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Effect of nitrogen and weed management in direct-seeded rice (*Oryza sativa*) under upland conditions

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ABSTRACT

A field experiment was conducted during the rainy season of 2002 and 2003 at Sabour study the effect of nitrogen and weed management in direct-seeded upland rice (*Oryza sativa* L.). Grain and straw yields of rice and N, P and K uptake by rice crop and weeds increased significantly with successive increase in nitrogen up to 120 kg/ha. The splits in which basal application of nitrogen was skipped off resulted in significantly higher yield attributes, grain and straw yields and nutrient uptake by crop in comparison to splits wherein part of nitrogen was applied at sowing owing to lower weed dry weight and nutrient depletion by weeds that resulted in higher weed-control efficiency and N-use efficiency. Among the weed-management practices, 2 hand-weedings at 20 and 40 days after sowing and pre-emergence application of butachlor at 1.5 kg/ha + 1 hand-weeding at 30 DAS were at par; they significantly reduced the density and dry weight of weeds and nutrient depletion by weeds. These treatments significantly increased the nutrient uptake by the crop, resulting in higher grain yield (4.18 and 4.16 t/ha) of 120 kg N/ha as a result of higher weed-control efficiency (90.6 and 84.3%), N-use efficiency (33.5 and 32.9 kg grain/kg of N applied) and production efficiency (60.4 and 60.3 kg grain/kg N applied) respectively. However, minimum nutrient uptake by crop and miximum nutrient removal by weeds were noted under weedy check.

Key words : Direct-seeded rice, Nitrogen, N-use efficiency, Nutrient uptake, Productivity, Weed management

Direct-seeded upland rice is becoming more popular as an alternative to transplanted rice, as it is more remunerative if the crop is managed properly. Weed is one of the major constraints for low productivity of upland rice (Angiras, 2002). In direct-seeded upland rice, weeds pose serious competition to the crop in early stage and cause heavy reduction in rice yield. Uncontrolled weeds reduce the yield up to 80% in direct-seeded upland rice (Subbaiah *et al.*, 2005). Weeds grow faster than the crop plants and thus absorb the available nutrients earlier, resulting in lack of nutrient for growth of the crop plants. Nitrogen is a key nutrient in determining the level of crop productivity. The efficiency of applied nitrogen is very low and varies from 20 to 25% in upland rice crop due to the oxidized condition prevailing in uplands and concomitant heavy nitrogen loss through percolating water. Hence, fractional application of nitrogen in right amount and proportion, and when it is needed the most seems to be a practical proposition. Weed control also facilitates higher absorption of applied nutrient, thus increases the efficiency of fertilizers application to the crops (Amarjit *et al.*, 2006). Since information on these aspects is meagre for direct-seeded rice grown under upland conditions, present investigation was undertaken to find out the optimum dose of nitrogen for direct-seeded upland rice and also to study the effect of time of nitrogen application and weed management on crop productivity and nitrogen-use efficiency.

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MATERIALS AND METHODS

A field experiment was conducted under rainfed, upland conditions at Bihar Agricultural College Farm, Sabour during the rainy season of 2002 and 2003. The soil was sandy-loam with pH 7.8 and organic carbon 0.42%, available N 185, available P 9.2 and available K 184.3 kg/ha. The experiment was laid out in split-plot design, replicated thrice. Three levels of nitrogen (40, 80 and 120 kg/ha) were kept in the main plots. A combination of 16 treatments consisting of 4 times of nitrogen application, viz. ½ N at 20 days after sowing (DAS) + ¼ at tillering (T) + ¼ at panicle initiation (PI), ¼ N at 20 DAS + ¼ at PI, ½ N at sowing (S) + ¼ at PI, and ¼ N at S + ½ at T + ¼ at PI; and 4 weed-management treatments, viz. weedy check, 2 hand-weedings (HW) at 20 and 40 days after sowing (DAS), pre-emergence application of butachlor at 1.5 kg/ha + 1 HW at 30 DAS and pre-emergence application of butachlor at 1.5 kg/ha + 2,4-D @ 1.0 kg/ha at 30 DAS were allocated to subplots.

