Vol. 43, No. 2, pp 170-174, 2015
Indian Journal of Soil Conservation
Online URL:http://indianjournals.com/ijor.aspx?target=ijor:ijsc&type=home

Productivity and water use efficiency of aerobic rice under different moisture regimes in Eastern India

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ARTICLE INFO

Article history :
Received : January, 2014
Revised : March, 2015
Accepted : April, 2015

Key words :
Aerobic rice,
Eastern India,
Rice growth,
Water management

ABSTRACT

A field experiment on aerobic rice culture was initiated at the Deras Farm, Mendhasal in Khurda district, Odisha during summer season (January to April) of 2007 and 2008 with the objective of identifying the suitable variety and irrigation regime for aerobic rice culture. Under aerobic condition, three rice varieities *viz.,* Lalat, Surendra and Kandagiri were directly sown in the main field without puddling. All the varieties were also sown on the same day in nursery and transplanted 25 days after sowing. Irrigation treatment consisted of I_1-keeping soil moisture at 80-90% of available soil moisture (ASM) throughout the crop season, I_2-keeping soil moisture at 60-70% of ASM during vegetative and thereafter 80-90% and I_3-keeping soil moisture at 60-70% of ASM throughout the crop season and I_4- Conventional rice cultivation. Growth and yield characters were significantly influenced by establishment methods, irrigation regime and varieties. Initial plant growth characters like plant height, tiller number were higher under aerobic rice. However, as the season advanced, values of growth characters were higher under transplanted rice. Yield attributes *viz.,* panicle numbers, grains per panicle were also higher under transplanted rice. Among irrigation regimes under aerobic culture, higher values of yield attributes were recorded in the treatment I_1. Under aerobic rice root mass density was maximum under Kandagiri, which was followed by the variety Lalat. The highest yield (4.88 t ha^{-1}) was recorded in the variety Surendra under transplanting method. In aerobic condition, the highest grain yield (3.98 t ha^{-1}) and higher water use efficiency (46 kg ha^{-1} cm^{-1}**)** was recorded in the variety Surendra, irrigated at 80-90% soil moisture content (I_1).

1. INTRODUCTION

The productivity of Asia's irrigated rice systems is increasingly threatened by water scarcity. Tuong and Bouman (2003) estimated that, by 2025, 2 m ha of Asia's irrigated dry-seasons rice and 13 m ha of its irrigated wet-season rice may experience "physical" water scarcity. Technologies developed for water saving in rice such as alternate wetting and drying, continuous soil saturation and direct seeding may reduce the water requirement of rice to some extent. But a fundamentally different approach to reduce water inputs in rice drastically is necessary for future rice cultivation. Aerobic rice culture is one of the options which not only reduce the water requirement but sustain the rice productivity. Direct-seeded aerobic management eliminates water losses associated with puddling and reduces losses due to evaporation and percolation, reducing total irrigation requirements by 30-50% (Castaňeda *et al.,* 2002). In Asia, upland rice is already grown aerobically with minimal inputs in the upland environment, but mostly as low-yielding subsistence crop to give stable yields under the adverse environmental conditions of the uplands. Upland rice varieties are drought tolerant, but have a low yield potential and tend to lodge under high levels of external inputs such as fertilizer and supplemental irrigation. Alternatively, high yielding lowland rice varieties grown under aerobic soil conditions, but with supplemental irrigation, have been shown to save water but at a severe penalty. Identification of improved upland and lowland varieties holds the key for the success of aerobic rice culture.

Experiments conducted in Philiphines revealed that a good rice yield (4 to 6 t ha^{-1}) could be harvested from wet as well as dry seasons. Bouman *et al.* (2005) reported that the highest yields of 5.7 t ha^{-1} under aerobic conditions were realized in the dry season with the improved upland variety and the water productivity was 32-88% higher than under flooded condition when the soil moisture was kept between 10 kpa to 30 kpa. In India, researchers currently test the growing of popular lowland rice varieties under aerobic conditions on raised beds. The first results on yields and water use are comparable with those obtained at IRRI (Singh *et al.,* 2002; Sharma *et al.,* 2002). Peeyush Sharma *et al*. (2012) concluded that in the presence of shallow water table condition, higher yield and water use efficiency can be obtained in rice under rainfed condition. The information on aerobic rice in India in general and in the eastern India in particular is meager. Keeping these points in view, an experiment was laid out in summer to identify the suitable rice varieties and water management practices for aerobic rice culture.

