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Yield attributing physio-morphological trait response in rice (*Oryza sativa*) genotypes grown under aerobic situation in eastern Indo-Gangetic plain

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ABSTRACT

A field experiment was carried out during wet season 2010-2012 with an objective to evaluate the effect of aerobic situation on yield attributes and physio-morphological trait performance of advanced breeding lines and popular high yielding rice (*Oryza sativa* L.) varieties of eastern India including aerobic check MAS 946. Significant yield decline was observed almost in all the rice genotypes grown under aerobic situation as compared to normal transplanted condition. The range of yield decline was 1.43 to 3.27 tonnes/ha under aerobic situation compared to normal irrigated condition. Rice genotypes capable of maintaining high early vegetative vigour, plant biomass, RWC, chlorophyll content and photosynthetic rate leads to produce higher grain yield under aerobic situation. The existence of genetic variation (PCV and GCV) revealed significant differences among genotypes for different morpho-physiological traits. Higher values of heritability and genetic advance were observed for plant height and DFF whereas low heritability for grain yield, plant biomass and test weight. Promising rice genotypes for aerobic situation, IR77298-14-1-2-130-2, IR84899-B-182-3-1-1-2, IR84887-B-157-38-1-1-3,IR84887-B-156-17-1-1, IR 84899-B-179-1-1-1-2 and IR 83927-B-B-278-5-1-1-1showed high yield advantage (40.29%) over susceptible genotypes due to better performance of physio-morphological traits. Hence these promising genotypes may be adopted in rainfed lowland ecosystem as well as under limited water availability areas. Moreover, these promising genotypes can also be utilised as donor parents in future aerobic rice breeding programme.

Key words: Aerobic Rice, Grain yield, Irrigated rice, Physiological traits, Water deficit

Rice (*Oryza sativa* L.) is cultivated under diverse ecologies ranging from irrigated to rainfed and upland to lowland to deep water system. Irrigated rice accounts for 55% world area and about 75% of total rice production. Rainfed rice accounts for around 45% of the world's rice area (IRRI 2002). Around 40 million ha of rainfed area is concentrated in South and Southeast Asia alone (Maclean *et al*. 2002). Rainfed rice-growing areas are highly prone to water scare condition. Almost 28% of world's rice is grown under rainfed lowland (Khush 1997) and frequently affected by un-even rainfall distribution pattern. Another 13% of the rice area is under upland cultivation, which is always subjected to water stress during the growing season. Scarcity of freshwater resource has threatened the production of the flood-irrigated rice crop (IWMI 2000). By 2025, 15 out of 75 million hectare of Asia's flood-irrigated rice crop will experience water shortage. Being an extravagant consumer of water, rice uses around 5000 litres of fresh water to produce 1 kg of rice (Bouman 2009). The increasing depletion of fresh water resources is a major threat to the traditional way of rice cultivation (Gleick 1993). It has been estimated that 22 million hectare of irrigated dry season rice in South and Southeast Asia was experiencing economic water scarcity and 2 million hectare of Asia's irrigated dry season rice and 13 million hectare of its wet season rice would suffer from physical water scarcity by 2025 (Tuong and Bouman 2002).

Under present climate scenario, water scarcity that we are facing today is the greatest threat to rice cultivation. Because of increasing water scarcity, there is a need to develop alternative system that requires less water for rice crop production. Several technologies were developed to reduce water loss and increase the water productivity. However, the fields are still kept irrigated for some periods in most of systems, so water losses remain high. Aerobic rice, a new way of growing rice: it is high yielding rice grown in non-puddled, non-irrigated aerobic soils under irrigation and high external inputs (Bouman *et al.* 2002). It is efficient water saving rice technology for water short

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irrigated rice area. Aerobic rice promises substantial water savings by minimizing seepage and percolation and greatly reducing evaporation. The basis of yield variation and performance of genotypes are yet to be understood. Further, physiological basis of yield gap between aerobic and irrigated rice was not studied extensively. There are reports that compared photosynthetic rate among individual leaves of rice and some clear differences have been observed among varieties, among species and among progenies derived from crosses between species (Hirasawa *et al*. 2010). However, it is significantly affected by stomatal conductance and Rubisco content present in the leaf (Hirasawa *et al*. 2010). Currently in India, particularly in eastern region, aerobic rice cultivation practice is in initial phases. There is also need to establish reason of physiological basis for yield gap among genotypes under aerobic and irrigated situation. In this context, a field experiment was conducted for three consecutive wet seasons 2010-2012 to examine the yield and yield attributes response of seventy two rice genotypes under water scarcity (aerobic) situation and to identify promising genotypes for this condition and morpho-physiological basis for yield gap between aerobic and irrigated condition.