The seeds of rice variety 'IR 36' were drilled in rows 20 cm apart on 22 June 2002 and 24 June 2003 using a seed rate of 60 kg/ha. The crop received a uniform dose of 17.2 kg P and 16.6 kg K/ha in the form of diammonium phosphate and muriate of potash respectively. Urea was the source of nitrogen. The density and dry weight of weeds were taken at 60 DAS and at harvesting stage of crop using a quadrate of 0.25 m^2 from 2 places in each plot. Data of weed density, dry weight of weeds and intensity of weeds were transformed using $\sqrt{X+0.5}$ and arc sin, respectively, before statistical analysis. Nitrogen, phosphorus and potassium contents of weeds, grain and straw of rice at maturity were estimated by standard laboratory procedures. Their uptake was calculated by multiplying the drymatter accumulation by weeds, grain and straw yield of rice by their respective percentages. Production efficiency of absorbed nitrogen was calculated by dividing grain yield in a given plot by the total nitrogen uptake in the same plot and expressed as kg grain/kg nitrogen absorbed by the plant. Nitrogen-use efficiency was worked out by dividing the grain yield in the given treatment minus yield in the control plot by nitrogen applied in the given treatment (kg grain/kg N applied). The expected value of grain yield in the control plot was calculated to be 1.17 tonnes/ha. The total rainfall received during the crop season was 892 and 832 mm in 2002 and 2003 respectively.

RESULTS AND DISCUSSION

Weeds

The major weed flora of experimental field consisted of: *Echinochloa crus-galli* (L.) P. Beauv., *Dactyloctenium aegyptium* (S) Richter, *Setaria glauca* (L.) and *Cynodon dactylon* (L.) Pers. among grasses; *Cyperus rotundus* (L.) and *Cyperus iria* (L.), among sedges; and *Phyllanthus niruri* (L.), *Lindernia viscosa* and *Amaranthus viridis* (L.) among the broad-leaf weeds. The grasses, sedges and broad-leaved weeds constituted 30.0, 44.3 and 25.7% of total weed flora, respectively.

Irrespective of nitrogen level, time of nitrogen application and weed management practices, weed density and dry weight of weeds were higher in 2003 than in 2002. The crop experienced severe weed competition during 2003, which might be due to favourable weather conditions leading to vigorous growth of weeds.

Nitrogen level and its time of application did not influence the weed density and per cent intensity of grasses, sedges and broad-leaved weeds at 60 DAS and at harvest stages significantly (Table 1). This shows that the germination of weed seeds was not influenced by the application of nitrogen. However, dry weight of weeds and nutrient depletion by weeds increased significantly with increasing levels of nitrogen up to 120 kg/ha. This may be attributed to vigorous growth and development of weeds owing to higher uptake of nutrients by weeds (Table 3) under higher rate of N application. Similar results were reported by Roy and Mishra (1999) under upland condition.

The minimum weed dry weight and nutrient depletion by weeds were recorded with the treatment receiving ½ N at 20 DAS + ¼ N at tillering + ¼ N at panicle initiation (PI), followed by application of ¼ N at 20 DAS + ½ N at tillering + ¼ N at PI, which were significantly lower than that recorded with splits involving part of nitrogen at sowing. These results are in conformity with those reported by Singh *et al.* (2005). Higher dry weight of weeds and nutrient depletion by weeds under splits involving part of nitrogen at sowing might be attributed to vigorous growth of weeds due to nitrogen supply at sowing, which consequently resulted in higher dry weight of weeds at different stages of growth.

Among the weed-management practices, 2 hand-weedings at 20 and 40 DAS proved to be most effective in reducing weed density, dry weight of weeds and N, P and K depletion by weeds, followed by pre-emergence application of Butachlor at 1.5 kg/ha + 1 hand-weeding at 30 DAS. Similarly, plots receiving 2 hand-weedings registered the highest weed-control efficiency (90.6%), followed by application of Butachlor at 1.5 kg/ha + 1 hand-weeding at 30 DAS (84.3%). The effective control of weeds under these treatments resulted in the highest weed-control efficiency and lower nutrient depletion by weeds. Similar results were reported by Choubey *et al.* (1999) and Singh *et al.* (2005). Weedy check recorded the highest weed density, weed dry weight and nutrient depletion by weeds owing to their greater competitive ability than crop plant put forth highest biomass under weedy condition.

