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Full Research Article

Differential Yield, Nutrient Uptake and Water Productivity of Rice Cultivars under Aerobic Conditions on Alfisols of a Semi-arid Environment

A. V. Ramanjaneyulu[1*], A. Madhavi[2], T. L. Neelima[3], S. Ameer Basha[4], T. V. K. Singh[5], D. Madhusudhan Reddy[6], D. Shashibhushan[7], V. Gouri Shankar[8] and R. Jagadeeshwar[9]

[1,3,4,7,8]Regional Agricultural Research Station, Prof. Jayashankar Telangana State Agril. University, Palem, Mahabubnagar district, Telangana State (509 215), India

[2,6,9]Agricultural Research Institute, [5]College of Agriculture, Prof. Jayashankar Telangana State Agril. University, Rajendranagar, Hyderabad, Telangana State (500 030), India

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Correspondence to

E-mail: avr_agron@rediffmail.com

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Abstract

An experiment was conducted for three years (*kharif* seasons of 2007, 2008 and 2009) RARS (PJTSAU), Palem, Telangana state, India to study the yield and nutrient uptake of ten diverse popular high yielding low land rice varieties under aerobic conditions in relation to weather. The pooled analysis revealed that JGL-11727, MTU-1001 followed by MTU-1010 have performed better than other varieties with respect to yield attributes, yield and water productivity. JGL-11727 variety of rice has consumed significantly greater amounts of N and K than other varieties, barring MTU-1001 and MTU 1010. Regarding P mining by grain, straw and total plant, JGL-11727 was found to be more efficient. Of all varieties used in experimentation, Tellahamsa removed significantly less amount of N, P and K besides recording less protein content owing to its shorter duration. JGL-11727 variety has recorded higher mean water productivity (0.28 kg m^{-3}) and was the only variety with positive net returns (₹ 3012 ha^{-1}).

1. Introduction

Rice (*Oryza sativa* L.) is the staple food of Indian sub continent and about 90% of rice is consumed in Asia, and where the demand for rice is on the increase due to ever burgeoning population. The slogan 'Rice is Life' is appropriate for India as this crop plays a vital role in our national food security and is a means of livelihood for millions of rural households (Show et al., 2014). This global grain provides 35-80% of total calorie uptake to more than 2.7 billion people (Gorantla et al., 2005). It is cultivated in India in an area of 44.0 mha with a production of 104.3 mt and a productivity of 2372 kg ha^{-1} (Economic survey, 2012-13). Rice ecosystems in India represent 24% of irrigated areas, 34% of rainfed lowlands, 26% of flood-prone areas and 36% of rainfed uplands in the entire world.

Rice is a semi-aquatic plant and grows well under low land, flooded anaerobic conditions. Irrigated low land rice is the most predominant agricultural rice eco-system in India. Further, permanent flooded conditions provide a continuous and adequate supply of water, efficient weed control, facilitate the use of granular insecticides and herbicides, reduce loss of ammonium fertilizer and enhance the availability of nutrients following reduction of the soil due to the exclusion of oxygen by the flood water. However, the production of low land rice requires copious amount of water which includes water used for wetland preparation and the large losses by seepage, percolation and evaporation. The conventional flooding technique requires very high water consumption and nearly 48% (570 mm) of the total irrigation water applied (1180 mm) is lost through evapotranspiration besides loss due to runoff and infiltration.

In Asia, more than 50% of all water used for irrigation is for rice. About 55% of rice area is irrigated and accounts for 75% of total rice production in the world. It means rice crop utilizes lion's share of water in Agriculture. But water is becoming scarce day by day and proportion of water used in agriculture is coming down due to increasing demand from other sectors. Tuong and Bouman (2003) estimated that 2.0 mha of Asia's

irrigated dry season rice and 13 mha of its irrigated wetland rice may experience "physical water scarcity" and the rest of the approximately 22.0 mha of irrigated dry season rice in South and Southeast rice may suffer from "economic water scarcity" by 2025. On the otherhand, it is estimated that demand for rice will be 121 mt by 2030 (CRRI, 2011). This warrants water efficient method of rice cultivation which can save water without foregoing productivity.

Aerobic rice system (ARS) is a new production system in which rice is grown under non-puddled and non-flooded aerobic soil conditions (Tuong and Bouman, 2003). In this system, rice is sown directly into dry soil and irrigation is given to keep the soil sufficiently moist for good plant growth, but the soil is never flooded. Thus in ARS, soils are kept aerobic almost throughout the rice growing season. In addition to lesser water availability, other factors that prevail in ARS are low soil mechanical impedance, increased oxygen supply to roots, accumulation of ethylene and carbon dioxide in root tissue and availability of nitrogen as nitrate in place of ammonium (the dominant N ion under flooded conditions), and a changed soil fauna. In ARS, potentially high yielding, fertilizer responsive rice varieties are grown in fertile aerobic soils unlike low land puddled rice. Rice yields of more than 7 t ha^{-1} have been recorded under upland conditions, indicating that rice does not require flooded conditions for high yields. Aerobic rice is specially suitable for irrigated low lands where water is insufficient to keep low land paddy fields flooded, uplands with access to supplementary irrigation (Ramana Murthy et al., 2012) and tail end areas under irrigation projects. Aerobic rice production system is gaining importance in view of reduced water use during land preparation, limiting seepage, percolation and evaporation (Peng et al., 2012).