2. MATERIALS AND METHODS

Field experiments were conducted in the dry season (January to April) of 2007 and 2008 at Bhubaneswar ($20^0$30' N , $87^0$48' E, 45 m above msl) in the eastern region of India. The soil of experimental plot consisted of, 18% fine sand, 16% silt and 20% clay and it comes under sandy clay class. Bulk density, hydraulic conductivity and the available soil moisture were estimated as 1.44 gm cc^{-1}, 1.14 cm hr^{-1} and 0.18 cm^3 cm^{-3}, respectively. The soil of the experiment site was acidic in reaction (pH, 5.3) having EC 0.25 dS m^{-1} and organic carbon 0.45%. An experiment with three replications was set up in a split plot design with main and sub-plot treatments of water regime and the varieties, respectively. Individual subplot size was about 5 x 5 m. Plots were bunded and separated by one m wide strips of bare soil. The same field was used in both the years. The four water regime treatments under aerobic rice (AR) culture were: keeping soil moisture content at 80-90% throughout the crop season (I_1 AR-high moisture), keeping soil moisture content at 60-70% during vegetative and thereafter 80-90% (I_2 AR-Medium moisture) and keeping soil moisture content at 60-70% throughout the crop season (I_3 AR-Low moisture) and conventional cultivation(I_4 Transplanted rice). The amount of water received for each treatment is 700, 660, 540 and 1300 mm, respectively for I_1, I_2, I_3 and I_4 irrigation regimes. Variety treatments were consisted of three low land varieties (V_1-Surendra, V_2-Lalat and V_3- Kandagiri) with different duration predominantly grown in this region during dry season under flooded condition. For growing rice varieties under flooded conditions, rice varieties were sown in the wet nursery on the same day when these varieties were sown under aerobic condition and transplanted after 28 days. The flooded plots were puddled and kept continuously flooded from transplanting till 2 weeks before harvest. The water depth was initially 2 cm and gradually increased to 10 cm at full crop development.

The aerobic plots were dry-ploughed and harrowed. The seeds were hand dibbled at 3 cm depth with the spacing of 20 cm x 10 cm during the second week of January. In the AR, phosphorus (40 kg P ha^{-1} as single superphosphate), potassium (40 kg K ha^{-1} as KCl), and zinc (5 kg Zn ha^{-1} as zinc sulfate heptahydrate) were applied and incorporated in all plots one day before sowing. Fertilizer N in the form of urea was applied in three splits as top dress only (40 kg ha^{-1} at 10-day after sowing and 20 kg each at maximum tillering and panicle initiation stage). In both years, plots were kept weed-free by an application of pre-emergence herbicide and hand weeding after crop establishment. Pesticides were applied as appropriate for good crop protection. In the transplanted rice 21-day old seedlings from wet-bed nurseries were transplanted into puddle soil at three seedlings per hill at a spacing of 20 x 10 cm. The above mentioned quantity of P and K was applied in the field before transplanting. Nitrogen in the form of urea was applied in three splits (40 kg as basal before transplanting, 20 kg each as top dressing during maximum tillering and panicle initiation stages).

The irrigation water input was estimated from the pump operation time and the calibrated pump flow rate. Leaf area was measured with LI- 3100C area meter and, after oven drying at 70°C to constant weight, the dry weight was estimated. At rice maturity all the plants were harvested and dry weights of straw and grain yield were measured. Grain yield is expressed at 14% moisture content. Five samples from every plot were selected randomly before harvest to determine number of panicle, number of filled grain per panicle, and harvest index. Water Use Efficiency (WUE) (kg grain ha-cm^{-1} of water) was calculated as the weight of grains produced per unit of irrigation water input.