Crop

Growth and yield attributes: Nitrogen and weed-management practices had significant effect on growth and yield attributes, viz. plant height, effective panicles/m^2, grains/panicle, length of panicle and test weight. The growth and yield attributes increased significantly with increasing levels of nitrogen up to 120 kg/ha except panicle length and test weight. This might be due to greater availability of nutrients, resulting in increased biomass. These results are in accordance with the findings of Roy and Mishra (1999). Splits in which basal application of nitrogen was skipped off resulted in higher growth and yield attributes in comparison to splits involving part of nitrogen at sowing. The higher growth and yield attributes under these treatments might be attributed to supply of

Table 1. Effect of nitrogen and weed management on weed density, weed dry weight, weed intensity and weed-control efficiency of weeds at 60 days after sowing

Treatment	Weed density (no/m²)				Weed dry weight (g/m²)				Intensity of weeds at 60 DAS (%)			Weed-control efficiency at 60 DAS (%)		
	60 DAS		Harvest		60 DAS		Harvest							
	2002	2003	2002	2003	2002	2003	2002	2003	Grasses	Sedges	Broad-leaved-weeds	2002	2003	Mean
N (kg/ha)														
40	11.1	12.8	9.7	11.0	10.0	11.0	8.9	9.4	32.7	42.2	28.7	63.0	61.6	62.3
	(139.11)	(181.7)	(108.2)	(136.7)	(125.3)	(149.1)	(92.1)	(103.6)	(30.1)	(45.2)	(24.5)			
80	10.9	12.6	9.5	10.8	10.7	11.8	9.5	10.4	31.9	41.5	29.6	58.4	56.4	57.4
	(136.0)	(177.8)	(105.2)	(133.2)	(140.7)	(169.3)	(101.9)	(121.7)	(29.6)	(43.9)	(26.2)			
120	10.7	12.5	9.4	10.7	11.2	12.3	10.0	10.8	33.0	40.8	29.8	55.1	53.6	54.4
	(133.8)	(174.8)	(103.2)	(129.1)	(151.8)	(180.1)	(111.9)	(128.6)	(30.6)	(42.8)	(26.7)			
SEm ±	0.1	0.1	0.1	0.1	0.05	0.02	0.02	0.06	0.3	1.3	0.4			
CD (P=0.05)	NS	NS	NS	NS	0.19	0.09	0.06	0.24	NS	NS	NS			
Time of N application														
½ N at 20 DAS + ¼ at tillering + ¼ at PI	10.8	12.6	9.4	10.8	10.2	11.3	9.0	9.7	32.5	41.8	29.4	62.2	60.0	61.0
	(134.4)	(177.2)	(102.8)	(131.7)	(128.5)	(155.3)	(93.7)	(106.9)	(29.8)	(44.4)	(25.9)			
½ N at 20 DAS + ½ at tillering + ¼ at PI	10.9	12.7	9.5	10.9	10.4	11.4	9.3	9.9	32.7	40.8	29.8	60.9	59.2	60.1
	(136.6)	(179.1)	(105.6)	(133.4)	(132.2)	(179.0)	(98.8)	(110.7)	(30.2)	(42.8)	(26.6)			
½ N at sowing + ¼ at tillering + ¼ at PI	10.9	12.7	9.6	10.9	11.2	12.2	9.9	10.7	33.0	41.2	29.2	55.5	53.9	54.7
	(137.4)	(174.7)	(107.3)	(134.4)	(150.6)	(179.0)	(109.9)	(129.2)	(30.7)	(43.5)	(25.8)			
¼ N at sowing + ½ at tillering + ¼ at PI	10.9	12.5	9.6	10.8	10.9	11.9	9.7	10.5	42.2	42.2	28.9	56.9	55.7	56.3
	(136.7)	(176.5)	(107.0)	(132.5)	(145.7)	(172.0)	(105.4)	(125.0)	(45.3)	(45.3)	(25.0)			
SEm ±	0.1	0.1	0.1	0.1	0.1	0.08	0.07	0.07	0.4	0.4	0.4			
CD (P=0.05)	NS	NS	NS	NS	0.2	0.23	0.2	0.2	NS	NS	NS			
Weed management														
Weedy check	7.7	19.4	16.0	17.5	18.4	19.7	15.1	16.1	34.6	43.3	27.1			
	(311.9)	(378.3)	(257.0)	(306.3)	(338.3)	(338.3)	(227.9)	(259.8)	(32.3)	(47.0)	(20.7)			
2 hand-weeding at 20 and 40 DAS	7.5	8.8	6.6	7.8	5.5	6.1	6.4	6.9	22.5	45.5	35.7	91.0	90.1	90.6
	(55.8)	(78.6)	(44.0)	(60.9)	(30.4)	(38.3)	(41.8)	(49.1)	(14.9)	(50.9)	(34.1)			
Butachlor at 1.5 kg/ha + 1 HW	7.7	9.4	6.8	8.1	7.1	7.9	6.8	7.3	26.9	36.9	40.7	84.9	83.6	84.3
	(59.3)	(88.7)	(46.4)	(64.7)	(51.2)	(63.8)	(46.8)	(53.4)	(20.7)	(36.2)	(42.6)			
Butachlor at 1.5 + 2,4 D at 1.0 kg/ha	10.9	12.9	8.7	10.0	11.7	13.2	9.5	10.4	46.3	40.3	14.0	59.5	55.1	57.3
	(118.1)	(116.9)	(75.3)	(100.4)	(137.3)	(174.3)	(91.3)	(109.6)	(52.2)	(41.8)	(5.9)			
SEm±	0.1	0.1	0.1	0.1	0.08	0.08	0.07	0.07	0.4	0.4	0.4			
CD (P=0.05)	0.2	0.2	0.2	0.2	0.23	0.23	0.20	0.21	1.4	1.2	1.2			