MATERIALS AND METHODS

A field experiment was carried out at the experimental farm of the ICAR Research Complex for Eastern Region, Patna, India (latitude 25.30ºN, longitude 85.15ºE) during three consecutive wet seasons 2010-2012. The experimental site was typical rainfed having clay loam soil with pH 7.5, organic carbon 0.67%, bulk density 1.47 g/cm^3, electrical conductivity 0.26 dS/m, available nitrogen 227 kg/ha, available phosphorous 28.4 kg/ha, and exchangeable potassium 218 kg/ha. The total rainfall was 568 mm, 624mm, and 502 mm during crop growth periods in 2010, 2011 and 2012, respectively. Seventy two rice genotypes comprised of advanced breeding lines, popular high yielding cultivars rainfed lowland ecosystem and check varieties (IR 64, Rajendra Bhagwati and MAS 946) of the eastern region were evaluated under both aerobic and normal transplanted irrigated irrigated condition following alpha lattice design. The rice genotypes used under study were collected from International Rice Research Institute (IRRI), Philippines and Central Rice Research Institute (CRRI), Cuttack.

In aerobic field, surface irrigation was given once in a week at vegetative stage and 2-3 days interval at reproductive stage. During vegetative growth period, irrigation was applied at soil moisture tension of -30 KPa at 15cm soil depth while at reproductive phase the threshold for irrigation was reduced to -10 kPa to prevent spikelet sterility. In control (irrigated) field, twenty one days old, 2-3 seedling per hill were transplanted at a spacing of 20 cm×15 cm and at least 5 cm standing water is maintained till 25 days before harvesting. Both aerobic and control field were fertilized at the rate of 100-60-40 kg N, P, K/ha, respectively. Nitrogen was applied in three equal splits (as basal, at maximum tillering and at panicle initiation stage), while total dose of P_2O_5 and K_2O were applied as basal. The observations on yield and yield attributes such as early vegetative vigour (EVV), total plant biomass, effective tillers/m^2, panicle length, test weight, harvest index, spikelet/panicle, percent spikelet sterility and fertility under both the situation (control and aerobic) were recorded. EVV was recorded by using 1-9 scale developed by IRRI (1996).

Ten promising genotypes along with three check varieties were selected out of seventy two genotypes on the basis of yield and yield attributes for further physiological studies; Relative water content (RWC), chlorophyll content, stomatal conductance and photosynthesis rate were recorded by using following formulae and techniques.

Relative water content (RWC) was estimated by (Weatherly 1950) method.

Relative water content (%) = [(Fresh weight- Oven dry weight) × 100/(Turgid weight- Oven dry weight)]

Chlorophyll content was estimated by extracting 0.05 g of leaf material in 10 ml dimethylsulfoxide (DMSO) (Hiscox and Israelstam 1979).Total chlorophyll = $(20.2 \times OD_{645} + 8.02 \times OD_{663}) \times V/1000 \times w$. Chlorophyll content was expressed as mg/gfreshweight. Photosynthesis rate and stomatal conductance were measured using portable Infrared Gas Analyzer (IRGA LI-6400 Model). The rate of photosynthesis was measured by operating the IRGA in the closed mode. The net photosynthetic rate was expressed as µmol/m^2/s. The stomatal conductance was expressed as cm/s.

Agro-morphological data were analyzed by following Gomez and Gomez (1984) using CropStat 7.2 (IRRI 2009) programme. The genetic parameters, genotypic and phenotypic coefficient of variation, heritability and genetic advance were computed following the Singh and Chaudhury (1985) procedure. Physiological data was analyzed using OPSTAT software of Hisar Agricultural University, Hisar.

