice intensification (SRI), ground-cover rice production system (GCRPS), raised beds, and alternate wetting and drying (AWD), have been tested. These methods though can drastically cut down unproductive water outflows and increase water-use efficiency (WUE), these technologies can sometimes lead to some yield penalty, if the existing lowland varieties are used (Farooq *et al*., 2009). Rice varieties differ in their water use efficiency and thus to their response to different water regimes. To achieve high and sustainable yields in nonflooded soil, identification of varieties with better water use efficiency assumes great importance. Shifting of rice lands from being continuously anaerobic to being partly or even completely aerobic will produce profound changes in water conservation, soil organic matter turnover, nutrient

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dynamics, carbon impounding, weed flora, and greenhouse gas emissions. The challenge will be to develop suitable water management regimes and identify efficient varieties which would allow profitable rice cultivation under deficit water availability. Owing to poorer status of organic matter, nitrogen, phosphorus, sulphur and acidic soil reaction due to lower base contents, the soils in the Red and Laterite agro-climatic zone of West Bengal are hungry and because of their light and porous texture are thirsty too. In this agro-climatic zone rice is grown in 3 out of 4 agro-ecological situations and in the lowest strata of undulating topography of this zone no other crop except rice could be grown after harvest of *kharif* (wet rainy season) rice. Irrigation water is a very scarce natural resource in this zone, particularly during the *boro* (dry summer) season. It becomes imperative thus to find out if instead of traditional system of flooded rice culture, some amount of water could be curtailed at different phenological growth stages and saved for horizontal expansion of rice during the *boro* season. The above facts concurrently propound an intensive study to explore the suitability of some locally grown rice varieties under field capacity water regime and also to quantify possible reduction in rice grain yield due to suboptimum supply of water and the present field experiment was thus undertaken in farmer's field for two seasons (during *boro* season) in an Alfisol soil.

MATERIALS AND METHODS

The research programme comprised two field experiments conducted in succession during *boro* (pre-summer) season (January-April), 2010 and 2011 in a farmer's field at Jhargram located at $22^0 45^/$ N and $86^0 98^/$ E at an elevation of 81 m above mean sea level (MSL) in the sub-humid tropical zone of Eastern India. The soil was typical lateritic (*Typic Haplustalf*) growing rice with good drainage facilities and texturally classified as sandy loam. The sand, silt and clay contents of the surface (0-0.15 m) soil were 77.12 per cent, 6.0 per cent and 16.88 per cent, respectively. The initial soil sample was collected from surface (0-0.15 m) layer, air dried, ground, passed through a 2 mm sieve and analyzed following standard methods (Jackson, 1973). Maximum water holding capacity (MWHC) was determined by equilibrating the soil with water through capillary action in a KR box (Baruah and Barthakur, 1999). Percent clay, silt and sand were determined by Hydrometer method (Bouyoucos, 1922, 1962). Soil pH and EC were determined at 1:2.5 soil–water ratios using a glass electrode and conductivity bridge, respectively. Cation exchange capacity (CEC) was measured by 1N NH_4OAc, pH 7.0 solution method (Schollenberger and Simon, 1945); soil organic carbon (SOC) was determined by dichromate oxidation (Walkley and Black, 1934); total soil N by the Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus (P) in soil was determined by extracting samples with 0.5 M $NaHCO_3$, and determining P colorimetrically using molybdate (Olsen *et al.*, 1954). Available potassium was determined using 1N ammonium acetate extraction followed by emission spectrometry (Jackson, 1973). Some of the basic chemical and physico-chemical properties of the surface (0-0.15 m) soil are presented in table1. A uniform dose of fertilizer N, P_2O_5 and K_2O (80:40:40 kg ha^{-1}, respectively) through urea, single super phosphate and muriate of potash were applied in the experimental plots (5 x 4 m). Two days before transplanting, half of the nitrogen and total of phosphate and potassic fertilisers were applied as basal dose. The remaining half of nitrogen was applied as uniform top dressing after 21 days of transplanting. Two rice seedlings of each of the seven varieties of rice viz., IET-10899; IET- 8682; CN-907-6-2; UPLRi-7; IET – 4786; Khitish and IR-36 were transplanted per hill in plots with specified spacing between the hills and rows (0.15 x 0.20 m). The crop was transplanted during 2nd week of January. Usual agronomic practices were followed during the entire period of crop growth. The crop was grown to maturity under 2 water management practices *viz*., CF (Continuously flooded throughout the entire growth periods) and FC (Field capacity maintained throughout the entire growth periods). Scheduled water regimes were maintained by supplying irrigation water as required. The crop was harvested at maturity; grain and straw yields and other growth parameters were recorded. Seven varieties of rice and 2 water management practices were replicated thrice and laid out in in a factorial Randomized Complete Block Design (Gomez and Gomez, 1984). Statistical significance of treatment effects on grain and straw yields and other plant growth parameters was inferred from least significant difference (LSD, P=0.05) test using analysis of variance. Using a PC, with the help of SPSS software (SPSS 7.5, 1997), different plant growth and yield parameters were statistically analyzed.