Root samples were collected in between the rows, using a sampling core with 8 cm in diameter and 15 cm long at progressive depths of 15-30 cm. The roots were washed and dried in an oven at 65°C and root weight was recorded. Total root length (RL) of fresh plant samples was determined by the line intersection method described by Tennant (1975). Root morphological parameters included root diameter (RD), root length density (RLD) (mm cm^{-3}), and root weight density (RWD) (g cm^{-3}) calculated by using the following formula:

$$RLD = RL/V \quad ...(1)$$

$$RWD = RW/V \quad ...(2)$$

Where, RW is root weight (g), RL is root length (cm), and *V is* the volume of the soil core.

3. RESULTS AND DISCUSSION

Plant Growth Attributes

All the growth attributes *viz*., plant height, number of tillers per panicle, biomass and root growth were significantly influenced by the irrigation regime and varieties (Table 1 and Fig.1). Plant height and leaf area index (LAI) were significantly higher at 35 days after sowing in aerobically grown rice compared to rice grown under standing water condition (I_4). However, as season advanced rice under puddle condition produced taller plant (82.4 cm) and higher LAI (3.9) compared to other three irrigation regimes. Higher plant growth characters recorded under aerobic irrigation regime (I_1, I_2 and I_3) during the initial period may be due to the favourable condition created when the seeds are directly sown in the main field with the required spacing in compared to the transplanted rice (I_4) and in the later stages, the condition under transplanted condition was more favour for rice. The highest tiller per hill and biomass) were recorded in conventional system (I_4) and aerobic rice irrigated at 80-90 % of available soil moisture (I_1 AR-high moisture). Rice produced significantly lesser tillers during 90 days after sowing and harvest in the treatments: I_2 AR-Medium moisture and I_3 AR-Low moisture regimes. Among the varieties, the highest tiller number and biomass were recorded under the variety Surendra which was followed by the variety Lalat. However, interaction effect of variety and irrigation regimes shows that there was no difference in number of tillers hill^{-1} among the variety in medium and lesser water regimes under aerobic cultivation. This may be due to the fact that the long duration rice variety Surendra sustains it tiller production when it is cultivated as transplanted condition or under higher soil moisture regimes when it is cultivated under aerobic condition. Shaobing Peng *et al*. (2006) reported that there was no significant effect on biomass between flooded and aerobic rice culture during the early stage and flooded rice produced significantly more biomass as season advanced. Higher biomass and LAI in rice under flooded condition compared to aerobic rice has also been reported by Bouman *et al*. (2006).

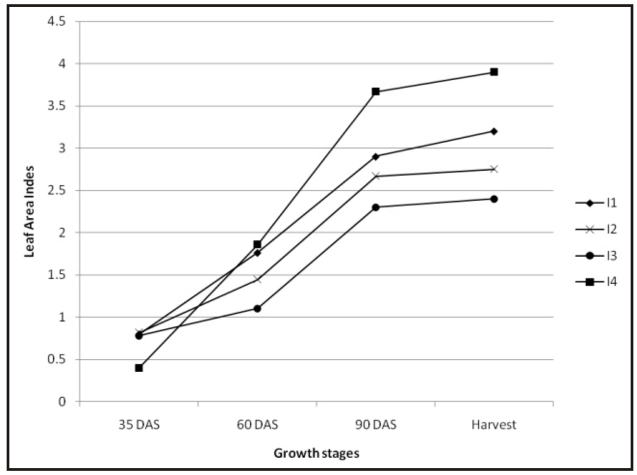

Fig. 1. Leaf area Index as influenced by the water regime

Method of cultivation caused great changes in root growth characters (Table 2). Root volume was more under aerobic condition except low moisture regime (I_3). At 90 days the highest root volume was recorded with rice cultivated under aerobic condition with high moisture regime (I_1) compared to conventional method of rice cultivation irrespective of the varieties. Higher root volume observed under aerobic method of rice cultivation may be due to the lesser soil compaction and bulk density (1.38 gm cc^{-1}) compared to the puddle condition (1.53 gm cc^{-1}) and lesser competition between plants as in the case of conventional cultivation, where rice is kept in nursery with closer plantation for one month duration and thick primary and secondary roots developed under aerobic condition with higher moisture regime. In lowland rice production, the soil structure is deliberately destroyed which restricts the depth of rice root (Willem *et al*., 2002). Iijima *et al.* (1991) reported reduced root growth of rice when soil compaction increases. However, root length density (4.3 mm cm^{-3}) was observed under conventional planting due to more number of tertiary roots produced under submerged condition. Rice short fine roots grown under submerged condition do not develop secondary thickness in their walls (Matsuo and Hoshikawa, 1993). Higher root dry weight

