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Research Paper

Optimization of nitrogen fertilization for aerobic rice (*Oryza sativa*)

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ABSTRACT

Field experiments were conducted during the rainy (*kharif*) seasons of 2014 and 2015 at Aduthurai, Tamil Nadu, to assess the efficiency of N scheduling and dosage for aerobic rice (*Oryza sativa* L.) cultivation. The soil was clay loam. The experiments were laid out in a split-plot design with 3 replications. The main plot treatments consisted of 4 nitrogen(N) levels and the subplots 6 N split doses. Among the N levels, application of 200 kg N/ha registered higher growth parameters, N uptake and yield attributes. The growth attributes of aerobic rice increased with the increased N dose up to 200 kg N/ha and was comparable with 175 and 150 kg N/ha. The higher grain yield and benefit: cost (B: C) ratio were observed with the application of 175 kg N/ha. Among the split doses, N at 4 splits (1/4 at 10–12 days after emergence + 1/4 at active tillering stage + 1/4 at panicle-initiation stage + 1/4 at flowering) recorded higher growth parameters, yield attributes, grain yield, gross returns, net returns and eventually higher B: C ratio. Achieving higher yield with remunerative B: C ratio, a nitrogen dose of 175 kg N/ha in 4 splits 1/4 at 10–12 days after emergence + 1/4 at active tillering stage + 1/4 at panicle-initiation stage + 1/4 at flowering can be recommended for sustaining the aerobic rice yield.

Key words: Aerobic rice, B:C ratio, Grain yield, Growth parameters, Split doses, Yield attributes

Rice production and food security largely depend on the irrigated lowland rice system, whose sustainability is threatened by freshwater scarcity, water pollution and competition for water use. Water scarcity is the major problem which causes decrease in crop yield. Flooded and irrigated rice system consumes twice or thrice the amount of water need for other cereals, such as maize or wheat. Aerobic rice is one of the approaches in rice production that leads to a considerable amount of water saving. It is characterized by aerated soil environment during the crop-growth period. This concept was first developed in China during mid 1980's. The term "Aerobic rice" was coined by the International Rice Research Institute for high-yielding rice grown in non-puddled and non-flooded aerobic soil with the use of external inputs such as supplementary irrigation and fertilizers (Bouman and Tuong, 2001). Research on aerobic rice have high hopes because some strains of rice known as upland varieties are already successfully grown in dry soil. Impact of aerobic irrigation on growth characters and yield of aerobic rice was well documented under clay soils of Tamil Nadu (Subramanian *et al.,* 2008; Srimathi *et al.,* 2018).

Nitrogen is a key element in determining the level of crop productivity. In India, about 67% of rice soils are estimated to be deficit in nitrogen and consequently rice crop has become a major consumer of nitrogen fertilizer. The efficiency of applied nitrogen fertilizer by rice crop is very low ranging from 25 to 50%. Rice consumes about 40% of total fertilizer nitrogen used in India. Nitrogen nutrition is the important agronomic practice that affects the yield and quality of rice crop. Nitrogenous fertilizer is one of the costliest and perhaps the most crucial primary nutrients which can limit the rice yield. Though modern rice varieties respond well to N fertilization, the recovery of applied N is very low. Application of N in 3 to 4 splits at sowing, active tillering, late tillering and panicle-initiation stage to semi-dwarf varieties proved beneficial in terms higher yield coupled with minimum N loss. Therefore, application of appropriate quantity of fertilizer N at the right time is one of the important agronomic techniques to increase yield and N uptake of aerobic rice (Mohana Keerthi *et al.,* 2018). Hence fractional application of nitrogen in right quantity and proportion and timely supplement seems to be a practical preposition. Many workers (Pandey and Namdeo, 2016; Pooja *et al*., 2018) found that, splitting the

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application of nitrogen at appropriate physiological growth stages of rainy season (*kharif*) crops increased the uptake compared to application of all the quantity of fertilizer N at sowing. In view of the above facts, the present research on N levels and split doses for aerobic rice was taken up during the *kharif* season in the clay loam soils.

