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Research Paper

Response of rice (*Oryza sativa*) varieties to nitrogen under aerobic and flooded conditions

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ABSTRACT

A field experiment was conducted on a sandy clay loam soil of Central Telangana Zone of Andhra Pradesh during rainy seasons of 2008 and 2009 to compare the performance of popular rice (*Oryza sativa* L.) varieties, viz. 'MTU 1001', 'WGL 32100', 'WGL 14 'and 'WGL 3825' (check) under aerobic and flooded methods of water management and their response to levels of nitrogen viz. 120. 180 and 240 kg/ha. Cultivation of rice with aerobic method (3.49 t/ha) resulted in 29% yield reduction compared with flooded method (4.93 t/ha). Among the yield attributes, filled spikelets/panicle were significantly affected under aerobic method, while panicles/m^2, test weight and harvest index were not influenced by the method of water management. 'WGL 32100' gave highest grain yield under aerobic (3.94 t/ha) with the least yield reduction (17%) compared to flooded method, while yield gap was high (40%) in 'MTU 1001'. The water-use efficiency was highest with 'WGL 32100' and aerobic method (3.4 kg/ha-mm), while flooded method showed more nitrogen-use efficiency (33.5 kg grain/kg nitrogen), and nitrogen uptake (76 kg/ha). Higher net returns (₹26,300/ha) and benefit: cost ratio (1.11) were realized with flood irrigated method. Application of 240 kg N/ha resulted in better yield attributes, increased yield (4.50 t/ha), N uptake (72 kg/ha), water-use efficiency (3.0 kg/ha-mm), net returns (₹23,062/ha) and benefit: cost ratio (1.21), whereas, the nitrogen-use efficiency was superior with 120 kg N/ha (32.5 kg grain/kg nitrogen) both under aerobic and flood irrigated conditions.

Key words **:** Aerobic rice, Crop production, Flooded rice, Net-returns, Nitrogen-use efficiency, Water-use efficiency

Scarcity of freshwater resources in the world's leading rice-producing countries, such as, China and India is limiting the production of the flooded rice crop. Since more rice needs to be produced with less and less water to feed the ever-growing population, it needs judicious water management practices and suitable water-saving technologies in rice cultivation (Tuong and Bouman, 2003; Belder *et al*., 2005). Several such technologies like saturated soil culture, alternate wetting and drying, system of rice intensification, direct seeding and aerobic rice have been developed in recent years. These approaches are receiving increasing attention because they increase the water-use efficiency, mainly by reducing unproductive seepage and percolation losses and evaporation (Belder *et al*., 2005; Bouman *et al*., 2005). The International Rice Research Institute (IRRI) developed aerobic rice technology, wherein the crop is established in non-puddled, non-flooded fields and rice is grown like an upland crop (unsaturated condition) with adequate inputs and supplementary irrigation when rainfall is insufficient (Bouman 2001; Prasad, 2011). It is an emerging cultivation system that aims at maximizing crop productivity with substantial water savings by minimizing seepage and percolation and greatly reducing evaporation but with severe yield penalty in high-yielding lowland rice varieties (Peng *et al*., 2006). Yield penalty and yield stability of aerobic rice have to be considered before promoting this water-saving technology in the tropics. The rice varieties suitable for aerobic system must possess the combined drought resistance and high-yielding characters (Prasad, 2011). Research is under way to develop special aerobic and nutrient-responsive varieties across the rice growing countries.

In flooded rice with saturated anaerobic soils, ammonium is the dominant form of available N. In aerobic systems, on the other hand, the dominant form of N is nitrate. The application of irrigation water will create soil moisture conditions close to saturation immediately following irri-

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gation and below field capacity a few days later. These alternate moist-dry soil conditions may stimulate nitrification-denitrification process, resulting in a loss of nitrogen through N_2 and N_2O (Prasad, 2005). The differences in soil N dynamics and pathway of N losses between flooded and aerobic systems may result in different fertilizer-N recoveries. With even high nitrogen applications in aerobic rice, grain filling may be limited by a low contribution of post-anthesis assimilates (Zhang *et al*., 2009). Of late, many studies indicated the response of high-yielding rice varieties to nitrogen above the recommended dose under flooded condition as well (Saoji *et al*., 2008; Ganga and Sumathi, 2011; Rao *et al*., 2011). Keeping this in view, an attempt was made to evaluate the performance of high-yielding, low-land rice varieties under aerobic and flooded conditions at different nitrogen levels.