RESULTS AND DISCUSSION

Genetic parameters

Genetic variability in any crop is the pre-requisite for selection of superior genotypes over the best existing cultivar. In the present study, the genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were computed separately for the irrigated condition (IC) and aerobic condition (AC) (Table 1). Yield and yield contributing traits showed low genotypic coefficient of variation (GCV) than phenotypic coefficient of variation (PCV), which indicated the influence of environment on these traits. Under irrigated (control), the minimum difference between PCV and GCV values were observed for almost all the characters under study. This was also supported by higher values of heritability and genetic advance, while in aerobic conditions; coefficients of variation (PVC and GCV) have more difference in comparison to control condition, which is supported by moderate to high heritability for all the characters. Girish *et al*. (2006) also reported that that the PCV was higher than GCV and indicated the influence of

Table 1 Variability parameters of different morphological traits under irrigated condition (IC) and aerobic condition (AC)

Character	Environments	LSD	CV	Coefficient of variation		Heritability	Genetic advance
				GCV (%)	PCV (%)	(h^2b)	(as % of mean)
Days to 50 per cent flowering (days)	IC	3.36	1.94	4.97	5.25	93.18	23.24
Plant Height (cm)	AC	2.52	1.85	6.32	9.93	84.35	19.75
	IC	6.53	4.11	13.72	14.34	89.17	42.57
Tiller number/m^2	AC	4.95	3.68	13.86	18.77	77.41	33.49
	IC	25.63	5.64	16.51	18.38	77.63	26.89
Panicle length (cm)	AC	16.91	8.33	12.42	21.15	55.44	21.47
	IC	1.69	6.21	6.33	8.24	83.31	25.94
Plant biomass (g)	AC	1.24	7.23	11.81	17.19	60.39	22.64
	IC	0.74	7.29	7.07	12.26	78.46	15.44
Sterility (%)	AC	0.53	5.88	6.11	21.43	31.53	4.29
	IC	1.48	6.14	11.57	13.29	74.62	28.49
Test weight (g)	AC	2.06	8.79	15.82	24.45	33.57	13.16
	IC	1.59	5.48	8.76	12.25	83.59	19.28
Harvest index	AC	1.37	6.71	10.36	19.77	44.75	11.72
	IC	0.04	6.76	9.84	15.19	74.29	27.98
Spikelets/panicle	AC	0.03	5.49	12.78	22.96	43.22	14.57
	IC	7.45	6.59	13.92	16.81	76.88	28.26
Grain yield (tonnes/ha)	AC	6.94	8.27	11.25	21.57	52.91	15.34
	IC	0.45	6.37	19.51	26.63	57.61	34.41
Straw yield (tonnes/ha)	AC	0.27	11.96	27.84	39.61	29.83	18.77
	IC	0.52	8.72	17.95	24.06	48.94	27.56
	AC	0.44	9.34	23.91	36.57	32.35	11.49

AC (Aerobic condition), IC (Irrigated condition), DFF (Days to fifty percent flowering), Plant height (PH) and Harvest Index (HI)

environment on these characters. In aerobic condition, the GCV estimate ranged from 4.97% to 27.84%. Higher values of GCV and PCV were observed for grain yield (27.84, 39.61) while lowest for DFF (4.97, 5.25) and plant biomass (7.07, 12.26) under aerobic condition.

Under aerobic condition, the heritability estimate ranged from 29.83% for grain yield to 84.35% for DFF, whereas genetic advance varied from 4.29% for plant biomass to 33.47% for plant height. High values of heritability and genetic advance under aerobic management were observed for plant height and days to 50% flowering. Similar findings were reported for plant height by Girish *et al.* (2006), and Murthy *et al.* (2011). Moderate heritability and genetic advance were observed for effective tiller number/m^2, panicle length and spikelets/panicle. However, low heritability and genetic advance values were observed for grain yield, straw yield, test weight, plant biomass and percentage spikelet sterility indicating high environmental influence for these characters. Murthy *et al.* (2011) also reported the similar finding for these characters.