MATERIALS AND METHODS

The field experiment were conducted during rainy (*kharif*) season of 2014 and 2015 to assess the efficiency of N levels and dosage for aerobic rice cultivation at the Tamil Nadu Rice Research Institute, Aduthurai. The experiments were laid out in a split-plot design with 3 replications. The main-plot treatments consisted of 4 N levels, viz. 125, 150, 175 and 200 kg N/ha, mainly to optimize the N dose for aerobic rice. The subplot consisted of 6 nitrogen scheduling, viz*.,* N in 2 splits [1/2 at basal + 1/2 at panicle-initiation (PI stage)], N in 2 splits (1/2 at 10–12 days after emergence (DAE) + 1/2 at PI stage), N in 3 splits (1/3 at basal + 1/3 at active tillering (AT) stage + 1/3 at PI stage), N in 3 splits (1/3 at 10–12 DAE + 1/3 at AT stage + 1/3 at PI stage), N in 4 splits (1/4 at basal + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering stage) and N in 4 splits (1/4 at 10-12 DAE + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering stage). The absolute control was maintained for working out the agronomic indices. Seeds of 'ADT 45' (40 kg/ha) were soaked in water for 24 hours and incubated for 12 hours. The seed soaking and incubation is very essential for quick and uniform germination of seeds. The seeds were line sown at 20 cm × 10 cm spacing under unpuddled condition. Fertilizer application was done as per the treatment schedule. The pre-sowing composite soil samples were collected initially from the experimental field and analysed for the physico-chemical properties. The experimental field soil is clay loam in texture which is taxonomically known as *typic haplustalf.* The nutrient status of soil was 163 - 48 - 298 kg N-P_2O_5-K_2O/ha. The crop was irrigated at irrigation water: cumulative pan evaporation (IW: CPE) ratio 1 up to 60 days thereafter IW/CPE ratio 1.50. An amount of 168 mm of mean rainfall was received during the cropping period. Pre-emergence application of pendimethalin at 0.75 kg a.i/ ha was applied at 3 DAS followed by hand-weeding at 45 DAS. The yield of unfertilized plots was recorded separately. The crop yield was only 2.08 t/ha with the N uptake of 49.4 kg/ ha. The crop was harvested at full maturity, the border rows all around the plots were harvested first and then the plants from the net plots were harvested and threshed. Grain-moisture content was measured and grain yield was computed for 14% moisture. Straw from each plot was dried and weighed. The N-use efficiency parameters, viz. agronomic efficiency (AE), physiological efficiency (PE) and apparent N recovery, were worked out. The growth parameters at flowering, yield attributes and yield were recorded at the time of harvesting and analysed statistically.

RESULTS AND DISCUSSION

Growth parameters of aerobic rice

An increase in N level resulted in significant variation in growth parameters, viz. plant height, leaf-area index (LAI) and tillers/ m^2 (Table 1). Application of N at 200 kg/ha resulted in higher growth parameters, viz. plant height (119.8 cm), LAI (4.94) and tillers/m^2 (551) and was comparable with 150 and 175 kg N/ha. This may be owing to the fact that nitrogen is an integral part of chlorophyll, proteins, enzymes and structural material. Nitrogen functions as stored energy during active growth stage of the crop. Thus, it is deeply involved in photosynthesis, respiration and protein synthesis. Reddy *et al.* (2013) also reported beneficial effect of increased level of nitrogen fertilizer on growth parameters of aerobic rice. Among the split doses, nitrogen in 4 split doses significantly superior to the other split doses of 2 and 3 irrespective of the stages of application. Nitrogen in 4 split doses (1/4 at 10-12 DAE + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering) recorded higher growth parameters, viz. plant height (123.7 cm), LAI (5.34) and tillers / m^2 (568). This was comparable with N in 4 splits of 1/4 at basal + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering and N at 3 splits of 1/3 at 10-12 DAE + 1/3 at AT stage + 1/3 at PI stage. Application of nitrogen in 4 splits (1/4 at 10–12 DAE + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering) according to the crop needs was the reason for better rice growth parameters (Mohana Keerthi *et al.,* 2018).