MATERIALS AND METHODS

A field experiment was conducted during the rainy season of 2008 and 2009 at Regional Agricultural Research Station, Warangal (18^{o}00'53.2" N, 079^{o}36'17.2" E and 275 m above mean sea-level), Andhra Pradesh, India. Climate of the study site is sub-tropical and semi-arid type with mean annual rainfall of 885 mm and a mean annual evaporation of 1,621 mm. Soil of the experimental field was sandy clay loam with pH of 8.0, Electrical conductivity (EC) 0.3 ds/m, low in organic C (0.43%), available N (223 kg/ha), medium in available P (10.4 kg/ha) and K (164 kg/ha). A range of mean minimum temperatures of 22–26^{o}C and 21–27^{o}C and mean maximum temperature of 29–32^{o}C and 29.6–38.0^{o}C were recorded during 2008 and 2009 respectively. A total rainfall of 739 and 392 mm was received during the crop period of the respective years of experimentation. Treatments consisting of 2 water management practices (aerobic and flooded) in main plots and the combinations of 4 varieties ['MTU 1001', 'WGL 32100', 'WGL 14' and 'WGL 3825' (check)] and 3 nitrogen doses [120 (Recommended dose to flooded rice), 180 and 240 kg/ha] in subplots were tested in a split-plot design and replicated thrice. Under aerobic method, the plots were dry-ploughed and harrowed but not puddled during land preparation. Seeds were sown at a spacing 22.5 cm × soil rows in favourable soil moisture condition for germination. Thinning and gap filling was done at 15 days after sowing. Flash irrigations of 5 cm depth were given starting from 10 days after sowing, when the soil moisture tension at 15 cm depth reached –30 kPa. Around flowering, the threshold for irrigation was reduced to –10 kPa to prevent spikelet sterility. Weeds were controlled by pre-emergence application of pendimethalin @ 0.75 kg a.i./ha followed by pyrazosulfuron ethyl @ 30 g a.i./ha at 30 DAS and hand-weeding at 40 days after sowing.

In the flooded field, land preparation consisted of wet tillage and puddling in standing water. Thirty-day old seedlings from raised bed nurseries sown on the same date of aerobic rice, were transplanted with two seedlings/hill at a spacing of 20 cm × 15 cm. The field had always standing water from transplanting until about 1 week before physiological maturity, with water depth of 2 cm at transplanting to 5 cm at panicle-initiation stage. Sufficient care was taken to avoid seepage from the flooded to aerobic plots by providing strengthened bunds, drainage channel and buffer area between the 2 plots. Irrigation outlets were fitted with 15 cm (6-inches) PVC pipes that served as delivery channel of water for flooded and aerobic fields. Weeds could be controlled by the application of pre-emergence application of oxadiargyl @ 100 g/ha followed by bispyribac sodium @ 200 ml/ha at 25 days after transplanting and hand-weeding at 40 days after transplanting in flooded plots. A recommended dose of 60 kg P_2O_5 and 50 kg K_2O/ha was applied uniformly to all the plots as basal in the form of single superphosphate and muriate of potash respectively. Aerobic plots were sprayed with 0.5% ferrous sulfate solution (250 l/ha) at 20 and 40 days after sowing. Fertilizer N as per the treatments in the form of urea was applied in 3 splits (½ as basal, ¼ at maximum tillering stage and ¼ at panicle initiation stage). All the other recommended cultural practices for achieving maximum grain yield were followed.

Data on yield attributes, grain yield, straw yield and N uptake were recorded at crop maturity. Standard procedures were used for chemical analysis of soil and plant samples. The economic parameters (gross returns, net returns and benefit: cost ratio) were worked out on the basis of prevailing market prices of inputs and outputs. Water-use efficiency (WUE) was calculated as grain yield per total water received from rainfall and irrigation and expressed as: WUE = Y/R+I (kg/ha-mm). Nitrogen-use efficiency (NUE) (kg grain/kg applied N) was calculated using the equation: NUE = Y/N; where Y is the grain yield (kg/ha); R is the amount of effective rainfall(mm); I is the amount of irrigation water applied (mm) and N is the quantity of N applied (kg). The data were analyzed by using the 'Analysis of Variance Technique' as per the procedures described by Panse and Sukhatme (1985). The treatment means were compared at 5% level of significance.