In aerobic rice production system, crop is likely to experience higher levels of water stress before irrigation than usually occur in a saturated condition. Thus aerobic rice varieties need to be more drought tolerant, particularly at sensitive reproductive stage. Though efforts were made to identify location specific varieties suitable for aerobic conditions in India and China, the performance of varieties is highly varying depending on the soil type and rainfall pattern. The information on rice varieties for their suitability to aerobic conditions is scanty on Alfisols under semi arid climate. But adoption of right variety/hybrid is very important for augmenting productivity and increasing water use efficiency. Hence, this study was taken up to evaluate rice varieties for their suitability under aerobic conditions on Alfisols in the semi arid climate of Peninsular India.

2. Materials and Methods

2.1. Location and Experimental details

A field experiment was conducted during *kharif* seasons of 2007, 2008 and 2009 at Regional Agricultural Research Station, Prof. Jayashankar Telangana State Agril. University, Palem, Telangana State to study the performance of various rice varieties under aerobic conditions. The experimental site was situated at $16^{o}35^{1}$ latitude, $78^{o}1^{1}$ longitude and 642 msl altitude. The soil of the experimental site was Alfisol with pH of 7.6, EC of 0.23 dSm^{-1}, low available N (148.4 kg ha^{-1}), high available P (86.2 kg ha^{-1}) and K (419.3 kg ha^{-1}). The crop was sown on 20th June, 4th July and 6th July during 2007, 2008 and 2009, respectively depending on the commencement of monsoon. A set of 10 low land varieties viz., JGL-1798, JGL-3844, Tellahamsa, MTU-1010, JGL-384, JGL-11727, JGL-3828, RNR M-7, MTU-1001 and BPT-5204 were sown in a randomized block design, with three replications to test their performance under aerobic conditions. The characteristic features of these varieties have been furnished in Table 1. Seeds were line sown with a spacing of 20×15 cm^2. A common fertilizer dose of 120:60:40 kg N, P_2O_5, K_2O ha^{-1} was applied. The entire dose of P and half of the K were applied as a basal. Another half of the recommended K was applied at panicle initiation stage. Nitrogen was applied in three equal split doses at basal, active tillering and panicle initiation stages. All agronomic practices and need based plant protection measures were taken up during the crop growth period. Irrigation water was measured by using water meter installed at the experimental site. Irrigation water (5 cm in each irrigation) was applied to the field at an interval of 4-5 days and was measured using water meter installed at the experimental site. Irrigation was stopped at physiological maturity. Effective rainfall (ER) was calculated through USDA soil conservation method using CROPWAT model. Total water use (TWU) was obtained by summing up the ER and amount of water applied to the field. Fe deficiency observed on the crop was corrected by two sprays of FeSO4 @ 0.5% at weekly interval. The grain yield and straw yield recorded from net plot (4.2×3.9 m^2) was extrapolated to one hectare area. During the year 2007, there was excess rainfall, while normal rainfall was recorded during the year 2008. The cropping period in 2009 even though received normal rainfall but was unevenly distributed. Its' ill distribution has affected the crop growth at critical stages thus influencing productivity and water use efficiency.

2.2. Chemical analysis

Soil available N, P, and K were estimated using alkaline permanganate method (Subbaiah and Asija, 1956), Olsens' method (Olsen et al., 1954) and ammonium acetate method (Jackson, 1973), respectively. While, N, P and K content

in the plant were determined by micro-kjeldhal method, vanadomolybdo phosphoric yellow color method and flame photometer method (Jackson, 1973), respectively. Nutrient uptake by grain or straw was calculated by multiplying the nutrient content (%) with grain or straw yield.

2.3. Indices

Water productivity (WP), harvest index (HI) and benefit:cost ratio (B:C ratio) were calculated by using the formulae given below.