Application of 175 kg N/ha recorded higher accumulation of dry-matter production of 7.53 t/ha. Among the split doses, nitrogen in 4 split doses (1/4 at 10–12 DAE + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering) resulted in higher dry-matter production (DMP) of 7.72 t/ha.

Yield attributes and yield

Increasing N levels from 125 to 200 kg N/ha increased the yield attributes, viz. panicle/m^2, panicle weight and grains/panicle (Table 1). However, the magnitude of increase was higher up to 150 kg N/ha thereafter the increase was not marginal. Application of N at 200 kg/ha recorded higher values of yield attributes, viz. panicle/m^2 (339) and grains/panicle (126.1). This was comparable with application of 175 and 150 kg N/ha. The increased yield attributes under higher dose might be owing to accelerated photosynthetic rate of plant growth and partitioning of photosynthates (assimilates) to economic sink. These findings confirm results of Kumar *et al.* (2015). Trend was different in case of panicle weight. Application of N at 150 kg/ha recorded higher panicle weight (2.88 g). Nitrogen at 150 kg/ha was found at par with the application of N at 200 and 175 kg/ha in terms of panicle weight.

Among the split doses, nitrogen in 4 split doses (1/4 at 10–12 DAE + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering) resulted in higher yield attributes, viz. panicles/ m^2 (373), panicle weight (3.07 g) and grains/ panicle (130.4). This was comparable with N at 4 splits (1/4 basal + 1/4 AT stage + 1/4 at PI stage + 1/4 at flowering). This could be due to the fact that increasing dose of nitrogen at tillering stage produced higher leaf area, biomass coupled with more number of tillers. Further, increasing the dose at panicle-initiation stage might have improved the yield attributes like more number of panicle, grains/panicle and panicle weight through the mechanism of improved grain-filling process. This was in accordance with the findings of Sathiya and Ramesh (2009), who stressed the importance of split application of nitrogen at tillering and panicle-initiation stages.

Grain yield of aerobic rice was influenced by N scheduling and split doses (Table 1). Application of N at 175 kg/ha recorded higher grain yield of 3.78 t/ha and was comparable with 200 kg N/ha. The yield increase in 175 kg N/ha was to the tune of 16.6 and 7.3% higher than 125 and 150 kg N/ha, respectively. A further addition of N did not produce any significant variation in the yield of aerobic rice beyond 175 kg N/ha. Subramanian *et al.* (2008) and Sharma (2015) reported beneficial effect of higher dose of nitrogen

Among the split doses, nitrogen in 4 split doses (1/4 at 10–12 DAE + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering recorded higher grain yield of 4.15 t/ha. This was comparable with N in 4 splits of 1/4 at basal + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering and N at 3 splits of 1/3 at 10–12 DAE + 1/3 at AT stage + 1/3 at PI stage. Availability of adequate quantity of nitrogen during critical stages of plant growth might have resulted in better growth parameters and yield attributes at various phenological stages and finally on the yield of aerobic rice. Sathiya and Ramesh (2009) also reported that, application of N in 2 to 4 splits increases the rice yield. Hence application of N as basal may be skipped and be applied at 10–12 DAE for higher yield and to reduce the N losses; though the interaction effect of N levels and split applications was absent. Among the combination, the highest yield was obtained when N at 175 kg was applied in 4 split 1/4 at 10–12 days after emergence + 1/4 at active tillering stage + 1/4 at panicle-initiation stage + 1/4 at flowering.