Table: 1
Plant growth attributes as influenced by irrigation regime and varieties

Treatment	Plant height (cm)		Number of tillers hill^{-1}		Biomass (gm hill^{-1})
	30 DAS	Harvest	90 DAS	Harvest	at 90 DAS
Irrigation					
I_1 AR-High moisture	28.7	74.9	17.8	20.0	363
I_2 AR- Medium moisture	28.8	72.1	15.4	18.3	282
I_3 AR-Low moisture	28.5	69.8	15.2	17.7	281
I_4-Transplanted rice	19.5	82.4	16.3	21.4	441
CD (p=0.05)	1.1	1.9	0.92	1.7	17
Variety					
V_1 Surendra	28.0	74.5	17.3	20.6	375
V_2 Lalat	27.0	79.2	16.6	19.3	348
V_3 Kandagiri	24.3	70.6	14.6	18.2	302
CD (p=0.05)	0.7	1.3	0.95	0.77	8.0

under aerobic condition compared to submerged soil was also reported by Insalud *et al.* (2006). Among the varieties, the highest root volume was observed in Surendra followed by Lalat. Root to shoot ratio, which is one of the important trait for the suitability of a particular variety to aerobic rice was more in the case of Lalat.

Table: 2
Root growth of rice as influenced by irrigation regime and varieties

Treatment	Root volume (cc)	Root shoot ratio	RLD (mm cm^{-3})	RWD (g cm^{-3})
Irrigation				
I_1 AR-High moisture	28.7	74.9	17.8	20.0
I_2 AR-Medium Moisture	28.8	72.1	15.4	18.3
I_3 AR-Low moisture	28.5	69.8	15.2	17.7
I_4-Transplanted rice	19.5	82.4	16.3	21.4
CD (p=0.05)	1.1	1.9	0.92	1.7
Variety				
V_1 Surendra	28.0	74.5	17.3	20.6
V_2 Lalat	27.0	79.2	16.6	19.3
V_3 Kandagiri	24.3	70.6	14.6	18.2
CD (p=0.05)	0.7	1.3	0.95	0.77

Yield, Yield Attributes and WUE

The highest panicles m^{-2} was recorded when aerobic rice was irrigated with the moisture status of 80-90% of ASM. It was followed by the rice cultivated under conventional method (Table 3). However, rice cultivated under transplanted condition produced significantly more filled grains per panicle compared to the rice grown under aerobic condition. There was no significant difference in filled grains per panicle among the varieties. Under aerobic method of rice cultivation, higher moisture regime (I_1 AR-high moisture) produced significantly higher filled grains per panicle compared to I2 AR- Medium moisture and I_3 AR-Low moisture regimes. This may be due to the fact that rice requires higher soil moisture during the flowering to grain filling. Any moisture stress leads to higher chaff grain and lesser filled grain. Zubaer *et al.* (2007) reported that when rice was exposed to water stress, there was significant decrease in filled grain $panicle^{-1}$ and dry matter production.