Table 1: Some important properties of the experimental soil

Soil characteristics	Results
Mechanical analysis :	
Sand (%)	76.25
Silt (%)	7.00
Clay (%)	16.75
Textural Class	Sandy Loam
Water holding capacity (%)	31.73
Bulk Density (g/cm^3)	1.34
pH (Soil: Water = 1: 2.5)	4.84
Electrical conductivity (dsm^{-1})	0.05
Cation exchange capacity [c mol(p$^+$) kg^{-1}]	9.24
Organic carbon (%)	0.45
Total nitrogen (mg/Kg)	870
Available phosphorus (mg kg^{-1})	8.80
Available potassium (mg kg^{-1})	110.14

RESULTS AND DISCUSSION

Plant height at harvest

Mean value of plant height (at harvest) of seven genotypes under the influence of continuous flooding (CF) and field capacity (FC) water regimes, pooled over two seasons (Table 2), revealed, significant ($F < 0.05$) effect of water regime, genotypes and their interaction. Irrespective of genotypes, rice plants had the shortest height under continuous field capacity (FC) water regime during both the years. This was true for plant height in individual genotypes also. The mean plant height pooled over 2 years and irrespective of variety, was higher in CF (92.7 cm) than under FC (88.3 cm).

With the exception of UpLRi-7(V_4), all other genotypes produced taller plants under CF than under FC water regime.While the genotype IET-10889 produced the tallest plant height under CF water regime (122.1 cm), rice variety IR -36 had the shortest plants under FC water regime (70.9 cm) at harvest. Rice plants grew taller in the 2nd year (92.8 cm) compared to the 1st year (88.3 cm).

Number of tillers

Number of tillers (at harvest) (per m^2 area) of the 7 genotypes of rice grown under CF and FC water regimes over the 2 seasons was recorded and are presented (Table 2). Water regime alone and its interaction with different genotypes of rice significantly influenced the number of tillers per unit area. In general, the CF water regime (478.9) resulted in 17.52 per cent more tillers compared to Fc (407.5) water regime. The varieties differed significantly in their tillering ability under the influence of sufficient (CF) and deficient water supply (FC) (Table 1). While Khitish, irrespective of water regime, produced the highest number of tillers (502.1), UPLRi-7 produced the lowest (360.8) and was consistent during both the years. The effect of water regime significantly differed in their effect on the tillering of 7 genotypes of rice. The highest number of tillers was produced by Khitish (573.4) under CF water regime while the tiller number was the lowest in UPLRi-7 (307.4) under FC water regime. The response of different genotypes of rice to produce tiller under deficit water supply (FC) was different. While the reduction in tiller number due to deficit water supply (FC) compared to sufficient supply (CF) was the highest in UPLRi-7 (34.7%), it was insignificant in variety IR-36 (0.1%). The rice genotypes produced 5.11 per cent more tillers during the 2nd year as compared to the 1st year.