DAS, Days after sowing; PI, panicle initiation; Figures in parentheses are the means of original values nitrogen at critical stages of crop growth, which resulted in higher growth and yield attributes. Among weed-management practices, 2 hand-weedings at 20 and 40 DAS and application of butachlor at 1.5 kg/ha + 1 hand-weeding at 30 DAS caused significant increase in growth and yield attributes. This could be attributed to efficient control of weeds, which reduced the nutrient uptake by weeds (Table 4) and resulted in better growth and yield attributes of rice crop. Severe weed infestation decreased the growth and yield attributes in weedy check.

Crop yield and nutrient uptake

The grain and straw yields of rice were higher in 2002 than in 2003. The crop experienced severe weed competition during 2003 because of lower rainfall and unfavourable weather conditions, resulting in heavy weed infestation during 2003. However, the trends of various treatments with respect to yield were similar during both the years.

Application of 120 kg N/ha gave significantly higher grain and straw yields over 40 kg N/ha during both years. The increase in grain yield owing to application of 80 and 120 kg N/ha over 40 kg N/ha was 26.6 and 32.4% respectively. Significant increase in grain and straw yields could be attributed to the fact that nitrogen application improved the N, P and K uptake by the crop plants and ultimately photosynthetic activities, resulting in growth and yield attributes (Table 2), which laid down the foundation of higher yield. These findings are in conformity with those of Roy and Mishra (1999). Nitrogen and potassium uptake by grain and straw increased significantly with increasing levels of nitrogen up to 120 kg/ha . However, phosphorus

Table 2. Growth, yield attributes and grain yield of rice as influenced by nitrogen and weed-management practices (average of 2 years)