RESULTS AND DISCUSSION

Yield attributes and yield

Water management had significant influence on the yield attributes and yield of rice (Table 1). Under aerobic conditions, the filled spikelets/panicle were significantly reduced by 23% from flooded method of cultivation.

Flooded rice though produced more panicles than aerobic rice, the difference remained statistically non-significant. Ill filled spikelets/panicle were also significantly higher with flood method only. The test weight (1,000-grain weight) was slightly higher with aerobic method, though it was statistically at par with flooded condition. The grain yield obtained with aerobic method was 29% lower than that recorded with flooded condition. Similarly, straw yield was also reduced by 21% under aerobic compared to flooded method. However, harvest index was unaffected by the method of water management. It indicates that, under aerobic condition, it is the total dry matter (TDM) production that is reduced but not the partitioning efficiency. Yield gap between aerobic and flooded rice was also attributed primarily to the difference in sink formation (spikelet/panicle), TDM accumulation and partly to difference in panicles/m^2 and 1,000-grain weight. These observations are in close agreement with Patel *et al*. (2010) who reported that flood irrigation had significantly higher values of yield attributes and yield compared to aerobic treatment except panicle number/m^2, ripening ratio, 1,000-grain weight and harvest index, which were least influenced by water management practices. George *et al*. (2002); Belder *et al*. (2005); Peng *et al*. (2006); Xie *et al*. (2008) and Jagtap *et al*. (2012) also reported similar findings.

Kato and Okami (2010) found that the two morphological components of the rice system, i.e., adventitious root emergence and lateral root proliferation, were down-regulated under aerobic culture conditions, resulting in a significant decrease in total root length in this method. When soil-leaf hydraulic conductance became lower in rice plants grown in aerobic than in those grown in flooded culture due to considerably reduced rooting size, it had negative impact on leaf water potential (ψ_{leaf}) even under nearly saturated conditions. The reduction in ψ_{leaf} often leads to significant yield loss through the detrimental effect on canopy expansion and/or reproductive growth. Pal *et al*. (2008); Grassi *et al*. (2009) and Kreye *et al*. (2009) found that other than reduced water and N availability, nematodes and micronutrient imbalances as casual factors for yield decline in aerobic systems.

'MTU 1001' rice produced most panicles/m^2 followed by 'WGL 32100', whereas least panicles were noticed in 'WGL 3825'. On the other hand, number of filled spikelets/panicle was higher in 'WGL 32100', which was superior to 'MTU 1001' and 'WGL 3825' but on a par with 'WGL 14'. The ill-filled spikelets/panicle were significantly higher with 'WGL 3825' than 'MTU 1001' and 'WGL 14'. The variety, 'MTU 1001' registered the highest 1,000-grain weight and harvest index.

The interaction effect between the method of water management and varieties revealed that under flooded condition, 'MTU 1001' recorded significantly higher yield than the rest of the varieties (Table 4); while under aerobic condition 'WGL 32100' registered the highest yield. This variety also had minimum yield difference (16.5 %) between two methods of water management. The variety

Table 1. Effect of varieties and nitrogen levels on yield attributes and yield of rice under flooded and aerobic conditions (pooled data of 2 years)

Treatment	Panicles/m^2	Filled spikelets/ panicle	Ill-filled spikelets/ panicle	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
Water management							
Flooded	241	210	23	23.6	4.93	6.46	43
Aerobic	235	161	18	24.4	3.49	5.09	41
SEm±	3.3	2.8	0.2	0.15	0.06	0.04	0.5
CD (P=0.05)	NS	16.9	1.5	NS	0.35	0.22	NS
Variety							
'MTU 1001'	250	168	16	28.9	4.75	6.32	43
'WGL 32100'	242	212	21	19.2	4.33	5.94	42
'WGL 14'	239	203	20	20.0	4.02	5.55	42
'WGL 3825'	221	159	23	27.9	3.73	5.29	41
SEm±	3.0	4.1	0.9	0.22	0.05	0.09	0.5
CD (=0.05)	8.3	11.3	2.5	0.61	0.12	0.26	NS
N (kg/ha)							
120	216	174	21	23.3	3.91	5.43	42
180	238	187	20	24.0	4.21	5.80	42
240	260	196	19	24.7	4.50	6.09	42
SEm±	2.6	3.5	0.8	0.19	0.04	0.08	0.7
CD (P=0.05)	7.2	9.7	NS	0.53	0.11	0.23	NS

'MTU 1001' had the highest yield loss, i.e., 40% under aerobic compared to flooded condition followed by 'WGL 14' with 32% reduction. Similar trend was observed with respect to straw yield also. These findings are in consonance with Patel *et al*. (2010) and Ghosh *et al*. (2012).