Performance of yield and yield attributes

Observations on yield and yield contributing traits were recorded under both aerobic and irrigated situation. Aerobic rice produced significantly lower grain yield and total plant biomass than irrigated rice during all the three years of experimentation. The mean and range of grain yield was 2.19 tonnes/ha, 0.96-3.92 tonnes/ha, 4.21 tonnes/ha and 2.96-6.07 tonnes/ha observed under aerobic and irrigated condition, respectively. Similarly, the mean and range of sterility percentage was 11.6, 6.29-23.55, 29.7 and 13.81-61.82% observed under irrigated and aerobic condition, respectively. In general, in most of the genotype during all three years a slight but insignificant delay in days of fifty percent flowering was observed under aerobic condition as compared to control (irrigated); however, the responses varied among genotypes. Significant decrease in plant height was also observed in rice genotypes grown under aerobic situation than irrigated condition (Table 2).

The result revealed that yield gap between aerobic and irrigated rice was more during third year wet crop season 2012 (Table 2).The yield difference between aerobic and irrigated rice ranged 19 to 78%. The yield difference between aerobic and irrigated rice were 19 to 57%, 26 to 64% and 23 to 78% in year 2010, 2011 and 2012, respectively. Out of seventy two rice genotypes evaluated, ten were identified as promising genotypes which performed better than checks and existing high yielding varieties of eastern region. Higher grain yields of 3.92 tonnes/ha was observed in IR77298-14-1-2-130-2 followed by 3.69/tha in IR84899-B-182-3-1-1-2 and 3.53 tonnes/ha inIR84887-B-157-38-1-1-3. Ventura and Watanabe (1978) reported 30-60% yield reduction in the second season under continuous upland rice cropping for variety IR2061- 464-2-4 and similar results were also

Table 2 Yield and yield attributes response of top ten promising rice genotypes and check varieties to aerobic and irrigated condition

Promising genotypes	DFF		pH (cm)		Grain yield in (tonnes//ha)		Number of effective tillers/m2		Spikelets/ panicle		HI	
	AC	IC	AC	IC	AC	IC	AC	IC	AC	IC	AC	IC
IR77298-14-1-2-130-2	88	85	116	124	3.92	5.68	351	469	194	216	0.42	0.48
IR84899-B-182-3-1-1-2	84	89	119	126	3.69	5.97	364	478	176	203	0.41	0.51
IR84887-B-157-38-1-1-3	85	84	109	114	3.53	5.16	338	433	191	224	0.41	0.46
IR84887-B-156-17-1-1	84	88	121	126	3.47	5.38	329	408	177	194	0.42	0.48
IR 84899-B-179-1-1-1-2	86	82	117	126	3.41	4.91	335	421	182	211	0.43	0.45
IR 83927-B-B-278-5-1-1-1	98	95	115	132	3.34	5.19	358	442	175	197	0.39	0.45
IR 84887-B-158-7-1-1-4	89	93	113	124	3.27	4.83	327	415	192	231	0.39	0.43
IR 84882-B-B-123-46-1-1	95	103	125	128	3.20	5.45	336	452	170	202	0.41	0.47
IR 84895-B-125-12-1-1	87	85	120	127	3.19	4.62	321	434	183	214	0.40	0.42
IR 84894-B-140-16-1-1-1	84	85	117	125	3.05	5.23	345	441	179	195	0.41	0.44
Rajendra Bhagwati (check)	89	85	108	119	1.97	4.68	267	424	148	209	0.34	0.45
MAS 946 (check)	92	90	103	111	2.32	4.53	289	437	156	197	0.36	0.44
IR 64 (check)	86	83	113	116	1.81	4.81	253	429	145	211	0.32	0.46
Mean	88.7	85.9	105.4	117.2	2.19	4.21	248	369	166	207	0.31	0.43
CV (%)	1.85	1.94	3.68	4.11	11.96	6.38	8.33	5.64	8.27	6.59	5.49	6.76
LSD (5%)	2.52	3.36	4.95	6.53	0.27	0.45	16.91	25.63	6.94	7.45	0.03	0.04

reported by George *et al.* (2002) under mono-cropping of aerobic rice in the Philippines. Significant difference of spikelet/panicle was observed between aerobic and irrigated condition. Spikelet number per panicle and effective tillers were more in irrigated rice than in aerobic rice in all three crop season and consequently higher harvest index was recorded in irrigated transplanted rice compared to aerobic rice. Similar trend was observed by Peng *et al.* (2006).