Treatment	Plant height (cm)	Effective panicles/m²	Panicle length (cm)	Grains/ panicle	Test weight (g)	Straw yield (t/ha)	Grain yield (t/ha) 2002	2003	Mean
Level of N (kg/ha)									
40	70.0	273	17.5	74.0	20.6	3.02	2.36	2.08	2.22
80	73.2	311	18.7	77.2	21.4	3.30	3.02	2.60	2.81
120	75.1	343	18.9	79.9	21.5	3.45	3.13	2.75	2.94
SEm±	0.3	0.3	0.2	0.8	0.2	0.04	0.03	0.04	0.04
CD (P=0.05)	1.0	10.0	0.6	2.3	0.4	0.13	0.10	0.14	0.12
Time of N application									
½ at 20 DAS + ¼ at tillering + ¼ at PI	73.4	333	18.7	77.7	21.3	3.56	3.21	2.91	3.06
¼ at 20 DAS + ½ at tillering + ¼ at PI	72.7	324	18.9	78.7	21.8	3.43	3.07	2.75	2.91
½ at sowing + ¼ at tillering + ¼ at PI	72.2	286	17.9	75.5	21.0	2.94	2.47	2.07	2.27
¼ at sowing + ½ at tillering + ¼ at PI	72.7	294	18.1	75.9	21.2	3.04	2.58	2.18	2.38
SEm±	0.6	3	0.2	0.7	0.1	0.04	0.03	0.04	0.04
CD (P=0.05)	NS	8	0.4	2.1	NS	0.12	0.09	0.12	0.11
Weed management									
Weedy check	65.8	164	16.0	60.9	19.5	1.26	0.70	0.58	0.64
Two hand-weedings at 20 and 40 DAS	76.5	367	19.6	84.4	22.1	4.11	3.86	3.38	3.62
Butachlor at 1.5 kg/ha + 1 HW	75.8	365	19.6	84.3	22.0	4.08	3.81	3.37	3.59
Butachlor at 1.5 + 2,4-D at 1.0 kg/ha	72.9	341	18.3	78.1	21.2	3.55	2.98	2.56	2.77
SEm±	0.6	3	0.2	0.7	0.1	0.04	0.03	0.04	0.04
CD (P=0.05)	1.7	8	0.4	2.1	0.3	0.12	0.09	0.12	0.11

Table 3. Grain yield and nitrogen uptake by crop and weeds as influenced by interaction among levels of nitrogen and weed-management practices

Weed management	Grain yield (t/ha) 40	80	120	Uptake by crop (kg/ha) 40	80	120	N depletion by weeds (kg/ha) 40	80	120
Weedy check	0.90	0.64	0.38	16.9	13.6	10.9	24.7	29.0	32.3
2 hand-weedings at 20 and 40 DAS	2.85	3.83	4.18	53.5	71.4	82.3	4.4	6.3	8.0
Butachlor at 1.5 kg/ha + 1 HW	2.79	3.82	4.16	51.6	69.7	81.1	4.9	7.0	8.3
Butachlor at 1.5 + 2,4-D at 1.0 kg/ha	2.34	2.95	3.03	42.8	53.7	59.1	10.0	12.9	14.7
CD (P=0.05)									
Weed control at same level of N		0.18			3.15			1.07	
N levels at the same weed control		0.19			3.23			1.01	

uptake by grain and straw increased significantly up to 80 kg/ha. This may be ascribed to increase in N, P and K concentration in grain and straw and more dry-matter production due to addition of nitrogen.

The highest grain and straw yields were recorded with the application of ½ N at 20 DAS + ¼ N at tillering + ¼ N at panicle initiation (PI), which was significantly superior to remaining splits. Application of ¼ N at 20 DAS + ½ N at tillering + ¼ N at PI, in turn, also proved significantly superior to the treatment supplying a part of nitrogen at sowing. This clearly indicates that skipping the nitrogen dose at sowing and applying the same at 20 DAS was more favourable for higher grain and straw yields, obviously owing to higher N, P and K uptake, resulting in better yield and yield attributes. Skipping basal application of nitrogen and applying it at 21 DAS was reported by Singh *et al.* (2006). Similarly, skipping the dose of N at sowing resulted in significantly higher N, P and K uptake by the crop over the treatment receiving part of nitrogen at sowing (Table 4). Higher N, P and K uptake by the crop in these treatments could be attributed to more availability of nutrients in soil owing to less depletion of nutrients by weeds.