Number of panicles

Number of panicles (at harvest) (per m^2 area) of the 7 genotypes of rice grown under CF and FC water regimes over the 2 seasons was recorded and are presented (Table 2). Water regime alone and its interaction with different genotypes of rice also significantly influenced the number of panicles per unit area. In general, the CF water regime (444.4) resulted in 20.5 per cent more panicles compared to FC (368.7) water regime. The varieties differed significantly in their panicle producing ability under the influence of sufficient (CF) and deficient water supply (FC) (Table 1). While Khitish, irrespective of water regime, produced the highest number of panicles (461.5), UPLRi-7 produced the lowest (330.1) and was consistent during both the years. The effect of water regime significantly differed in their effect on the number of panicles of 7 genotypes of rice. The highest number of panicles was produced by Khitish (549.5) under CF water regime while the panicle number was the lowest in UPLRi-7 (268.6) under FC water regime (Table 3). The response of different genotypes of rice to produce panicle under deficit water supply (FC) was different. While the reduction in tiller number due to deficit water supply (FC) compared to sufficient supply (CF) was the highest in Khitish (47.1%), it was insignificant in variety IR-36 (0.9%). The genotypes of rice followed the order: Khitish (47.1%) > IET-10899 (43.1%) > UPLRi-7 (39.3%) > CN-907-6-2 (12.3%) > IET- 8682 (9.6%) > IET – 4786 (3.5%) > IR- 36 (0.9%). The rice genotypes produced 5.09% more panicles during the 2nd year as compared to the 1st year.

Grain yield

Mean grain yield of seven genotypes of rice under field capacity (FC) vis-à-vis continuously submerged (CF) water regimes, pooled over two seasons (Table 2), revealed significant influence of the effect of water regime, genotypes and their interaction on grain yield. Irrespective of genotypes, highest rice grain yield (3.46 t ha^{-1}) was obtained under continuously flooded (CF) water regime. Keeping the soil at field capacity (FC) throughout the rice growing periods led to 38.15 per cent decline in rice grain yield (Table 2). Lower photosynthetic rate in water stressed plants was the reason for this decrease in grain yield (Feng and Shiung, 1997). Castillo *et al*. (1992) also observed reduced plant height and grain yields when plants were subjected to deficit water supply during the vegetative growth stage. Borell *et al*., (1991) opined that significantly lower rice yields in most tropical rice fields were due to intermittent drying or keeping soils saturated during the growing season either vegetative or reproductive phase. Among the seven genotypes of rice, the highest grain yield was obtained in IR -36 (3.50 tha^{-1}). Mean grain yield of different genotypes pooled over the 2 seasons, followed the order IR -36 (3.50 $tha^{-1)}$ > IET 4786 (3.13 tha^{-1}) > Khitish (3.09 tha^{-1}) > UPLRi 7 (3.07tha^{-1}) > IET 8682 (2.39tha^{-1}) >IET-10889 (2.29 tha^{-1}) > CN 907-6-2 (2.14tha^{-1}). Interaction of water management with rice genotypes brought to the focus some interesting information. While under optimum water supply (CF), highest grain yield was recorded in UPLRi 7 (4.52 tha^{-1}), under deficit water supply scenario IR 36 produced the highest (3.16 tha^{-1}) grain yield. The degree of grain yield reduction under field capacity water regime compared to continuously submerged (CF) water regime ranged from 17.8 per cent in IR 36 to 64.2 per cent in UPLRi-7 and followed the order: UPLRi-7 (64.2%) > IET -8682 (55.9%) > Khitish (43.4%) > IET -10899 (26.9%) > CN-907-6-2 (23.5%) > IET - 4786 (22.4%) > IR-36 (17.8%). Among the seven tested genotypes of rice, IR 36 was the least affected by deficit supply of irrigation throughout crop growth periods. Kato et al (2006) also observed differential response of rice genotypes to deficit water supply in Japan.

Straw yield

Mean straw yield of seven genotypes of rice under field capacity (FC) vis-à-vis continuously submerged (CF) water regimes, pooled over two seasons (Table 2, 3), revealed significant influence of the effect of water management, genotypes and their interaction on straw yield. Irrespective of genotypes, highest rice straw yield (5.38 t ha^{-1}) was obtained under field capacity water regime (FC). Keeping the soil at field capacity (FC) throughout the rice growing periods led to 3.26 per cent increase in rice straw yield (Table 2). Among the seven genotypes of rice, the highest straw yield was obtained in CN 907-6-2 (6.37 tha^{-1}). Mean straw yield of different genotypes pooled over the 2 seasons, followed the order: CN 907-6-2 (6.37tha^{-1}) > Khitish (5.40 tha^{-1}) > IET-10889 (5.35 tha^{-1}) > UPLRi 7 (5.34 tha^{-1}) > IR -36 (5.27 $tha^{-1)}$ > IET 8682 (5.01 tha^{-1}) > IET 4786 (4.32 tha^{-1}). Interaction of water management with rice genotypes brought to the focus some interesting information. While under optimum water supply (CF), highest straw yield was recorded in CN 907-6-2 (6.02 tha^{-1}), the same genotype also produced the highest straw yield under deficit water supply scenario (6.71 tha^{-1}). While in 3 rice genotypes there was decrease in straw yield ranging from 5.8 to 18.9 per cent under deficit supply of water under FC water regime, the other 4 genotypes produced higher straw yield ranging from 4.2 to 30.4 per cent under FC. The increase in straw yield under FC compared to CF in the 4 genotypes followed the order: UPLRi-7 (30.4%) > CN-907-6-2 (11.5%) > IET -10899 (8.2%) > Khitish (4.2%).