All the promising genotypes in the present study have shown high early vegetative vigour (EVV) whereas, check varieties have average to low vegetative vigour under aerobic situation (Table 3). EVV is an important trait because it enables crop plant to compete with weed and also ensure that the crop achieves its critical leaf area at flowering. The yield gap between aerobic and irrigated rice was attributed more to difference in e number of effective tiller per m^2, plant biomass and harvest index (Table 4). Aerobic rice had lower test weight (1000 grain weight) and grain filling percentage than irrigated rice. Irrigated rice showed more consistent 1000 grain weight in all three seasons than aerobic rice.

Physiological traits

Physiological traits, viz. Relative water content (RWC), chlorophyll content, photosynthetic rate, and stomatal conductance influenced under aerobic situation to a larger extent.

The capacity to maintain higher relative water content (RWC) under moisture stress condition has been suggested as a possible water scarcity tolerance mechanism in rice (O'Toole and Garrity 1984). A significant difference in RWC was observed among genotypes between aerobic and irrigated conditions. In aerobic condition, higher value of RWC was recorded in water deficit stress tolerant rice genotypes as compared to sensitive one at reproductive stage. Highest value of RWC was observed in IR84887-B-157-38-1-1-3 (72.2%) followed by IR77298-14-1-2-130-2 (71.4%) and IR84889-B-179-1-1-1-2 (69.1%) (Fig 1). Study revealed that relative water content of all genotypes reduced significantly under aerobic (water scarcity) situation as compared to normal irrigated condition. Reena *et al*. (2011) and Jongdee *et al*. (1998) also reported the similar findings.

Chlorophyll content of all the best performing genotypes as well as check varieties (IR 64, Rajendra Bhagwati and MAS 946) was higher under normal (irrigated) situation. Genotypes IR77298-14-1-2-130-2 and IR84887-B-156-17-1-1 have much higher chlorophyll content in comparison to other genotypes and check varieties under aerobic situation (Fig 1). Higher genotypic differences in chlorophyll content were observed under aerobic situation. Madhan Mohan *et al*. (2000) stated that the chlorophyll content is an indication of stress tolerance capacity of plants and its high value means that the stress did not have much effect on chlorophyll content of tolerant plants. Gowri (2005) observed decrease in chlorophyll content under aerobic situation than irrigated environment.

Out of better yield performing genotypes under aerobic situation, IR77298-14-1-2-130-2, IR84887-B-156-17-1-1 and IR84887-B-157-38-1-1-3 showed higher photosynthetic rate and stomatal conductance in comparison to other high yielding genotypes as well as check varieties whereas, all the genotypes showed higher photosynthetic rate and stomatal conductance under control (Fig 1). The increase in leaf photosynthetic rate is important to increase the yield potential of rice (Hirasawa *et al*. 2010) because the photosynthetic rate of individual leaves which form the canopy, affect dry

Table 3 Plant biomass, panicle length, test weight, grain sterility percentage and early vegetative vigour of top ten promising rice genotypes and check varieties to aerobic and irrigated (control) condition