All the weed-management treatments significantly increased the grain and straw yields as well as N, P and K uptake by crop compared to weedy check. The pronounced effect of increase in grain and straw yields and NPK uptake by crop was observed with 2 hand-weedings at 20 and 40 DAS and application of butachlor at 1.5 kg/ha + 1 hand-weeding at 30 DAS and both were found at par with each other, but significantly superior to rest of the treatments. The increase in yields under these treatments may be attributed to significant reduction in dry weight of weeds, thereby crop under 2 hand-weedings at 20 and 40 DAS and application of Butachlor at 1.5 kg/ha + 1 hand-weeding at 30 DAS increased significantly with the increasing level of nitrogen up to 120 kg/ha. However, grain yield under application of butachlor at 1.5 kg/ha + 2,4 D at 1.0 kg/ha at 30 DAS increased significantly up to 80 kg N/ha.

At 120 kg N/ha, grain yield and nitrogen uptake by crop in 2 hand-weedings treatment were as high as 4.18 tonnes/ha and 82.32 kg

Table 4. Effect of nitrogen and weed management on nutrient uptake by weeds and crop and N-use efficiency (average of 2 years)

Treatment	Nutrient depletion by weeds by harvest (kg/ha)			Nutrient uptake by crop (kg/ha)						Total			Efficiency of absorbed N (kg grain/kg N absorbed)	N-use efficiency (kg grain/ kg N applied)
				N		P		K						
	N	P	K	Grain	Straw	Grain	Straw	Grain	Straw	N	P	K		
Level of N														
40	11.0	3.4	14.7	25.7	15.4	6.0	5.3	6.2	41.1	41.1	11.3	47.3	54.8	26.3
80	13.8	3.6	17.3	34.2	17.9	7.4	5.5	7.8	47.6	52.1	12.9	55.4	53.9	20.5
120	15.8	3.7	19.4	38.6	19.8	7.7	5.6	8.1	51.8	58.3	13.3	59.8	50.3	14.8
SEm±	0.1	0.1	0.3	0.6	0.2	0.1	0.1	0.1	0.5	0.7	0.2	0.6		
CD (P=0.05)	0.5	0.3	1.0	1.7	0.6	0.4	NS	0.4	1.9	2.3	0.7	2.3		
Time of N application														
½ at 20 DAS + ¼ at tillering + ¼ at PI	12.4	3.3	15.8	37.7	19.6	8.0	5.9	8.5	51.9	57.3	13.9	60.3	53.4	25.5
¼ at 20 DAS + ½ at tillering + ¼ at PI	13.4	3.5	16.9	36.4	19.7	7.7	5.8	8.1	50.9	56.1	13.5	58.9	52.0	23.7
½ at sowing + ¼ at tillering + ¼ at PI	14.2	3.7	18.3	26.7	15.1	6.1	5.1	6.2	41.0	41.8	11.2	47.2	53.7	15.8
¼ at sowing + ½ at tillering + ¼ at PI	14.1	3.7	18.0	28.7	16.3	6.3	5.2	6.6	43.7	44.9	11.5	50.2	52.9	17.2
SEm ±	0.1	0.1	0.3	0.5	0.3	0.2	0.2	0.1	0.6	0.7	0.3	0.7		
CD (P=0.05)	0.6	0.3	0.8	1.4	0.8	0.5	0.5	0.3	1.7	1.9	0.8	1.9		
Weed management														
Weedy check	28.7	7.3	35.3	7.5	6.3	1.7	2.2	1.8	17.7	13.8	3.9	19.4	36.2	-6.6
Two hand weeding at 20 and 40 DAS	6.2	1.7	8.4	45.3	23.7	9.5	6.8	10.0	59.9	69.1	16.3	69.9	60.4	33.5
Butachlor at 1.5 kg/ha + 1 HW	6.7	1.8	8.8	44.5	22.9	9.5	6.9	9.9	59.5	67.5	16.3	69.4	60.3	32.9
Butachlor at 1.5 + 2,4-Dat 1.0 kg/ha	12.5	3.3	16.3	33.3	18.5	7.4	6.1	7.6	50.3	51.9	13.4	58.0	55.1	22.4
SEm±	0.1	0.1	0.3	0.5	0.3	0.2	0.2	0.1	0.5	0.7	0.3	0.7		
CD (P=0.05)	0.6	0.3	0.8	1.4	0.8	0.5	0.5	0.3	1.7	1.9	0.8	1.9		

N/ha respectively. The respective values for weedy check were 0.38 t/ha and 10.92 kg N/ha. Such a high nitrogen uptake by crop with above treatments can be interpreted in terms of high biological yield and nitrogen content in plants tissue.