WP= Grain yield (kg ha^{-1})/Total water used (m^3)
HI=Grain yield (kg ha^{-1})/Grain yield+Straw yield (kg ha^{-1})
B:C ratio=Gross returns (kg ha^{-1})/Cost of cultivation (₹ ha^{-1})

2.4. Brown spot disease severity

Brown spot severity (BSS) was evaluated on four leaves per plant between flowering to milky stage based on the leaf area affected by using a scale 1-9 (1=0%, 2=less than 1%, 3=1-3%, 4=4-10%, 5=11-15%, 6=15-25%, 7=26-50%, 8=51-75% and 9=76-100%) (IRRI, 1996). Percent disease index (PDI) was calculated by using the formula given below-

$$\frac{\text{Sum of all disease ratings}}{\text{Total no. of ratings} \times \text{Maximum disease grade}} \times 100$$

3. Results and Discussion

3.1. Yield and water productivity

A perusal of data in Table 3 revealed that JGL-11727 variety has significantly outyielded other varieties under test during 2008 and 2009 but it was at par with that of MTU-1001 during 2007. The pooled data also showed superiority of JGL-11727 (3.48 t ha^{-1}) over all other varieties. Irrespective of drought/normal rainfall year, JGL-11727 had performed better than other varieties with 19.0 to 104.2% increase in grain yield. Increase in yield was due to higher no. of productive tillers plant^{-1}, greater length of ear head and no. of grains ear head^{-1} (Table 2). Such results were earlier reported by Ghosh et al., (2012) and Mahajan et al., (2012). Further, this variety had recorded low incidence of brown spot with 41 PDI (Table 1) which otherwise is a serious disease in aerobic rice. Besides, JGL-11727 variety had more flag leaf width with high photosynthetic efficiency. Further, though Fe deficiency was observed in all the tested varieties, the magnitude was high in the varieties like Tellahamsa as it was not fully corrected even after application of FeSO4 @ 0.5% twice at weekly interval. The incidence was low in the varieties viz., JGL-11727, MTU-1010 and MTU-1001 and the same could be completely corrected by FeSO4 @ 0.5%. Singh and Chinnusamy (2007) while reviewing the research results reported that 'Han Dao' yielded up to 7.0 t ha^{-1} under aerobic conditions in temperate regions of China and saved 50% water. In farmers' field conditions in China, HD 297 and 502 yielded 4.6 to 6.6 t ha^{-1} with only 476-612 mm total water input. First tropical rice variety 'Apo' released from IRRI, Philippines yielded 5.7 t ha^{-1} with the total water savings of 40-50%. Lowland variety JD 305 recorded the highest yield

Table 1: Characteristic features and behaviour of various rice cultivars under aerobic conditions

Sl. no.	Variety	Special features	Maturity under low land conditions (DAS)	Under aerobic conditions		
				Actual maturity duration (DAS)	Decrease/ increase in days to maturity	% Disease (Brown spot) Index (PDI)
1.	JGL-1798 (Jagtial Sannalu)	Resistant to gall midge	120	126	+6	39.0
2.	JGL-3844 (Jagtial Samba)	Resistant to gall midge	120	126	+6	50.6
3.	RNR 10754 (Tellahamsa)	Resistant to blast and BLB	125	118	-2	56.3
4.	MTU-1010 (Cotton dorasannalu)	Tolerant to BPH and moderately resistant to blast	120	117	-8	80.6
5.	Polasa Prabha (JGL-384)	Resistant to gall midge	135	133	-2	16.3
6.	JGL-11727	Fine quality rice, resistant to gall midge	135	131	-4	41.0
7.	JGL-3828	Resistant to gall midge but susceptible to panicle mite and blast	135	131	-4	57.3
8.	RNR M-7 (Early Samba)	Mutant of BPT-5204 and resistant to blast	135	126	-9	34.3
9.	MTU-1001 (Vijetha)	Resistant to BPH and moderately resistant to blast	145	126	-9	84.7
10	BPT-5204 (Samba Mahsuri)	Fine quality rice with good cooking quality thus highly popular among consumers but susceptible to pests and diseases	135	126	-19	30.0

(8.8 t ha^{-1}) with 1400 mm water. Under aerobic conditions, the total water input varied from 470 to 644 mm. With 470 mm water, the aerobic rice varieties HD 297 yielded 2.5 t ha^{-1}, HD 502 3.0 t ha^{-1}, and the low land variety JD 305 1.2 t ha^{-1} while with 644 mm water, HD 502 and HD 297 yielded 5.3 and 4.7 t ha^{-1}, respectively, while JD 305 yielded 4.2 t ha^{-1}. Singh and Chinnusamy (2007) reported that Pusa Rice Hybrid 10, Pusa Sugandh 3, 4 and 5 have yielded upto 4.75 to 5.75 t ha^{-1} under aerobic conditions at IARI, New Delhi. With the adoption of recommended practices, 'MAS 946- 1', a new mid-early, medium fine grain, high yielding variety with erect plant type, drought and blast disease tolerance, profuse rooting and high tillering (60 nos.) released for aerobic cultivation by Gandhi Krishi Vigyan Kendra (GKVK) in Karnataka in 2007 gave 5.5 t ha^{-1} of grain and 6.0 t ha^{-1} of straw with 40-50% water saving under aerobic conditions (Hittalmani, 2009). Ramana Murthy et al., (2012) from Southern Agro-climatic zone of Andhra Pradesh reported that Vasundhara (4.41 t ha^{-1}) variety of rice has significantly outyielded Sona Mahshuri (3.88 t ha^{-1}), MTU-1001 (3.71 t ha^{-1}) and BPT-5204 (3.49 t ha^{-1}) when grown aerobic conditions on sandy clay loam textured soils. The water-use efficiencies of the aerobic varieties under aerobic conditions were 164-188% higher than that of the lowland variety under lowland conditions. Aerobic rice maximizes water use in terms of yield and is a suitable crop for water-limiting conditions. Such variation among different varieties was earlier reported by Bouman et al., (2006).

