Indian Journal of Agronomy **58** (4): 506–511 (December 2013)

Research Paper

Effect of establishment methods and nitrogen levels on basmati rice (*Oryza sativa*)

JAGJOT SINGH GILL[1] AND SOHAN SINGH WALIA[2]

Punjab Agricultural University, Ludhiana, Punjab 141 004

Received : June 2013; Revised accepted : December 2013

ABSTRACT

A field experiment was conducted during the rainy (*kharif*) season 2010 and 2011 at the Punjab Agricultural University, Ludhiana, with 6 establishment methods in horizontal plots and 4 nitrogen levels in vertical plots in strip-plot design on sandy-loam soil. Machine transplanted basmati rice (*Oryza sativa* L.) after puddling being statistically on par with direct-seeding methods, showing significantly higher values of growth and yield attributes. Yield attributes like panicle length and 1,000-grain weight were statistically at par among different methods of establishment, but spikelets/panicle and grains/panicle were significantly higher with machine-transplanted basmati rice after puddling. Machine transplanted rice after puddling gave 0.87, 2.67, 4.53, 4.85 and 7.12% more grain yield over direct-seeded basmati rice with brown manuring, direct-seeded basmati rice without brown manuring, conventional transplanted rice, machine transplanted rice in zero-tilled plots with brown manuring and machine transplanted rice in zero tilled plots without brown manuring respectively. Machine transplanting after puddling recorded significantly higher N-use efficiency followed by direct-seeded basmati rice with brown manuring and machine transplanting in zero-tilled plots with brown manuring. Direct-seeding of basmati rice and machine transplanting of basmati rice in zero-tilled plots showed the benefit: cost ratio and net return, and hence proved more remunerative than machine transplanting after puddling and conventional practice. The plant growth characters, yield attributes, grain and straw yields were significantly higher with application of 125% of recommended dose of nitrogen. 125% of recommended dose of nitrogen showed significantly higher N-use efficiency as compared to all other nitrogen levels.

Key words : Brown manuring, Crop production, Direct-seeded basmati rice, Establishment methods, Machine transplanting, Nitrogen

Rice is a staple food for majority of world's population. Rice is grown by transplanting of the seedling in the puddled fields of Indo-Gangetic plains (IGP) in general and Trans-Gangetic region of IGP of Punjab in particular. This technique, however, is very cumbersome, labour intensive, time consuming and costly. It requires raising of nursery, its uprooting, transplanting in the field and continuous ponding of water for the first 15 days. This in turn leads to nutrient losses through leaching besides causing high evapotranspiration (ET) losses during the hot summer months. Moreover, under practical situation of contractually transplanted fields, it often, at cultivars' fields leads to lesser plant population, which generally varies from 16 to 21 hills/m^2 as against the optimum of 33 hills/m^2. Presently, in Punjab the underground water is being over-exploited by excessive pumping to meet the water need of transplanted paddy. As a consequence it has been causing a sharp decline in water table. Rice production under current inputs and technology is likely to fail to meet the projected demand (Leeper, 2010) besides an urgent need to increase rice productivity per unit area in the world. Increasing yields in aerobic rice systems (ARSs) 'the direct-seeded rice' (DSR) can play a key role in increasing rice production globally (Prasad, 2011).

Therefore, DSR offers the advantage of faster and easier planting, ensure proper plant population, reduce labour and hence less drudgery, 10–12 days earlier crop maturity, more efficient water use and higher tolerance to water deficit, and often high profit in areas with assured water supply (De Datta, 1986) and (Dingkuhn *et al.*, 1990). To make the rice cultivation cost-effective, to ensure the rational use of water and to get rice best fit in different cropping systems on account of early maturity, cultivation of DSR seems to be the best option. Nitrogen is an

Based on part of Ph.D. Thesis of first author submitted to Punjab Agricultural University, Ludhiana during 2012 (Unpublished)

[1]**Corresponding author Email:** jagjotsinghgill@yahoo.co.in
[1]Ph.D. Scholar; [2]Agronomist, Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab 141 004

influential factor in rice production and its immense role in increasing rice productivity is well documented Kropff *et al.* (1993). The information on nitrogen requirement of direct- seeded basmati rice for realizing optimum yield is meager. The present experiment was undertaken to study the effect of different rice establishment methods and nitrogen levels on yield of basmati rice.