Promising genotypes	Plant biomass (g/plant)		Panicle length (cm)		Test weight (g)		Sterility (%)		EVV (1-9 scale)	
	AC	IC	AC	IC	AC	IC	AC	IC	AC	IC
IR77298-14-1-2-130-2	20.7	28.4	27.2	27.9	25.6	26.6	14.5	7.8	1	1
IR84899-B-182-3-1-1-2	18.3	26.9	26.5	27.1	25.3	27.2	16.9	11.5	1	1
IR84887-B-157-38-1-1-3	19.8	27.8	25.9	26.6	24.5	26.1	13.8	14.2	1	1
IR84887-B-156-17-1-1	21.8	26.4	24.7	25.8	25.9	26.9	16.5	9.4	3	1
IR 84899-B-179-1-1-1-2	22.5	30.7	25.2	25.8	24.8	25.6	22.4	10.7	1	1
IR 83927-B-B-278-5-1-1-1	17.9	25.6	24.8	25.4	23.7	24.3	16.7	7.3	3	3
IR 84887-B-158-7-1-1-4	19.2	26.9	24.6	25.3	24.5	25.1	19.5	11.2	1	1
IR 84882-B-B-123-46-1-1	20.7	29.3	25.7	25.9	23.8	24.9	25.1	8.3	1	3
IR 84895-B-125-12-1-1	16.8	24.8	24.2	24.7	23.6	24.7	24.6	12.5	3	1
IR 84894-B-140-16-1-1-1	18.7	27.5	26.4	27.2	24.3	25.1	22.4	13.7	3	1
Rajendra Bhagwati	15.3	26.1	23.8	22.8	17.8	23.7	36.9	15.1	5	3
MAS 946 (check)	16.7	25.3	24.1	24.7	19.2	24.8	33.7	12.5	5	1
IR 64 (check)	13.6	26.9	24.5	24.9	16.3	25.2	41.8	12.8	7	1
Mean	15.7	23.4	24.5	25.7	22.6	24.2	29.7	11.6	4.39	1.24
CV (%)	5.88	7.29	7.23	6.21	6.71	5.48	8.79	6.14	-	-
LSD (5%)	0.53	0.74	1.24	1.69	1.37	1.59	2.06	1.48	-	-

AC (Aerobic condition), IC (Irrigated condition) and Early Vegetative Vigour (EVV)