Higher nitrogen uptake was recorded with application of 200 kg N/ha (95.4 kg/ha) (Table 2). This might be due to higher dose of nitrogen that ledleads to better growth and development of rice with higher DMP in this treatment. Among the split doses, nitrogen in 4 split doses (1/4 at 10–12 DAE + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flow-

Table 1. Effect of different nitrogen levels and doses on growth attributes, yield attributes and yield of aerobic rice (pooled data)

Treatment	Plant height (cm) at flowering	LAI at flowering	Tillers/ m^2	Dry-matter production (t/ha)	Panicles /m^2	Panicle weight (g)	Grains/ panicle	Yield (t/ha)
Nitrogen levels (kg N/ha)								
125	112.1	4.67	511	6.86	298	2.77	119.3	3.24
150	116.2	4.82	531	7.22	326	2.88	124.0	3.52
175	117.5	4.90	542	7.53	337	2.86	124.6	3.78
200	119.8	4.94	551	7.30	339	2.87	126.1	3.69
SEm±	1.5	0.06	10.4	0.17	7.5	0.05	1.2	0.10
CD (P=0.05)	3.7	0.14	24.5	0.40	18	0.14	3.0	0.25
Split doses								
2 splits (½ basal + ½ PI stage)	109.5	4.34	497	6.65	269	2.64	116.7	2.99
2 splits (½ 10–12 DAE + ½ PI stage)	110.9	4.36	504	6.87	286	2.68	119.5	3.14
3 splits (basal + $^1/_3$ AT stage + $^1/_3$ PI stage)	116.4	4.73	534	7.16	329	2.85	123.9	3.51
3 splits ($^1/_3$ 10–12 DAE + $^1/_3$ AT stage + $^1/_3$ PI stage)	118.0	4.85	546	7.35	345	2.89	126.4	3.63
4 splits (¼ basal + ¼ AT stage + ¼ at PI stage + ¼ at flowering)	119.7	5.26	553	7.51	359	2.99	128.0	3.93
4 splits (¼ 10–12 DAE + ¼ AT stage + ¼ at PI stage + ¼ at flowering)	123.7	5.34	568	7.72	373	3.07	130.4	4.15
SEm±	1.8	0.07	12.6	0.16	9.4	0.07	1.4	0.13
CD (P=0.05)	3.8	0.15	25.5	0.37	20	0.15	2.9	0.28

PI, Panicle initiation; DAE, days after emergence; At, active tillering

ering) recorded higher nitrogen uptake of 97.6 kg/ha.

Efficiencies, apparent nitrogen recovery and benefit: cost ratio

Agronomic efficiency (AE) indicates the quantity of rice/unit of N applied and is the product of efficiency of absorption as well as utilization. Increased levels of N tend to lower the AE. Higher AE (14.5 %) is associated with the lowest N level of 125 kg/ha and it tends to decrease progressively with additional level of N. The highest level of 200 kg N/ha resulted AE of only 11.3 kg rice/kg N applied. Application of 175 kg N/ha registered higher physiological efficiency (PE) of 39.0 and 125 kg N/ha showed higher apparent nitrogen recovery (ANR) of 28.32%. Among the split doses, nitrogen in 4 splits (1/4 at 10–12 DAE + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering) registered higher physiological efficiency of 42.9 and apparent nitrogen recovery of 29.6%. Application 175 kg N/ha resulted in higher gross return (₹58,711/ha), net returns (₹35,690/ha) and benefit: cost ratio (2.55) (Table 2). This might be owing to higher yield of aerobic rice with increased N level. Among the split doses, nitrogen in 4 split doses (1/4 at 10–12 DAE + 1/4 at AT stage + 1/4 at PI stage + 1/4 at flowering) registered higher cost of cultivation (₹23,021/ha), gross returns (₹64,193/ha), net returns (₹41,171/ha) and B: C ratio (2.78) than the same dose applied in 4 split doses including basal application.

Optimization of nitrogen for aerobic rice

The yield response to different N levels was fitted into mathematical equation for working out physical and economic optimum. The optimum dose of nitrogen level at which higher yield can be obtained was found to be 184.4 kg (By equating dY/dN = 0). The economic optimum is the nitrogen level at which highest net return can be obtained and it was found to be 180.1 kg (by equating dY/dN = pY/pN). Presently, nitrogen dose for aerobic rice is the same as that for transplanted rice (150 kg/ha) in the rice bowl of Cauvery delta zone of Tamil Nadu (Karthika *et al.,* 2019).