MATERIALS AND METHODS

The field experiment was conducted at Department of Agronomy, Punjab Agricultural University, Ludhiana during the rainy (*kharif*) seasons of 2010 and 2011. The composite soil samples from 0–15 and 15–30 cm profile layers. The soil was sandy loam with normal soil reaction (8.10 and 8.00) and electrical conductivity (0.36 and 0.32 dS/m), low in organic carbon (0.28 and 0.26 %) and available N (255.02 and 238.20 kg/ha), medium in available P (19.10 and 17.20 kg/ha) and K (155.00 and 140.00 kg/ha) at both the locations. The experiment was conducted in strip plot design with 4 replications. The treatments consisted of 6 establishment methods, viz. direct-seeded basmati rice, direct-seeded basmati rice with brown manuring, machine transplanting in zero-tillage (ZT) with brown manuring, machine transplanting in zero-tillage (ZT) without brown manuring, machine transplanting after puddling and conventional practice in horizontal plots; and 4 nitrogen levels, viz. control, 75% of recommended dose of nitrogen, 100% of recommended dose of nitrogen and 125% of recommended dose of nitrogen in vertical plots. Nitrogenous fertilizer was applied in 2 equal splits to transplanted basmati rice at about 3 weeks and 6 weeks after transplanting. Two equal splits of nitrogenous fertilizer were also applied to DSR with half dose after 2 weeks and rest half of nitrogen was applied 5 weeks after sowing. Basmati rice variety ‘Punjab Mehak 1’ was used as test variety. For brown manuring, seeding of *Sesbania* was done 30 days before the sowing of direct-seeded rice and machine transplanting of rice in zero-tilled plots. 2, 4-D @ 1 kg/ha was sprayed on *Sesbania* 3 days before direct sowing of rice and transplanting of rice with machine in zero tilled plots. The sowing of direct-seeded rice (DSR) was done on 24 June during the first year and 27 June during the second year with rice drill in dry moist soil. Nursery for machine transplanting was raised in plastic trays. Sowing of nursery was done on 24 June during the first year and 27 June during the second year using seed @ 30 kg/ha for raising nursery in trays. Twenty-five-day-old nursery was used in mechanized transplantation. In case of conventional transplanting, nursery was raised by broadcasting seed on 24 June during the first year and 27 June during the second year with seed rate of @ 20 kg for transplanting a hectare. Transplanting was done using 25-day-old seedlings. Machine transplanting was done by paddy transplanter. In zero-tilled plots it was done in standing water. In conventional transplanting, nursery was irrigated before uprooting. Seedlings were uprooted and transplanted 2 seedlings/hill about 2–3 cm deep in puddled field in lines at 20 cm × 15 cm spacing manually. In direct-seeded rice and transplanted rice weeds were controlled by applying pendimethalin @ 2.5 litres/ha within 2 days of sowing and transplanting of basmati rice and bispyribac @ 250 ml/ha at 30 days after sowing and 25 days after transplanting of basmati rice respectively. The left-over weeds were removed by 2 hand-weedings in DSBR after 51 and 66 days after sowing and 1 hand-weeding in transplanted rice 56 days after transplanting during the rainy *(kharif*) season of 2010. In the rainy (*kharif*) season of 2011 left-over weeds were removed by 2 hand-weedings in DSBR 50 and 72 days after sowing and 1 hand-weeding in transplanted rice 49 days after transplanting. Irrigation was applied as per requirement to direct-seeded basmati rice. In transplanted rice, water was kept standing continuously for first 15 days after transplanting. After that irrigations were applied 2 days after the ponded water had infiltrated into soil. No irrigation was applied on rainy days. Irrigation application was withheld 15 days before harvesting of crop. Fungicide Tilt 25 EC @ 500 ml/ha and insecticide monocrotophos @ 1,400 ml/ha during the rainy *(kharif*) seasons of 2010 and 2011 was applied to basmati rice. Direct-seeded basmati rice was harvested on 18 and 19 October during the first and second year and harvesting of transplanted basmati rice was done on 29 October and 3 November during the first and second year. Observations of growth and yield-attributing characters were recorded at 60 and 90 days after sowing and harvesting of basmati rice under different treatments. Plant height was recorded from each plot at 10 different selected plants. Data on dry matter were recorded on 5 random places in each plot and plant biomass taken from these places to ensure the increase in biomass production overtime. Leaf-area index (LAI) was recorded by using the Sun Scan Canopy Analyzer. The numbers of panicle-bearing tillers were counted with the help of scale from 1 m row length for effective tillers/m^2. Five panicles were selected at random from each plot to compute panicle length, spikelets/panicle, and grains/panicle. For test weight, 1,000 grains were counted from each treatment and then their weight was recorded. The crop was harvested manually with the help of sickle when grain almost matured and straw had turned yellow and data on grain and straw yield were recorded. Nitrogen-use efficiency (N-use efficiency) was worked out as per Raun and Johanson (1999). The cost of cultivation and returns were calculated by taking into account the prevailing cost of inputs and prices of output.