Nitrogen application induced an increased in yield both under aerobic and flooded fields. Application of 240 kg N/ha significantly increased panicles/m^2, filled spikelets/panicle and 1,000-grain weight over the lower doses of 120 and 180 kg N/ha, while the ill-filled spikelets and harvest index were not influenced. The grain and straw yield obtained at 240 kg N/ha was significantly higher than that with the other the two levels. Grassi *et al*. (2009) and Lampayan *et al*. (2010) also observed significant increase in the yield of rice owing to N application at 150 kg/ha in both aerobic and flooded fields. Response of rice varieties beyond the recommended dose of N may be attributed to the depletion of organic matter in the soil and lack of addition of it from the external sources besides the high-yield potential of the recently developed varieties.

Nitrogen uptake

Water management influenced the N uptake in rice (Table 2). Significantly higher N uptake was recorded under flooded compared to aerobic condition with respect to both grain and straw. Belder *et al.* (2005) also reported relatively low uptake of nitrogen under aerobic conditions compared to flooded conditions, which was reflected by the relatively low fertilizer-N recovery under aerobic conditions. The variety 'MTU 1001' registered significantly higher N uptake (grain + straw) over the other 3 varieties, which were also different with each other. Difference in N uptake may be ascribed to the difference in grain and straw yields and N content. Nitrogen uptake of both flooded and aerobic rice was significantly increased with an increase in nitrogen levels. The highest N uptake was observed with 240 kg N/ha, significantly superior to the two lower doses. Nitrogen application increases the pre-anthesis dry-matter accumulation by increasing the number of tillers, LAI, pre-anthesis crop growth rate and translocation to grains (Zhang *et al*., 2009).

Water-use and water-use efficiency

The total quantity of water used under aerobic method (1,104 and 1,244 mm, respectively) was lower by 41 and 39% compared to flooded method (1,866 and 2,023 mm, respectively) during 2008 and 2009 respectively (Table 3). Thus water-use efficiency was significantly influenced by the method of water management to rice. It was increased by 18% under aerobic compared to flooded irrigated method (Table 2). Aerobic rice production system eliminates continuous seepage and percolation losses, greatly reduces evaporation as no standing water is present at any time during cropping season, and effectively uses the rainfall and thus helps in enhancing the water productivity (Priyanka *et al.,* 2012; Bouman *et al*., 2005) reported a

Table 2. Effect of varieties and nitrogen levels on nitrogen uptake and economics under flooded and aerobic conditions (pooled data of 2 years)

Treatment	N uptake (kg/ha)			WUE	NUE	Net returns	Benefit:
	Grain	Straw	Total	(kg/ha-mm)	(kg grain/kg N)	(× 10^3 ₹/ha)	cost ratio
Water management							
Flooded	46.0	30.0	76.0	2.5	33.5	24.26	1.11
Aerobic	34.6	19.9	54.5	3.0	23.6	16.90	1.07
SEm±	0.68	0.05	0.72	0.05	0.38	0.54	0.03
CD (P=0.05)	4.14	0.30	4.38	0.30	2.31	3.27	NS
Variety							
'MTU 1001'	49.0	30.3	79.3	3.1	32.2	26.52	1.42
'WGL 32100'	41.1	25.6	66.8	2.9	29.4	22.43	1.23
'WGL 14'	37.0	22.9	59.8	2.6	27.2	17.88	0.90
'WGL 3825'	34.1	21.0	55.2	2.50	25.31	15.49	0.81
SEm±	0.51	0.49	0.70	0.03	0.29	0.42	0.02
CD (P=0.05)	1.41	1.36	1.94	0.08	0.80	1.16	0.06
N (kg/ha)							
120	35.2	22.5	57.7	2.6	32.5	18.03	0.96
180	40.9	24.9	65.8	2.8	28.0	20.66	1.10
240	44.8	27.5	72.3	3.0	25.0	23.06	1.21
SEm±	0.44	0.42	0.61	0.03	0.25	0.36	0.02
CD (P=0.05)	1.22	1.16	1.69	0.08	0.69	1.01	0.06