Irrespective of the varieties tested, the grain yield declined over the years. For instance, maximum reduction in grain yield was witnessed with MTU-1001 (2.30 t ha^{-1}) from the year 2007 to 2009 and minimum yield reduction (0.367 t ha^{-1}) was observed with the variety Tellahamsa. Prasad (2011) reported that decline in rice yield over years in aerobic rice system (ARS) is not uncommon due to N, P, K, Fe and Zn deficiencies, weed menace and soil borne root knot nematodes, thus ARS may not be sustainable over a long period. Nearly 1206 mm rainfall was received (40 rainy days) during 2007 while only 497.3 mm (29 rainy days) and 624.6 mm (27 rainy days) in 2008 and 2009, respectively. Rainfall in 2007 can be categorized as excess as 86.5% more rainfall than normal was received during the crop growth period. While, it is deficit by 23.0% in 2008 and normal during 2009. During 2009, though amount of rainfall received was more or less equal to normal rainfall, the distribution is improper as 376.6 mm of rainfall (60.3%) was received in 6 rainy days during 39th and 40th meteorological weeks, which means only 248 mm rainfall (39.7%) was received in 25 rainy days during the crop period. This might have created stress during 39th and 40th standard meteorological weeks. High evaporation rate (9.4 to 12.1 mm day^{-1} in 2009 and 8.7 to 8.9 mm day^{-1} in 2008) was recorded from 25th to 27th std. weeks which coincided with germination phase as compared to that of 2007 (3.2 to 6.1 mm day^{-1}) in the corresponding standard weeks. An evaporation of 6.8 to 9.5 mm day^{-1} was recorded during 30th and 32nd weeks in 2009, which is more than that of evaporation recorded in the corresponding period during 2008 and 2007. Low relative humidity (R.H) (PM) i.e., 38.6 to 49.7% and 44.9 to 51.7% prevailed from 25th and 30th std. week during 2008 and 2009 as compared to 2007 (55.1 to 75.9%) in the corresponding period coinciding with germination and vegetative growth period. Again during 43rd and 44th week also, low R.H. (PM) prevailed during 2008 (37.1 and 22.6%) and

Table 2: Agronomic characters of rice varieties as influenced under aerobic conditions (*Kharif* 2007-09)

Variety	No. of productive tillers plant^{-1}				Length of ear head (cm)				No. of grains ear head^{-1}				1000 grain weight (g)			
	2007	2008	2009	Pooled	2007	2008	2009	Pooled	2007	2008	2009	Pooled	2007	2008	2009	Pooled
JGL-1798	9.7	9.7	8.3	9.2	18.6	15.4	10.0	14.7	86.6	65.0	69.7	73.7	12.4	12.1	12.3	12.3
JGL-3844	9.5	8.7	9.3	9.2	19.6	16.5	12.3	16.1	90.2	76.0	75.3	80.5	15.5	13.8	14.0	14.4
Tellahamsa	10.7	6.3	5.7	7.6	12.7	13.8	8.3	11.6	80.3	78.0	61.7	73.4	23.5	20.1	20.4	21.3
MTU-1010	11.3	12.8	10.3	11.5	15.9	15.9	12.3	14.7	108.3	96.0	91.7	98.8	25.6	20.1	18.6	21.5
JGL-384	9.5	9.3	9.3	9.4	17.9	16.6	11.7	15.4	102.7	88.0	76.7	89.1	13.7	13.7	11.3	12.9
JGL-11727	13.0	12.8	11.0	12.3	18.6	16.0	13.6	16.1	121.0	102.7	91.7	105.1	20.2	20.6	19.2	20.0
JGL-3828	9.3	8.0	7.3	8.2	17.3	16.9	8.3	14.2	102.0	33.0	85.0	89.1	14.6	13.3	13.3	13.8
RNR M-7	11.8	10.8	7.3	9.9	15.8	15.2	9.0	13.3	92.3	79.3	73.3	81.7	13.7	12.5	12.7	13.0
MTU-1001	11.5	11.7	11.0	11.4	18.1	15.3	11.3	14.9	103.3	92.3	85.3	93.7	24.0	20.3	19.7	21.3
BPT-5204	11.5	7.7	8.0	9.1	15.3	19.9	9.0	14.7	92.9	86.3	72.7	84.0	11.7	12.8	11.7	12.1
SEm±	0.8	0.9	0.8	0.5	0.6	1.4	0.8	0.6	5.0	80.3	4.6	2.9	0.8	0.5	0.3	0.4
CD (p=0.05)	NS	2.7	2.3	1.5	1.7	NS	2.4	1.7	14.9	5.7	13.5	8.6	2.4	1.5	1.0	1.2

2009 (28.7 and 39.7%) as compared 2007 (56.4 and 63.6%) which coincided with milky stage. According to Singh et al., (2012), regression analysis revealed that both maximum and minimum temperatures has strong impact on grain yield and however, minimum night temperature has comparatively higher impact. Low temperature at anthesis decreased grain yield and response varied with cultivar. High temperature and evaporation leads to spikelet sterility at reproductive stage. The occurrence of various phenological events and the biomass production depend on the accumulated heat sums, which is having a strong linear relationship (Murthy, 2007).