RESULTS AND DISCUSSION

Growth parameters

Establishment methods: Plant height was significantly higher with machine transplanting of basmati rice after puddling (Table 1) than that with all other treatments but was on a par with direct-seeded basmati rice with brown manuring, which was also on a par with direct-seeded basmati rice without brown manuring (Singh *et al.,* 2005; Yadav and Singh, 2006). Machine transplanting of basmati rice after puddling produced significantly more dry matter than all the other transplanting methods of establishment of basmati rice, but was statistically on a par with both direct-seeding methods of basmati rice. Significantly more LAI was produced by machine transplanting of basmati rice after puddling (Table 1) over all other methods of establishment (Gangwar *et al.,* 2009; Dixit *et al.,* 2010). Both methods of direct-seeding, viz. direct-seeded basmati rice with brown manuring and direct-seeded basmati rice without brown manuring, produced significantly more LAI than both methods of transplanting with machine in zero-tilled plots and conventional method of transplanting of basmati rice (Zhang and Zhu, 1999).

Nitrogen: Plant height recorded in the control, 75% of recommended dose of nitrogen and 100% of recommended dose of nitrogen were statistically at par (Table 1), whereas 125% of recommended dose of nitrogen recorded significantly taller plants than all other nitrogen levels during both the years, as also reported by (Kumar *et al.,* 2007; Sathiya *et al.,* 2008. Nitrogen application might have resulted in beneficial effect on cell division and cell elongation and it resulted in increased chlorophyll content and net photosynthetic rate which might be attributed to the increase in plant height with increase in nitrogen level as reported by (Venkataramon *et al.,* 2000). The results showed that 125% of recommended dose of nitrogen produced significantly higher dry matter (Table 1) as compared to all other levels of nitrogen, confirming findings of (Rammohan *et al.,* 2000). Nitrogen is primary nutrient required for development of leaves and had significant effect on LAI. There was an increase in LAI with increase in nitrogen levels and LAI was significantly higher in treatment 125% of recommended dose of nitrogen than the other N treatments and control (Table 1). All nitrogen levels were significantly different from each other for LAI. Increase in nitrogen levels helped in better development of leaves and was also involved in chlorophyll formation that is main source of photosynthesis and hence resulted in increase in LAI (Mhaskar *et al.,* 2005).

Yield attributes and yield

Establishment methods: Effective tillers/m^2 varied with different establishment methods (Table 1) and significantly higher effective tillers/m^2 were recorded with machine transplanting after puddling method which was statistically at par with direct-seeded basmati rice with brown manuring method during both the years and gave 2.70, 4.23, 5.03 and 7.12% more effective tillers/m^2 than direct-seeded basmati rice without brown manuring, conventional transplanting, machine transplanting in zero-tilled plots with brown manuring and machine transplanting in zero-tilled plots without brown manuring (Gangwar *et al.,* 2009; Gill *et al.,* 2006. Inter-plant competition ultimately might have resulted in more tiller mortality and thus showed decline in number of effective tillers/m^2. Effect of

Table 1. Effect of different crop establishment methods and nitrogen levels on growth and yield attributes of basmati rice (pooled data of 2010 and 2011)