Weeds in weedy check removed 28.7, 7.3 and 35.3 kg N, P and K/ha, respectively, being 67.5, 65.2 and 64.8 and 64.5% of total N, P and K removed by crop and weeds. However, a reverse trend was observed in weed-management treatments (Table 4). Weeds under 2 hand-weedings treatment removed 6.2 kg N, 1.7 kg P and 8.4 kg K/ha, which were correspondingly 9.2, 9.0 and 8.9% of total N, P and K removal from the soil. This indicates that where the removal of nutrients by weeds was more, the corresponding uptake by the crop was less and vice versa. The results further revealed that under unrestricted weed growth N, P and K removal by crop was 52.0, 46.5 and 44.8% lesser than that of weeds.

Production and nitrogen-use efficiency

Production efficiency of absorbed nitrogen (kg grain/kg N absorbed) and N-use efficiency (kg grain/kg N applied) showed a diminishing trend, as the levels of nitrogen increased from 40 to 120 kg/ha. This was mainly due to denominator goes on increasing, whereas the numerator does not increase proportionately. As a result, the production efficiency of absorbed nitrogen and N-use efficiency at higher levels were low.

The differences in production efficiency of absorbed nitrogen due to time of application of nitrogen were not significant (Table 4). This can probably be due to the fact that any increase in uptake was followed by a correspondig increase in grain yield also. However, splits in which basal application of nitrogen was skipped off enhanced the N-use efficiency compared to splits involving part of nitrogen at sowing.

Production efficiency of absorbed nitrogen and N-use efficiency were positively influenced by weed-management practices (Table 4). The maximum production efficiency of 60.4 kg grain/kg N absorbed and N-use efficiency of 33.5 kg grain/kg N applied were obtained by 2 hand-weedings at 20 and 40 DAS, followed by Butachlor + 1 hand-weeding at 30 DAS having corresponding values of 60.3 and 32.9, respectively. This was mainly due to higher grain production per unit of nitrogen applied and nitrogen uptake. The results confirm the findings of Amarjit *et al.* (2006).

Response functions

The relationship between grain yield under various weed-management measures to nitrogen application was worked out by fitting response equations, and following estimated equations were obtained from grain yield data pooled over 2 years.

Two hand-weedings:	$Y = 12.65 + 0.4721\,X - 0.0019\,X^2$
Butachlor + 1 hand-weeding:	$Y = 10.69 + 0.5176\,X - 0.0022\,X^2$
Butachlor + 2,4-D:	$Y = 12.16 + 0.3464\,X - 0.0016\,X^2$

where Y, grain yield of rice (q/ha); and X, dose of nitrogen (kg/ha) under weed-management treatments

These equations revealed that response of weed management measures to nitrogen application in relation to grain yield was quadratic, indicating operation of law of diminishing return. The maximum grain yields 41.98, 41.13 and 30.91 q/ha under 2 hand-weedings, butachlor + 1 hand-weeding and butachlor + 2,4-D were obtained by applying 123.6, 119.2 and 106.4 kg N/ha respectively. The optimum dose of nitrogen was also calculated, being 117.9, 114.1 and 99.7 kg/ha and their grain yields were 41.9, 41.1 and 30.8 q/ha, respectively.

Thus application of 120 kg N/ha in splits involving ½ N at 20 DAS + ¼ N at tillering + ¼ N at panicle initiation and weed management either through 2 hand-weedings at 20 and 40 DAS or by applying Butachlor at 1.5 kg/ha + 1 hand-weeding at 30 DAS may be adopted for realizing higher productivity of direct-seeded rice grown under upland conditions.

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