In respect of straw yield of rice under aerobic conditions, BPT-5204 (5.18 t ha^{-1}) was found to be significantly superior to other varieties except JGL-11727, MTU-1001 and MTU-1010 during 2007, while during 2008, JGL-11727 variety (4.67 t ha^{-1}) has surpassed all other varieties (Table 3). On the otherhand during 2009, JGL-1798 being at par with JGL-3844, BPT-5204, MTU-1010, Tellahamsa, RNR M-7 and JGL-3828 has significantly outyielded other varieties. The results indicate that in a high rainfall year (2007) long duration variety (BPT-5204), and in a normal rainfall year (2008) medium duration variety (JGL-11727) produced higher straw yield. The pooled data across the three years indicated that BPT-5204, JGL-11727 and MTU-1001 recorded higher straw yield (Table 3).

MTU-1001 variety had water productivity of 0.33 kg m^{-3} during 2007 and 2008 but declined to 0.16 in 2009 with a mean value of 0.27 kg m^{-3}. Among all varieties tested in the experimentation, the variety JGL-11727 was found to have produced higher mean grain yield (0.281 kg) per m^3 of water used (Table 3). Neelima and Ashok Kumar (2011) reported that MTU-4870 (4.8 t ha^{-1}), RDR-1010 (4.0 t ha^{-1}), RDR-977 (3.9 t ha^{-1}) and RDR 996 (3.9 t ha^{-1}) performed better under aerobic conditions with water use efficiency of 0.46 to 0.58 kg m^{-3} which is considerably more than that of low land puddle rice (0.37 kg m^{-3}) in scarce rainfall zones of South India.

The pooled data indicated that harvest index ranged from 0.36 (BPT 5204) to 0.45 (JGL-11727) and was significantly influenced by different varieties of rice under aerobic conditions. Significantly higher harvest index was observed with JGL-11727 than other varieties except RNR M-7, MTU 1010 and MTU 1001 (Table 3). Singh and Chinnusamy (2007) reported that high HI under aerobic conditions as compared to low land rice is due to high percentage of filled grains contribution to grain yield.

3.2. Maturity

In case of long duration varieties like BPT-5204, days to maturity declined by 19 days while in case of medium duration

Table 3: Grain and Straw yield, harvest index (HI) and Water productivity (WP) of different rice varieties under aerobic conditions (*Kharif* 2007-09)

Treatment	Straw yield (t ha^{-1})				% increase in yield of JGL-11727 over other varieties	HI				WP (kg m^{-3})			
	2007	2008	2009	Pooled		2007	2008	2009	Pooled	2007	2008	2009	Mean
JGL-1798	3.16	2.52	2.14	2.61	33.3	3.09	4.1	4.08	3.78	0.51	0.38	0.35	0.41	0.26	0.25	0.20	0.24
JGL-3844	2.97	2.09	1.26	2.11	65.0	2.72	3.33	3.79	3.28	0.52	0.39	0.25	0.39	0.24	0.21	0.12	0.19
Tellahamsa	2.04	1.39	1.67	1.70	104.2	3.82	2.08	3.30	3.07	0.35	0.40	0.35	0.37	0.16	0.15	0.17	0.16
MTU-1010	3.60	2.78	2.23	2.87	21.2	4.24	3.47	3.59	3.77	0.46	0.45	0.39	0.43	0.27	0.24	0.18	0.23
JGL-384	2.94	2.23	1.43	2.20	58.1	3.82	3.49	2.55	3.28	0.44	0.39	0.36	0.40	0.22	0.20	0.12	0.18
JGL-11727	4.26	3.47	2.71	3.48	-	4.72	4.67	3.14	4.18	0.47	0.43	0.46	0.45	0.32	0.30	0.22	0.28
JGL-3828	3.14	2.45	1.79	2.46	41.5	3.82	3.30	3.34	3.48	0.45	0.43	0.35	0.41	0.24	0.21	0.14	0.20
RNR M-7	3.04	2.25	2.41	2.57	35.6	3.19	3.15	3.57	3.30	0.49	0.42	0.40	0.44	0.23	0.20	0.19	0.21
MTU-1001	3.99	3.07	1.69	2.92	19.2	4.70	4.19	2.94	3.94	0.47	0.42	0.37	0.42	0.33	0.33	0.16	0.27
BPT-5204	2.99	2.38	1.88	2.41	44.0	5.18	4.07	3.58	4.28	0.36	0.37	0.35	0.36	0.20	0.21	0.15	0.19
SEm±	0.21	0.10	0.06	0.07		0.33	0.15	0.25	0.12	0.02	0.02	0.02	0.01				
CD (p=0.05)	0.63	0.29	0.18	0.22		0.98	0.45	0.73	0.36	0.07	0.05	0.05	0.03				