Treatment	Plant height (cm)	Dry matter accumulation (t/ha)	Leaf area index	Effective tillers/m^2
Establishment methods				
DSBR	101.7	15.0	3.2	251.9
DSBR with brown manuring *Sesbania*	103.1	15.3	3.4	256.2
Machine transplanting in ZT with brown manuring	100.9	12.9	2.9	246.3
Machine transplanting in ZT without brown manuring	97.3	12.6	2.8	241.5
Machine transplanting after puddling	103.7	15.4	3.6	258.7
Conventional practice	101.2	13.3	3.0	248.2
SEm±	0.5	0.2	0.1	1.1
CD (P=0.05)	1.6	0.5	0.2	3.2
Nitrogen levels (kg/ha)				
Control	99.4	13.7	1.9	173.8
75% of recommended dose of nitrogen	99.8	13.9	2.9	244.0
100% of recommended dose of nitrogen	100.6	14.3	3.3	283.9
125% of recommended dose of nitrogen	105.5	14.6	3.6	300.3
SEm ±	0.6	0.0	0.1	1.1
CD (P=0.05)	1.7	0.3	0.2	3.2

different crop establishment methods on panicle length was non-significant. The results confirm the reports of Meisner *et al.* (2005); Gill *et al.* (2006). Machine transplanting of rice after puddling recorded significantly more spikelets/panicle than all other methods of establishment, but was statistically at par with both direct-seeding methods. Direct-seeded basmati rice without brown manuring was on a par with conventional transplanting method. Conventional transplanting method resulted in significantly more spikelets/panicle over both the methods of machine transplanting in zero tilled plots (Table 2). Machine transplanting of rice after puddling significantly increased grains/panicle (Table 2) compared to other methods of establishment but was statistically at a par with both methods of direct seeding (Pradhan, 1969). Test weight is a function of various production factors that gives an indication of grain development and filling patterns as influenced by various factors. Crop-establishment methods did not affect this attribute and the differences among different crop establishment methods were found to be non-significant our results confirm those of Gill *et al.* (2006). Grain yield is a function of growth and yield-attributing parameters. Grain yield is the main criterion for judging the comparative efficacy of different treatments. Machine transplanting of rice after puddling yielded significantly higher rice yield than the other methods of establishment but was statistically at par with direct-seeded basmati rice with brown manuring (Table 2). Machine transplanted basmati rice after puddling resulted in 3.12, 3.12, 3.12 and 6.45% higher grain yield over direct-seeded basmati rice without brown manuring, conventional transplanted rice, machine transplanted rice in zero-tilled plots with brown manuring and machine transplanted rice in zero-tilled plots without brown manuring. Direct-seeded basmati rice without brown manuring, conventional transplanted rice and machine transplanted rice in zero-tilled plots with brown manuring were statistically at par. Higher grain yield with machine transplanting of rice after puddling was mainly owing to better yield attributes through optimum utilization of resources, which had a direct bearing on production of higher yield of basmati rice. The results confirm the findings of Gangwar *et al.* (2009); Dixit *et al.* (2010). The straw yield is a function of crop biomass developed during the crop growth period. The data on straw yield (Table 2) showed that different crop establishment methods had a non-significant effect on straw yield. The increase in straw yield in machine transplanted rice after puddling was 1.19, 3.66, 4.94, 4.94 and 7.59% with respect to direct-seeded basmati rice with brown manuring, direct-seeded basmati rice without brown manuring, conventional transplanted rice, machine transplanting basmati rice in zero-tilled plots with brown manuring and machine transplanting of rice in zero-tilled plots without brown manuring.

Nitrogen: Nitrogen had a significant effect on number of effective tillers/m^2. Effective tillers/m^2 increased with each corresponding increase in nitrogen level up 125% of recommended dose of nitrogen. All nitrogen levels differed significantly from one another and significantly higher effective tillers/m^2 were recorded with 125% of recommended dose of nitrogen. 125% of recommended dose of nitrogen level gave 5.77, 23.07 and 72.78% higher

Table 2. Effect crop establishment methods and nitrogen on panicle length, spikelets/panicle and grains/panicle, test-weight, grain and straw yield of basmati rice (pooled data of 2010 and 2011)