Water management practices exerted differential influence on plant height, number of tillers, number of panicles, grain and straw yield of the seven rice genotypes studied. Though FC water regime had positive influence on straw yield, it resulted in 38.1 per cent reduction in grain yield. Varietal interaction with water regime was very prominent. Similar detrimental effect of deficit supply of irrigation water on rice growth and yield was reported earlier (Ghosh *et al.*, 2014). While IR-36 was least affected among 7 varieties, genotype UPLRi-7 was the most severely affected. In IR-36 the reduction in grain yield was 17.8 per cent, while in UPLRi-7 this reduction was 64.2 per cent. Although varietal interaction with water regime indicated the necessity to identify water efficient varieties and IR-36 and IET-4786 showed some prospect, the present research work demonstrated that rice cultivation without ensuring adequate supply of irrigation water may not be profitable in the Red and Laterite zone of West Bengal, particularly during the *boro* season.

Table 2: Different plant parameters of rice varieties under aerobic and anaerobic water regimes

	Plant height (cm)			Tillers (m^{-2})			Panicles (m^{-2})			Grain yield (t. ha^{-1})			Straw yield (t. ha^{-1})		
Variety	**1st Year**	**2nd Year**	**Mean**	**1st Year**	**2nd Year**	**Mean**	**1st Year**	**2nd Year**	**Mean**	**1st Year**	**2nd Year**	**Mean**	**1st Year**	**2nd Year**	**Mean**
IET-10899	114.8	120.7	117.7	457.8	480.5	469.1	416.7	437.4	427.0	2.24	2.35	2.29	5.22	5.48	5.35
IET- 8682	101.4	106.7	104.0	378.9	398.9	388.9	349.4	367.9	358.7	2.33	2.45	2.39	4.88	5.13	5.01
CN-907-6-2	86.6	91.1	88.9	436.1	458.6	447.3	382.2	402.0	392.1	2.09	2.20	2.14	6.20	6.53	6.37
UPLRi-7	90.6	95.6	93.1	351.1	370.6	360.8	312.8	330.1	321.4	2.99	3.15	3.07	5.20	5.48	5.34
IET – 4786	74.4	78.1	76.2	453.9	476.3	465.1	431.1	452.2	441.7	3.05	3.20	3.13	4.22	4.42	4.32
Khitish	80.1	84.4	82.2	488.9	515.3	502.1	449.4	473.6	461.5	3.01	3.17	3.09	5.26	5.55	5.40
IR-36	69.9	73.1	71.5	458.3	479.4	468.9	433.3	453.2	443.3	3.43	3.58	3.50	5.15	5.38	5.27
SEm (±)	**0.73**	**0.74**	**0.60**	**0.24**	**0.23**	**5.75**	**0.26**	**0.23**	**7.02**	**0.05**	**0.05**	**0.04**	**0.07**	**0.08**	**0.05**
LSD (p=0.05)	**2.12**	**2.15**	**1.69**	**0.69**	**0.68**	**16.30**	**0.76**	**0.68**	**19.91**	**0.15**	**0.14**	**0.10**	**0.21**	**0.22**	**0.14**
								Water Regime							
CF	90.6	94.9	92.7	467.8	490.0	478.9	434.1	454.7	444.4	3.38	3.54	3.46	5.09	5.33	5.21
FC	85.9	90.7	88.3	396.5	418.4	407.5	358.7	378.6	368.7	2.09	2.20	2.14	5.23	5.52	5.38
SEm (±)	**0.39**	**0.39**	**0.318**	**0.13**	**0.12**	**3.072**	**0.14**	**0.12**	**3.753**	**0.03**	**0.08**	**0.019**	**0.04**	**0.04**	**0.027**
LSD (p=0.05)	**1.13**	**1.15**	**0.902**	**0.37**	**0.36**	**8.710**	**0.41**	**0.36**	**10.641**	**0.02**	**0.07**	**0.054**	**0.11**	**0.12**	**0.076**
								Year							
1st Year		88.3			432.1			396.4			2.73			5.16	
2nd Year		92.8			454.2			416.6			2.87			5.43	
Mean		**90.5**			**443.2**			**406.5**			**2.80**			**5.29**	
SEm (±)		**0.318**			**3.072**			**3.753**			**0.019**			**0.027**	
LSD (p=0.05)		**0.902**			**8.710**			**10.641**			**0.054**			**0.076**	