WUE, Water-use efficiency; NUE: N-use efficiency

Table 3. Quantity of water applied in flooded and aerobic methods

Water management	2008			2009		
	Effective rainfall (mm)	Water applied (mm)	Total water used (mm)	Effective rainfall (mm)	Water applied (mm)	Total water used (mm)
Aerobic	554	550	1,104	294	950	1,244
Flooded	554	1,312	1,866	294	1,729	2,023

32–88% higher water-use efficiency under aerobic condition over flooded conditions. Interaction effect between the method of water management and varieties revealed that three was 39% increase in water-use efficiency in 'WGL 32100' under aerobic condition over flooded method, being the highest among the tows varieties (Table 4). It was followed by 'WGL 3825' with a difference of 27%, while 'MTU 1001' registered no significant difference between the 2 methods. Among the nitrogen doses, 240 kg N/ha resulted in significant increase in water-use efficiency compared to lower doses. It is attributed to improved grain productivity with increased N application.

Nitrogen-use efficiency

The efficiency of applied nitrogen was found to be significantly higher (42%) with flooded method compared to aerobic method (Table 2). Among the 4 varieties, 'MTU 1001' registered superior N-use efficiency over the other varieties. Further, maximum efficiency was recorded with the lower dose of N, i.e. 120 kg/ha compared to 180 or 240 kg/ha.

Economics

There was significant difference in net returns and benefit: cost ratio (Table 2). Higher net returns were recorded under flooded than aerobic condition but no significant difference in benefit: cost ratio was noticed due to high cost of cultivation in the former method. The interaction between the water management and variety showed that significantly higher net returns were realized with 'MTU 1001' in flooded while 'WGL 32100' gave good returns in aerobic method than the other varieties. Similar trend was observed for benefit: cost ratio also. Higher dose of nitrogen, i.e. 240 kg/ha recorded the significant increase in net returns and benefit: cost ratio over the rest of the N levels.

It was concluded that the performance of rice cultivar 'WGL 32100' was better under aerobic method, while 'MTU 1001' gave higher yield under flood irrigated method. It appears that a nitrogen dose of 240 kg/ha needs to be applied for rice cultivation in sandy clay loam soils of Telangana region of Andhra Pradesh, especially where native soil N status is low.

Table 4. Interaction between water management and varieties on yield, water and nitrogen-use efficiency and economics in rice (pooled data of 2 years)

Treatment	Flooded	Aerobic	Reduction in aerobic compared to flooded condition (%)
Grain yield (t/ha)			
'MTU 1001'	5.94	3.56	40.2
'WGL 32100'	4.72	3.94	16.5
'WGL 14'	4.79	3.24	32.4
'WGL 3825'	4.26	3.21	24.6
SEm±	0.06		
CD (P=0.05)	0.18		
Straw yield (t/ha)			
'MTU 1001'	7.47	5.18	30.6
'WGL 32100'	6.34	5.55	12.4
'WGL 14'	6.29	4.81	23.5
'WGL 3825'	5.76	4.82	16.3
SEm±	0.13		
CD (P=0.05)	0.37		
WUE (kg/ha-mm)	Flooded	Aerobic	% increase in aerobic compared to flooded condition
'MTU 1001'	3.08	3.09	0.0
'WGL 32100'	2.44	3.39	38.9
'WGL 14'	2.47	2.81	13.8
'WGL 3825'	2.20	2.80	27.3
SEm±	0.05		
CD (P=0.05)	0.14		
Net returns (× 10^3 ₹/ha)			
'MTU 1001'	34.96	18.08	
'WGL 32100'	23.78	21.09	
'WGL 14'	21.47	14.30	
'WGL 3825'	16.83	14.15	
SEm±	0.59		
CD (P=0.05)	1.65		
B : C ratio			
'MTU 1001'	1.67	1.17	
'WGL 32100'	1.15	1.32	
'WGL 14'	0.91	0.88	
'WGL 3825'	0.72	0.89	
SEm±	0.03		
CD (P=0.05)	0.08		

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