Treatment	Panicle length (cm)	Spikelets/ panicle	Grains/ panicle	Test-weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	NUE (%)
Establishment methods							
DSBR	26.3	74.9	136.0	21.4	3.2	8.2	71.8
DSBR with brown manuring *Sesbania*	26.4	75.5	137.2	21.4	3.3	8.4	76.8
Machine transplanting in ZT with brown manuring	25.7	67.7	125.8	21.7	3.2	8.1	72.2
Machine transplanting in ZT without brown manuring	25.4	65.4	121.0	22.0	3.1	7.9	67.1
Machine transplanting after puddling	26.7	77.4	141.1	21.6	3.3	8.5	83.7
Conventional practice	26.2	71.9	129.9	22.0	3.2	8.1	63.8
SEm±	0.4	1.1	2.0	0.2	0.0	0.1	1.4
CD (P=0.05)	NS	3.2	5.8	NS	0.1	NS	4.2
Nitrogen levels (kg/ha)							
Control	20.6	55.5	98.1	18.7	2.1	6.2	0.0
75% of recommended dose of nitrogen	25.9	70.8	130.0	21.5	3.1	7.6	78.1
100% of recommended dose of nitrogen	26.3	72.2	132.6	21.6	3.7	8.7	97.2
125% of recommended dose of nitrogen	26.7	75.0	142.1	21.8	3.9	9.7	115.0
SEm±	0.2	1.5	4.3	1.1	0.0	0.2	1.4
CD (P=0.05)	0.6	4.4	12.7	0.4	0.1	0.6	4.3

effective tillers/m^2 over 100% of recommended dose of nitrogen, 75% of recommended dose of nitrogen and control respectively (Table 1). Higher number of effective tillers/m^2 were probably recorded owing to more utilization and uptake of nutrients mainly nitrogen which had significant role to play in photosynthesis and tillering of rice (Kumar and Ikrammullah, 2004). Panicle length increased with increase in nitrogen levels. Nitrogen @ 125% of recommended dose of nitrogen being statistically at par with 100% of recommended dose of nitrogen gave significantly longer panicles as compared to control and 75% of recommended dose of nitrogen (Table 2). Vishvakarma *et al.* (2008) and Kanyika *et al.* (2007) also reported increase in panicle length with increasing nitrogen level. Spikelets/panicle differed significantly with increasing levels of nitrogen. Nitrogen level 125% of recommended dose of nitrogen produced significantly higher number of spikelets/panicle as compared to other nitrogen levels but was statistically at par with 100% of recommended dose of nitrogen and 75% of recommended dose of nitrogen levels. Nitrogen level control recorded significantly lower number of spikelets/panicle. Nitrogen @ 125% of recommended dose of nitrogen resulted in significantly more grains/panicle (Table 2) compared with the control and was statistically at par with 100% of recommended dose of nitrogen and 75% of recommended dose of nitrogen. Nitrogen @ 125% of recommended dose of nitrogen recorded significantly highest test-weight compared with control and was statistically at par with 100% of recommended dose of nitrogen and 75% of recommended dose of nitrogen. Control recording significantly lowest test-weight. Increase in nitrogen level will ultimately lead to increase in plant growth. Nitrogen is also present in all proteins, nucleic acids and protoplasm. Nitrogen had significant effect on grain yield of basmati rice. The grain yield increased with each increase in nitrogen level up 125% of recommended dose of nitrogen (Table 2). All the levels of N differed significantly from one another and highest grain yield was obtained with 125% of recommended dose of nitrogen the results confirm the findings of Sandhu (2011); Mahajan *et al.* (2011) and Singh and Walia, (2010). Application of 125% of recommended dose of nitrogen resulted in 88.44, 25.81 and 5.41% higher grain yield over the control, 75% of recommended dose of nitrogen and 100% of recommended dose of nitrogen respectively. Higher grain yield with higher nitrogen level might have been obtained owing to better growth which might have resulted in better utilization of solar energy and might have led to enhanced values of yield-attributing characters, that ultimately resulted in realizing higher grain yield of rice. Amongst the various nitrogen levels (Table 2), 125% of recommended dose of nitrogen produced significantly higher straw yield, confirming the findings of Meena *et al.* (2003) and Jaiswal and Singh, (2001). Higher straw yield with higher levels of nitrogen could be attributed to more tillers/m^2, higher dry matter, higher LAI and plant height than the other treatments.

N-use efficiency

Establishment methods: Machine transplanting after puddling recorded significantly higher N-use efficiency followed by direct-seeded basmati rice with brown manuring and machine transplanting in zero-tilled plots with brown manuring. Conventional transplanting gave significantly lower N-use efficiency which was statistically at par with machine transplanting in zero-tilled plots without brown manuring (Table 2). Higher N-use efficiency with machine transplanting after puddling can probably be due to increase in biological yield and nitrogen uptake.