Interaction effect of irrigation regimes and varieties on grain yield is given in Table 4. The highest grain yield (4.05 t ha^{-1}) and straw yield (4.35 t ha^{-1}) were observed in the conventional rice cultivation. Among varieties, Surendra produced higher yield and it was on par with the variety Lalat. Reduction in yield due to aerobic cultivation compared to puddle condition was only 19% in case of I_1 treatment (higher moisture regime) and 59% in case of I_3 treatment (lower moisture regime). Interaction effect of irrigation regimes and variety shows that Surendra and Lalat produced higher grain yield when they were cultivated under transplanted condition. Among the irrigation regimes under aerobic condition, grain yield of all the varieties produced higher grain yield when they are grown under high and medium moisture regimes. More filled grains $panicle^{-1}$ were the most important factor which contributed for higher grain yield obtained from conventional rice cultivation. Even though rice produced higher biomass and panicles per m^2 under higher irrigation regimes under aerobic cultivation (I_1 AR-high moisture), the yield was lesser due to the higher chaffy grains present in the panicle compared to the conventional rice cultivation (I_4). Even though rice cultivated under aerobic condition produced higher root volume initially, it could not sustain the root growth as suberization of roots occurred in the later stages due to unfavourable condition compared to transplanted rice. Less

Table: 4
Interaction effect of irrigation regimes and varieties on yield (t ha^{-1})

Treatment regimes	Varieties			Mean
	Surendra	Lalat	Kandagiri	
I_1 AR-high moisture	3.95	3.82	2.32	3.36
I_2 AR-Medium moisture	3.62	3.60	2.24	3.15
I_3 AR-Low moisture	2.57	2.63	1.97	2.39
I_4-Transplanted rice	4.88	4.76	2.50	4.05
Mean	3.75	3.70	2.26	

CD (p=0.05) for main plot effect: 0.44; for sub plot effect: 0.21; interaction effect: 0.43

Table: 3
Yield attributes of different rice varieties under various irrigation regime

Treatment	Panicles m^{-2}	Filled grains per panicle	Chaff per panicle	Straw yield (t ha^{-1})	Harvest index
Irrigation					
I_1 AR-high moisture	555	50.3	20.1	3.65	0.48
I_2 AR- Medium moisture	492	44.7	23.5	3.47	0.48
I_3 AR-Low moisture	435	37.7	28.2	2.98	0.44
I_4-Transplanted rice	525	57.6	16.7	4.35	0.48
CD (p=0.05)	22	3.20	2.75	0.44	0.01
Variety					
V_1 Surendra	507	51.1	23.9	4.23	0.47
V_2 Lalat	496	49.6	21.5	3.85	0.49
V_3 Kandagiri	501	42.3	21.1	.75	0.45
CD (p=0.05)	NS	2.24	1.56	0.27	0.01

nutrient uptake (data not shown) due to the less feeder root in aerobic condition might contributed in the less biomass and grain in the later stages of rice growth. Suralta and Yamauchi (2008) concluded that when rice is grown under aerobic condition, the inability of roots to acclamatise to such changes in soil water regimes may result in reduced growth and function thereby, dry matter production.

However, higher Water Use Efficiency (WUE) was recorded under the aerobic method of rice cultivation compared to the transplanted rice (Table 5). The highest WUE and optimum yield was recorded in the variety *Surendra* under aerobic condition when irrigated at 80-90 % available soil moisture (I_1). Bouman *et al*. (2005) observed total water use and water productivity of aerobic rice was 27-51% lower and 32-88% higher than that of flooded rice, respectively.

Table: 5
Interaction effect of irrigation regimes and varieties on water use efficiency (kg grain ha^{-1} cm^{-1} of water)

Treatment regimes	Varieties			Mean
	Surendra	Lalat	Kandagiri	
I_1 AR-High moisture	53.2	51.5	31.3	45.3
I_2 AR-Medium moisture	51.6	51.3	31.9	44.9
I_3 AR-Low moisture	44.0	45.2	33.9	41.0
I_4-Transplanted rice	36.9	33.9	18.9	29.9
Mean	46.4	45.5	29.0	

CD (p=0.05) for main plot effect: 4.9; for sub plot effect: 3.09; interaction effect: 2.9

4. CONCLUSIONS

The result of the study shows that aerobic rice can be grown in water-short areas that have insufficient water for the production of lowland rice. Compared with lowland rice, the reduction in water requirement much more than the yields and thus the water productivity of aerobic rice is higher than the lowland rice (64-88% in our study). Consequently, in areas where water is relatively scarce, total rice production can be maximized by growing aerobic rice. Among the varieties, Surendra performed better under aerobic condition followed by the variety Lalat.

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