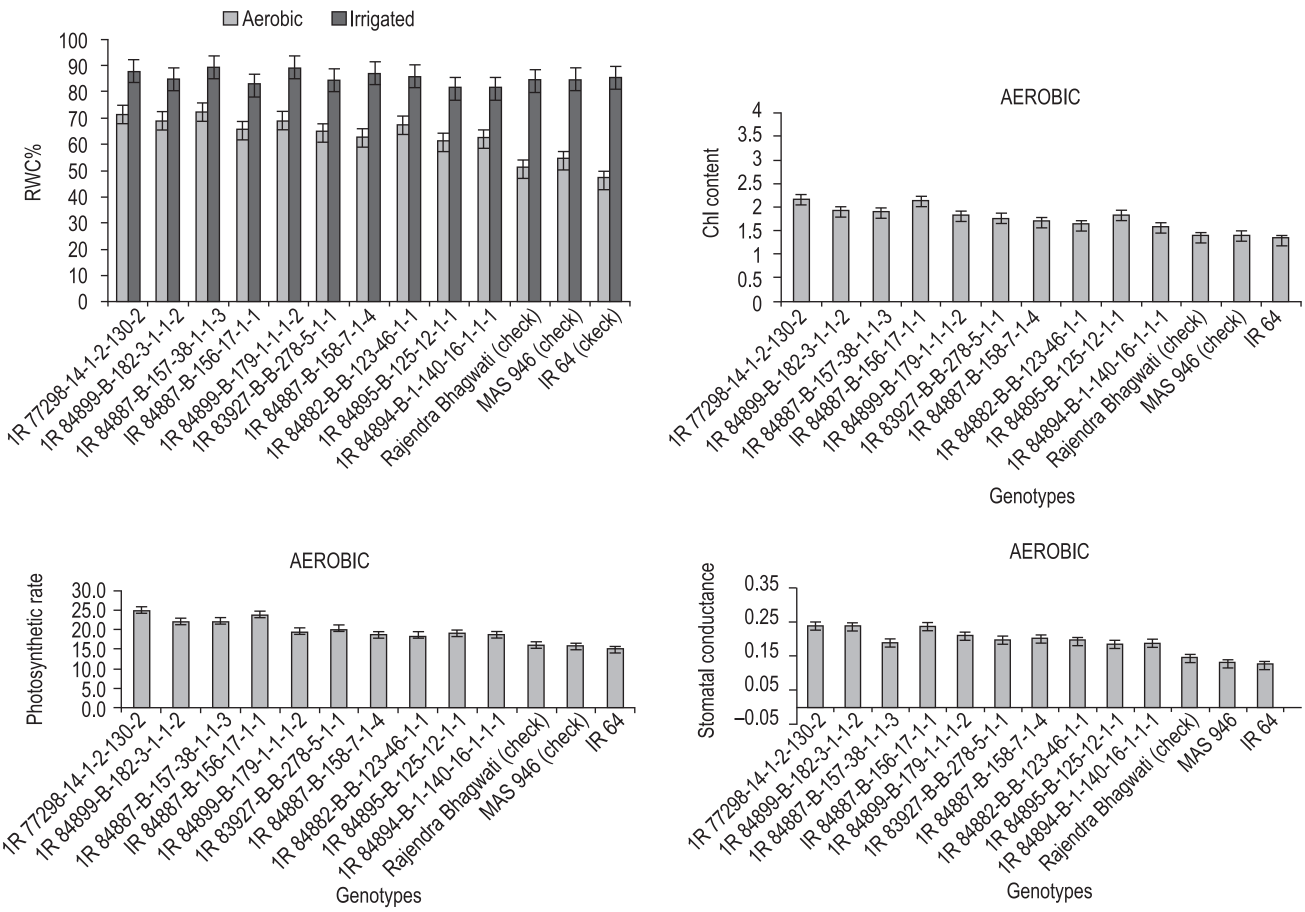

Fig 1 RWC (%), chlorophyll content (mg/g fw), photosynthetic rate and stomatal conductance (cm/S) in best performing rice genotypes as well as in three check varieties (Rajendra Bhagwati, MAS 946 and IR 64)) under aerobic condition

Table 4 Yield and yield components of rice genotypes grown under aerobic and irrigated condition

Year	Treatment	Plant biomass (g/plant)	Harvest index (%)	Tillers/ m^2	1000 grain wt. (g)	Spikelet/ panicle	Sterility (%)	Grain filling (%)	Yield (tonnes/ ha)	Panicle length (cm)	Leaf area index (LAI)
2010	Aerobic	15.9	0.33	261	22.2	181	28.1	71.9	2.62	24.1	2.29
	Irrigated	22.4	0.41	353	23.4	208	15.5	84.5	4.28	26.4	3.68
	Difference (%)	29	19	26	5	13.0	44.8	14.9	39	9	37
2011	Aerobic	16.7	0.31	243	23.1	163	29.4	70.6	2.07	24.7	2.46
	Irrigated	24.8	0.43	384	24.8	217	17.8	82.2	4.22	25.1	3.44
	Difference (%)	33	28	36	7	24.9	39.5	14.1	51	2	30
2012	Aerobic	14.4	0.29	222	21.6	154	31.5	68.5	1.89	24.6	2.18
	Irrigated	22.9	0.42	368	24.5	198	13.6	86.4	4.15	25.5	3.39
	Difference (%)	37	31	39	12	22.2	56.8	20.7	55	4	35
	Overall difference (%)	33.0	26.2	34.3	7.9	20.1	47.3	16.6	47.9	4.7	34.1

matter production via photosynthesis within the canopy.

On the basis of present finding it can be conduced that existence of phenotypic and genotypic variations among the genotype for grain yield and yield contributing physiological traits had showed differential reaction in their relative adaptation to aerobic environment. Study also revealed that plant biomass, harvest index, test weight and effective tiller number exhibited significant and positive direct effects on grain yield under aerobic condition. Yield improvements under aerobic situation can be achieved by identifying physiological traits contributing for water scarce tolerance and yield advantage against water stress. Selection of good aerobic rice genotypes with desired physiological traits gives better survival under targeted water shortage environments. Rice genotypes IR77298-14-1-2-130-2, IR84899-B-182-3-1-1-2, IR84887-B-157-38-1-1-3, IR 84899-B-179-1-1-1-2, IR84887-B-156-17-1-1 and IR 83927-B-B-278-5-1-1-1 having better physiological attributes showed significant yield advantage over checks under aerobic management, may be adopted in large area of rainfed ecosystem as well as those irrigated area where water is too scarce. Moreover, these promising genotypes can also be directly utilised as donor parents in future aerobic rice breeding programme.

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