Nitrogen: Nitrogen-use efficiency showed an increasing trend, as the level of nitrogen increased from 75% of recommended dose of nitrogen to 125% of recommended dose of nitrogen level. Application of 125% of recommended dose of nitrogen showed significantly higher N-use efficiency compared with the all other nitrogen levels (Table 2). This was mainly owing to increase in biological yield and nitrogen uptake with increase in nitrogen level.

Economics

Direct-seeded basmati rice without brown manuring gave more net returns than conventional transplanted basmati rice, machine transplanted basmati rice after puddling, machine transplanted basmati rice in zero-tilled plots without manuring and machine transplanted basmati rice in zero-tilled plots with brown manuring (Table 3). Direct-seeding of basmati rice and machine transplanting

Table 3. Economic analysis of basmati rice (pooled data of 2010 and 2011)

Establishment method	Input cost ($\times10^3$ ₹/ha)	Net returns ($\times10^3$ ₹/ha)	Benefit : cost ratio
DSBR	16.5	40.2	2.4
DSBR with brown manuring *Sesbania*	17.9	39.7	2.2
Machine transplanting in ZT with brown manuring	16.4	39.0	2.4
Machine transplanting in ZT without brown manuring	16.3	38.0	2.3
Machine transplanting after puddling	21.0	37.3	1.8
Conventional practice	21.4	34.4	1.6

of basmati rice in zero-tilled plots showed the maximum benefit: cost ratio and net return, and hence proved more remunerative than machine transplanting after puddling and conventional practice. This was owing to lower input cost in direct seeding of basmati rice and machine transplanting of basmati rice in zero tilled plots.

It was concluded that basmati rice growth and yield were statistically at par with machine transplanted basmati rice after puddling and direct-seeded basmati rice with brown manuring but was significantly higher than conventional transplanting method. Among levels of nitrogen, where 25% higher N than recommended was applied recorded higher grain yield than other nitrogen levels.

REFERENCES

De Datta, S.K. 1986. Technology development and the spread of direct-seeded flooded rice in South-East Asia. *Experimental Agriculture* **22**: 417–26.

Dingkuhn, M., Schnier, H.F. and Dorffling, K. 1990. Diurnal and development changes in canopy gas exchange in relation to growth in transplanted and direct-seeded flooded rice. *Australian Journal of Plant Physiology* **17**: 119–34.

Dixit. A., Manes, G.S., Singh, A., Singh, C., Dhaliwal, I.S. and Mahajan, G. 2010. Evaluation of direct-seeded rice drill against Japanese manual transplanted for higher productivity in rice. *Indian Journal of Agricultural Sciences* **80**(10): 884–87.

Gangwar, K.S., Chaudhary, V.P., Gangwar, B. and Panday, D.K. 2009. Effect of crop establishment and tillage practice in rice based cropping systems. *Indian Journal of Agricultural Sciences* **79**(5): 334–39.

Gill, M.S., Kumar, A. and Kumar, P. 2006. Growth and yield of rice (*Oryza sativa*) cultivars under various methods and time of sowing. *Indian Journal of Agronomy* **51**(2): 123–27.

Jaiswal, V.P. and Singh, G.R. 2001. Effect of planting methods, sources and level of nitrogen on the growth and yield of rice and on succeeding wheat. *Indian Journal of Agronomy* **46**(1): 5–11.

Kanyika, W.A., Saka, A.R. and Mviha, P. 2007. Response of Nunkile rice variety to fertilizer nitrogen application and plant spacing under irrigated conditions in Malawi. *Malawi Journal of Agricultural Sciences* **3**: 58–69.

Kropff, M.J., Cassman, K.G., Van Laor, M.H. and Peng, S. 1993. Nitrogen and yield potential of irrigated rice. *Plant and Soil* **155**: 391–94.

Kumar, N., Prasad, R. and Zaman, F.U. 2007. Relative response of high yielding variety and a hybrid of rice (*Oryza sativa*) to levels and source of nitrogen. (In) *Proceedings of Indian National Science Academy* **73**(1): 1–6

Kumar, R. and Ikrammullah, M. 2004. Influence of nitrogen levels and planting dates on productivity of scented rice (*Oryza sativa*) varieties. *Journal Research ANGRAU* **32**: 5–9.