Table 3: Changes in different plant parameters under the interaction of rice varieties and water regimes

Variety	**Water**	**Plant height**			**Tillers (m^{-2})**			**Panicles (m^{-2})**			**Grain yield**			**Straw yield**		
		Yr_1	**Yr_2**	**Mean**	**Yr_1**	**Yr_2**	**Mean**	**Yr_1**	**Yr_2**	**Mean**	**Yr_1**	**Yr_2**	**Mean**	**Yr_1**	**Yr_2**	**Mean**
IET-10899	CF	119.6	124.7	122.1	514.4	536.4	525.4	492.2	513.2	502.7	2.59	2.70	2.64	5.03	5.24	5.14
	FC	110.0	116.6	113.3	401.1	424.7	412.9	341.1	361.6	351.3	1.88	1.99	1.93	5.40	5.72	5.56
IET- 8682	CF	104.0	109.3	106.6	396.7	417.7	407.2	365.6	384.6	375.1	3.23	3.40	3.31	5.03	5.29	5.16
	FC	98.8	104.0	101.4	361.1	380.2	370.6	333.3	351.3	342.3	1.43	1.50	1.46	4.73	4.98	4.86
CN-907-6-2	CF	89.2	92.8	91.0	472.2	491.3	481.7	406.7	423.1	414.9	2.38	2.48	2.43	5.90	6.14	6.02
	FC	84.0	89.5	86.8	400.0	425.9	412.9	357.8	381.0	369.4	1.80	1.92	1.86	6.50	6.92	6.71
UPLRi-7	CF	89.0	94.3	91.6	402.2	426.2	414.2	363.3	385.1	374.2	4.39	4.65	4.52	4.50	4.77	4.64
	FC	92.3	96.9	94.6	300.0	314.9	307.4	262.2	275.1	268.6	1.58	1.66	1.62	5.90	6.19	6.05
IET – 4786	CF	78.6	82.7	80.6	468.9	493.6	481.2	437.8	460.6	449.2	3.43	3.61	3.52	4.33	4.56	4.45
	FC	70.2	73.4	71.8	438.9	459.0	448.9	424.4	443.8	434.1	2.67	2.79	2.73	4.10	4.29	4.20
Khitish	CF	83.0	87.0	85.0	560.0	586.9	573.4	536.7	562.4	549.5	3.85	4.04	3.94	5.17	5.42	5.30
	FC	77.1	81.8	79.4	417.8	443.7	430.7	362.2	384.8	373.5	2.17	2.30	2.23	5.35	5.68	5.52
IR-36	CF	70.6	73.4	72.0	460.0	478.2	469.1	436.7	453.9	445.3	3.77	3.92	3.845	5.67	5.89	5.78
	FC	69.1	72.7	70.9	456.7	480.6	468.6	430.0	452.5	441.2	3.08	3.24	3.16	4.63	4.75	4.69
SEm (±)		**1.03**	**1.04**	**0.84**	**0.34**	**0.33**	**8.13**	**0.37**	**0.33**	**9.93**	**0.07**	**0.07**	**0.05**	**0.10**	**0.11**	**0.07**
LSD (p=0.05)		**3.00**	**3.04**	**2.39**	**0.97**	**0.96**	**23.04**	**1.07**	**0.96**	**28.15**	**0.21**	**0.19**	**0.14**	**0.30**	**0.31**	**0.20**

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