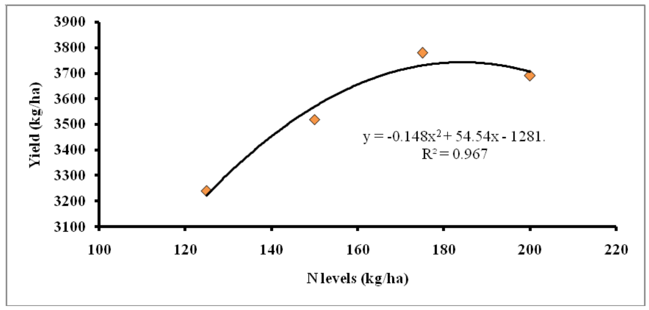

Fig. 1. Optimization of N levels for aerobic rice

Table 2. N uptake, agronomic efficiency (AE), physiological efficiency (PE), apparent nitrogen recovery (ANR) and economics of aerobic rice as influenced by nitrogen level and splits (pooled data)

Treatment	N uptake (kg/ha)	AE (%)	PE (%)	ANR (%)	Cost of cultivation (× 10³₹/ha)	Gross return (× 10³₹/ha)	Net returns (× 10³₹/ha)	Benefit: cost ratio
Nitrogen (kg N/ha)								
125	84.8	14.5	32.8	28.3	22.56	50.6	28.09	2.24
150	89.5	13.9	35.9	26.7	22.62	54.97	32.35	2.43
175	93.0	13.4	39.0	24.9	23.02	58.71	35.69	2.55
200	95.4	11.3	35.0	23.0	23.41	57.49	34.07	2.45
SEm±	0.9	0.5	1.2	0.8	0.23	0.24	0.24	0.08
CD (P=0.05)	2.4	1.2	2.9	2.1	0.58	0.61	0.60	0.2
Split doses								
2 splits (½ basal + ½ PI stage)	84.9	9.7	25.6	21.8	22.98	46.81	23.82	2.03
2 splits (½ 10–12 DAE + ½ PI stage)	87.6	10.6	27.7	23.5	22.69	49.28	26.59	2.17
3 splits (⅓ basal + AT stage + ⅓ PI stage)	90.7	13.0	34.6	25.4	22.85	54.81	31.96	2.40
3 splits (⅓ 10–12 DAE + AT stage + ⅓ PI stage)	92.4	13.8	36.0	26.5	22.85	56.59	33.73	2.47
4 splits (¼ basal + ¼ AT stage + ¼ at PI stage + ¼ at flowering)	94.2	15.6	41.2	27.6	23.02	61.05	38.03	2.65
4 splits (¼ 10–12 DAE + ¼ AT stage + ¼ at PI stage + ¼ at flowering)	97.6	17.0	42.9	29.7	23.02	64.19	41.17	2.78
SEm±	0.97	0.05	1.1	0.8	0.23	0.25	0.27	0.07
CD (P=0.05)	2.1	0.8	2.4	1.8	0.50	0.55	0.58	0.14

DAE, Days after emergence; PI, panicle initiation; At, active tillering

Optimization studies and economic analysis, based on gross returns, net returns and B: C ratio, indicated that an additional quantity of 25 kg fertilizer N is needed to enhance the yield potential of aerobic rice in the rice bowl of Cauvery delta zone of Tamil Nadu.

The results indicated that, the aerobic rice well responded to the applied nutrients especially nitrogen. Now, the N dose and its split for aerobic rice are same as that of transplanted rice in the rice bowl of Cauvery delta zone of Tamil Nadu. Hence the revision of fertilizer dose and split application is needed for increasing the production and productivity when rice is grown by aerobic method. For achieving higher yield with remunerative B:C ratio, a nitrogen dose of 175 kg N/ha in 4 splits 1/4 at 10–12 days after emergence + 1/4 at active tillering stage + 1/4 at panicle-initiation stage + 1/4 at flowering, can be recommended for sustaining the aerobic rice yield for Cauvery delta zone of Tamil Nadu.

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