Ladha, J.K., Kumar, V., Alam, M.M., Sharma, S., Gathala, M., Chandna, P., Saharawat, Y.S. and Balasubramanian, V. 2009. Integrating crop and resource management technologies for enhanced productivity, profitability, and sustainability of the rice–wheat system in South Asia. (In) *Integrated Crop and Resource Management in the Rice-Wheat System of South Asia* pp. 69–108, Ladha, J.K., Singh, Y., Erenstein, O. and Hardy, B. (Eds), International Rice Research Institute, Los Banos, Philippines.

Leeper, J.R. 2010. Back to basics in improving yield by controlling weeds. *Rice Today* **9**(3): 12–14.

Mahajan, G., Chauhan, B.S. and Gill, M.S. 2011. Optimal nitrogen fertilization timing and rate in dry-seeded rice in northwest India. *Agronomy Journal* **103**: 1676–82.

Meena, S.L., Singh, S. and Shivay, Y.S. 2003. Response of hybrids rice (*Oryza sativa* L.) to nitrogen and potassium application in sandy clay-loam soil. *Indian Journal of Agricultural Sciences* **73**: 8–11.

Meisner, C.A., Talukder, A.S.M.H.M., Hossain, I., Hossain, I., Gill, M., Rehman, H.M., Baksh, E., Justice, S., Sayre, K. and Haque, E. 2005. Permanent bed system in the rice-wheat cropping pattern in Bangladesh and Pakistan. (In) *ACIAR Proceedings No. 121*. Roth, C.H., Fischer, R.A., and Meisner, C.A. (Eds) Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico, pp. 72-79.

Mhaskar, N.V., Tharat, S.T. and Bhagat, S.B. 2005. Effect of nitrogen levels on leaf area, leaf area index and grain yield of scented rice varieties. *Journal of Soils and Crops* **15**(1): 218–20.

Pradhan, S.N. 1969. Drilling germinated paddy on puddledd land saves labour and yields more. *Indian Farming* **19**(10): 24–30.

Rammohan, J., Chandrase, K.B., Subramaniam, M., Poonguzhalan, R. and Mohan, R. 2000. Influence of nitrogen on growth and yield of rice (*Oryza sativa*) in the coastal saline soils of Karaikal region. *Oryza* **37**(1): 89–91.

Raun, W.R. and Johnson, G.V. 1999. Improving nitrogen-use efficiency for cereal production. *Agronomy Journal* **91**(3): 357–63.

Sandhu, S.S. 2011. 'Productivity, water use and quality of bed transplanted rice as influenced by planting density, nitrogen management and irrigation scheduling'. Ph.D. Dissertation Punjab Agricultural University, Ludhiana, India.

Sathiya, K., Sathiya, M.K. and Martin, G.J. 2008. Effect of nitrogen levels and split doses on the productivity of aerobic rice. *Research on Crops* **9**(3): 527–30.

Singh, G. and Walia, S.S. 2010. Influence of FYM, brown manuring and levels of nitrogen on yield and soil properties of direct seeded and transplanted rice. *Geobios* **37**: 210–16.

Singh, K.K., Jat, A.S. and Sharma, S.K. 2005. Improving productivity and profitability of rice–wheat cropping system through tillage and planting management. *Indian Journal of Agricultural Sciences* **75**: 396–99.

Venkataramon, N.S., Kempuchetty, N. and Mohadass, S. 2000. Photosynthesis and productivity of direct sown rice under semi dry ecosystem. *Journal of Ecobiology* **12**: 69–72.

Vishwakarma, S.P., Kushwaha, H.S., Kanaujia, V.K. and Singh, J.P. 2008. Response of sowing techniques, nitrogen and phosphorus levels on yield and nutrient uptake by rice (*Oryza sativa* L.) under rainfed condition. *Progressive Research* **3**: 151–53.

Yadav, V. and Singh, B. 2006. Effect of crop establishment methods and weed management practices on rice and associated weeds. *Indian Journal of Agronomy* **51**(4): 301–03.

Zhang, S.Y. and Zhu, X.H. 1999. Key factors affecting the yield of dry raised rice seedlings for broadcast transplanting in hilly areas. *Jiangsu Agricultural Science* **2**: 16–17.