WP: water productivity

varieties viz., MTU-1001 and Early samba (9), JGL-11727 and JGL-3828 (4) and JGL-384 (2), 2-9 days early maturity was observed under aerobic conditions. On the otherhand, short duration varieties like MTU-1010 (8) and Tellahamsa,(2) reached maturity stage earlier by 2-8 days. On the contrary, two short duration varieties viz., JGL-1798 and JGL-3844 took 6 days more time to attain maturity under aerobic conditions (Table 1). High rainfall and more number of rainy days during 34th and 35th standard meteorological weeks than preceding and succeeding weeks might be the reason for delayed maturity of JGL-1798 and JGL-3844 varieties by 6 days under aerobic conditions as compared to their corresponding original maturity duration under low land conditions. However, other varieties were not affected by this phenomenon. It shows differential crop maturity behavior of low land rice varieties when grown under aerobic conditions.

3.3. Nutrient mining and protein yield

Uptake of N by grain, straw and total plant was significantly higher by JGL-11727 variety of rice under aerobic conditions in all the years of experimentation (Table 4). But N uptake by grain was at par with that of MTU-1010 (63.0 kg ha^{-1}) and MTU-1001 (62.1 kg ha^{-1}) during 2007 and by straw in 2007 and 2009 (28.6 kg ha^{-1}and 18.0 kg ha^{-1}).

Pooled data furnished in Table 5 revealed that significantly higher amount of P was removed by JGL-11727 variety (grain: 10.9 kg ha^{-1}; total P: 15.9 kg ha^{-1}) irrespective of year of experimentation. It was mainly owing to significantly higher grain yield (3.48 t ha^{-1}). On the contrary, though there was a significant difference among varieties with regard to P uptake

Table 4: N uptake by dif. rice verities under aerobic condition (*Kharif* 2007-09)

Treatment	N uptake by grain (kg ha^{-1})				N uptake by straw (kg ha^{-1})				Total N uptake (kg ha^{-1})				Protein content (%)	Protein yield (kg ha^{-1})
	2007	2008	2009	Pooled	2007	2008	2009	Pooled	2007	2008	2009	Pooled	Pooled	Pooled
JGL-1798	38.9	30.8	26.2	32.0	11.0	14.6	14.6	13.4	49.8	45.4	40.8	45.4	7.7	199.9
JGL-3844	39.2	27.8	16.7	27.9	10.1	12.5	14.1	12.2	49.3	40.3	30.8	40.1	8.3	174.5
Tellahamsa	19.5	13.2	15.7	16.2	12.5	06.8	10.7	10.0	32.0	20.0	26.4	26.2	5.9	101.0
MTU-1010	63.0	48.7	39.1	50.3	18.1	14.8	15.4	16.1	81.1	63.5	54.5	66.4	10.9	314.3
JGL-384	34.3	26.0	16.7	25.7	14.2	12.8	09.5	12.2	48.5	38.8	26.2	37.8	7.3	160.4
JGL-11727	73.8	59.0	45.9	59.6	30.8	30.5	20.5	27.3	104.6	89.5	66.4	86.9	10.6	372.3
JGL-3828	43.1	33.6	24.5	33.7	16.5	14.3	14.5	15.1	59.7	47.8	38.9	48.8	8.6	210.8
RNR M-7	38.4	28.6	30.5	32.5	09.8	09.7	11.0	10.1	48.2	38.3	41.5	42.7	7.9	203.3
MTU-1001	62.1	47.6	26.4	45.4	28.6	25.6	18.0	24.1	90.7	73.2	44.4	69.5	9.7	283.6
BPT-5204	33.9	26.1	20.4	26.8	15.8	12.3	10.8	13.0	49.7	38.4	31.2	39.8	6.8	167.4
SEm±	6.3	3.5	2.4	3.8	1.9	0.6	1.1	0.8	6.3	3.5	2.5	3.7	0.6	24.0
CD (*p*=0.05)	18.7	10.3	6.9	11.4	5.6	1.8	3.4	2.4	18.6	10.3	7.5	5.3	1.8	71.3

Table 5: P uptake by dif rice verities under aerobic conditions (*Kharif* 2007-09)

Treatments	P uptake by grain (kg ha^{-1})				P uptake by straw (kg ha^{-1})				Total P uptake (kg ha^{-1})			
	2007	2008	2009	Pooled	2007	2008	2009	Pooled	2007	2008	2009	Pooled
JGL-1798	9.8	7.8	6.7	8.1	3.4	4.6	4.6	4.2	13.2	12.4	11.2	12.3
JGL-3844	7.5	5.3	3.2	5.3	2.8	3.5	4.0	3.4	10.3	8.8	7.2	8.8
Tellahamsa	6.1	4.1	5.0	5.1	3.4	1.9	3.0	2.8	9.5	6.0	8.0	7.8
MTU-1010	10.9	8.4	6.7	8.7	4.5	3.7	3.8	4.0	15.4	12.1	10.5	12.7
JGL-384	7.5	5.7	3.7	5.7	4.0	3.6	2.6	3.4	11.6	9.3	6.3	9.0
JGL-11727	13.2	10.8	8.5	10.9	5.6	5.6	3.8	5.0	18.9	16.5	12.2	15.9
JGL-3828	8.0	6.2	4.5	6.2	3.7	3.2	3.2	3.4	11.6	9.4	7.8	9.6
RNR M-7	9.1	6.7	7.2	7.7	2.7	2.6	3.0	2.8	11.8	9.4	10.2	10.4
MTU-1001	12.4	9.5	5.2	9.0	5.3	4.6	3.2	4.4	17.6	14.1	8.5	13.4
BPT-5204	7.2	5.7	4.5	5.8	5.2	4.1	3.7	4.3	12.4	9.8	8.2	10.1
SEm±	0.8	0.4	0.3	0.4	0.6	0.5	0.5	0.5	1.0	0.7	0.7	0.7
CD (*p*=0.05)	2.3	1.3	1.0	1.3	1.9	1.6	NS	NS	2.9	2.0	2.0	2.0

during the years 2007 and 2008, but all varieties were found to be at par with regard to P uptake by straw (pooled data of three years). Irrespective of the year of experimentation, the uptake of P by grain and total plant was significantly higher by JGL-11727 than other varieties except MTU-1001 during 2007 and 2008 while M-7 and MTU-1010 during the year 2009.

The uptake of K by straw is 3-9 times higher than that of grain irrespective of the year and variety. K uptake by grain was significantly higher in case of JGL-11727 in all the years as compared to all other genotypes except MTU-1010 in 2007. Next best variety was MTU-1001 and JGL-1798 in respect of uptake of K by grain. Pooled data on K uptake by straw showed that JGL-11727 being at par with MTU-1010 and MTU-1001 has significantly removed greater amounts of K. Same is true for uptake of K by total plant (Table 6). The higher grain and straw yield of JGL-11727is the main reason for higher K uptake.

3.4. Disease incidence and disease score

Brown spot is the most serious disease of rice when cultivated under aerobic conditions. Based on the data presented in Table 1, the varieties can be categorized into four groups. The first group has two varieties with 15-30 PDI (very low), second group has 4 varieties with 31-50 PDI (low), third group has four varieties with 51-80 PDI (medium) and the fourth group has only one variety with 80-90 PDI range (high). Highest per cent disease index was recorded with MTU 1001 (84.70) followed by MTU 1010 (80.60), JGL 3828 (57.30), Tellahmsa (56.30), JGL 3844 (50.60), JGL 11727 (41.00), JGL1798 (39.00), M7 (34.30), BPT 5204 (30.00) and JGL 384 (16.00). Brown spot disease significantly varied with the type of genotype and further the average pooled maximum temperature (31.0^{0}C) and minimum temperature (21.4) and RH (86.4%) has favoured the disease development. This is in conformity with results reported by Picco and Rodolfi (2002) who has observed that the variation among the varieties is also attributed to deficiencies by zinc, potassium, manganese, magnesium, iron, or calcium in the soil. JGL cultures more specially JGL-11727, JGL-1798 and JGL-384 varieties had PDI below 50 which may be attributed to maximum width of flag leaf thus high photosynthetic use efficiency. The biological mineralization of organic nitrogen to ammonia and its subsequent nitrification to nitrate are dynamic process that provides a preponderance of one or other forms of N depending on the soil environment and biological activity. Both the cationic (NH_4^+) and anionic (NO_3^-) forms of N were assimilated by plants, but they may have opposite effects on disease particularly with brown spot of rice as evidenced by low incidence in JGL cultures as compared to other varieties tested in this study.

Table 6: K uptake by different rice verities under aerobic conditions (*Kharif* 2007-09)

Treatments	K uptake by grain (kg ha^{-1})				K uptake by straw (kg ha^{-1})				Total K uptake (kg ha^{-1})			
	2007	2008	2009	Pooled	2007	2008	2009	Pooled	2007	2008	2009	Pooled
JGL-1798	10.3	8.3	7.0	8.5	36.8	49.4	48.7	44.9	47.1	57.6	55.7	53.5
JGL-3844	9.2	6.6	3.9	6.6	30.2	36.7	41.5	36.1	39.4	43.9	45.5	42.7
Tellahamsa	4.6	3.2	3.8	3.9	36.3	19.8	31.6	29.2	40.9	22.9	35.4	33.1
MTU-1010	12.0	9.2	7.4	9.6	54.6	44.7	46.4	48.6	66.7	54.0	53.8	58.1
JGL-384	10.1	7.7	4.9	7.6	39.6	36.4	26.5	34.1	49.7	44.3	31.4	41.7
JGL-11727	15.0	12.4	9.7	12.4	57.9	57.5	38.6	51.3	72.9	69.9	48.2	63.7
JGL-3828	7.7	6.0	4.4	6.0	45.1	38.9	39.5	41.2	52.8	45.0	43.9	47.2
RNR M-7	7.4	5.4	5.9	6.2	32.4	32.0	36.5	33.6	39.7	37.4	42.4	39.9
MTU-1001	13.2	10.2	5.6	9.7	59.3	53.7	37.9	50.3	72.5	64.0	43.5	60.0
BPT-5204	8.8	6.9	5.4	7.0	51.8	39.7	35.2	42.2	60.6	46.6	40.6	49.3
SEm±	0.8	0.7	0.4	0.5	4.4	2.4	3.5	2.4	4.65	2.3	3.6	2.5
CD (*p*=0.05)	2.5	2.0	1.2	1.6	13.0	7.0	10.4	7.2	13.6	6.8	10.6	7.5

3.5. Economic returns

JGL-11727 is the only variety which has given positive net returns irrespective of the year of field trials (Pooled: (₹ 3012 ha^{-1}) and b:c ratio above one (1.1) among all 10 rice varieties tested under aerobic conditions (Table 7). It means all other nine rice varieties are not profitable to grow under aerobic conditions. Highest negative returns were accrued due to cultivation of Tellahamsa (₹ 10052 ha^{-1}) and JGL-3844 (₹ 11970 ha^{-1}). Wang Huaqi et al., (2002) opined that though the economic returns per hectare are lower, the net returns per unit of water used were two times higher in aerobic rice than in low land rice. Thus they felt, aerobic can an attractive alternative to low land rice in areas where water is the limiting factor rather than land and where growers want take up only rice.

Table 7: Economics of rice varieties grown under aerobic conditions (*Kharif* 2007-09)

Treatment	Cost of cultivation (₹ ha^{-1})				Gross returns (₹ ha^{-1})				Net returns (₹ ha^{-1})				B:C ratio			
	2007	2008	2009	Average	2007	2008	2009	Average	2007	2008	2009	Average	2007	2008	2009	Average
JGL-1798	21969	21412	21001	21461	26700	27000	27200	26967	-4731	-5589	-6199	-5506	0.82	0.79	0.77	0.80
JGL-3844	20662	17782	12299	16914	26700	27000	27200	26967	-6038	-9218	-14901	-10052	0.77	0.66	0.45	0.63
Tellahamsa	15205	12510	17273	14996	26700	27000	27200	26967	-11495	-14490	-9927	-11970	0.57	0.46	0.64	0.56
MTU-1010	25027	23588	21844	23486	26700	27000	27200	26967	-1673	-3413	-5356	-3480	0.94	0.87	0.80	0.87
JGL-384	20419	18938	14034	17797	26988	27288	27488	27255	-6569	-8350	-13454	-9458	0.76	0.69	0.51	0.65
JGL-11727	31707	31212	27882	30267	26988	27288	27488	27255	4719	3924	394	3012	1.17	1.14	1.01	1.11
JGL-3828	21816	20834	17493	20048	26988	27288	27488	27255	-5172	-6455	-9995	-7207	0.81	0.76	0.64	0.74
RNR M-7	21107	19125	23589	21274	26988	27288	27488	27255	-5881	-8163	-3899	-5981	0.78	0.70	0.86	0.78
MTU-1001	27717	26070	16591	23459	26988	27288	27488	27255	729	-1219	-10897	-3796	1.03	0.96	0.60	0.86
BPT-5204	22268	21375	19343	20995	27288	27588	27788	27555	-5020	-6213	-8445	-6559	0.82	0.77	0.70	0.76

Market rate (₹ kg^{-1}) (1 US$=39.47 INR) in 2007: JGL-11727, BPT-5204 and Tellahamsa- 7.45, Other varieties- 6.95; 2008 (1 US$=48.57 INR): JGL-11727, BPT-5204 and Tellahamsa- 9.00, Other varieties- 8.50; 2009 (1 US$=46.69 INR): JGL-11727, BPT-5204 and Tellhamsa- 10.30; Other varieties- 9.80

4. Conclusion

Medium (JGL-11727 and MTU-1001) or early duration varieties (MTU-1010) with profuse tillering and drought tolerance with less brown spot severity were found to be high yielding than long duration varieties (BPT-5204) with high disease susceptibility. Among 10 varieties tested for their suitability under aerobic conditions, JGL-11727 is the only variety that was proved economical due to higher yield than other varieties.

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