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Effect of irrigation and nitrogen management practices on productivity and nutrient uptake of direct-seeded rice (*Oryza sativa*)

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ABSTRACT

An experiment was conducted at ICAR-Indian Agricultural Research Institute, New Delhi during *kharif* seasons of 2015 and 2016 to evaluate the effect of irrigation and nitrogen management on productivity and profitability in direct-seeded rice. Results showed that an increase in water stress from 20 kPa to 40/10 kPa resulted in the decline of grain yield over the years. Irrigation at 0 and 10 kPa recorded higher grain (4.8 and 4.7 t/ha, respectively) and net returns (45.2 and 46.2 ₹ × 10^3 /ha, respectively). Similarly, N uptake in grain and total was recorded higher with 0 kPa and 10 kPa, and reduced with increase in water stress at 40/10 kPa. In 2015 and 2016, split N application enhanced the grain yield (5.42 t/ha) than no N application (2.72 t/ha). Change in N application from three to four splits resulted in higher grain yield and net benefit as compared to no N application. Four N splits registered an increase of 6.67% in grain yield compared to three N splits. N splits registered an increase of N uptake in grain and total by 18.14 and 16.26 %, respectively than three N splits (68.9 and 131.2 kg/ha, respectively). Results implied that irrigation at 10 kPa with four N split increased the productivity and profitability of direct-seeded rice.

Key words*:* Direct-seeded rice, Irrigation regimes, N splits, Nutrient uptake, Soil fertility

Rice (*Oryza sativa* L.) is the most important cereal crop of India which occupies about 23.3% of gross cropped area of the country. In India, rice is grown in 43.86 million ha and production level is 104.80 million tonnes with productivity of 2390 kg/ha (Economic Survey 2018). This conventional puddled transplanted rice (PTR) is input and energy intensive and steadily deteriorates soil health. The seasonal water requirement of PTR varies from 1100–2200 mm depending on the climate and soil conditions (Tuong and Bouman 2003). Thus, continued pumping of irrigation water for the rice cultivation results in the decline of groundwater table by 0.1 to 1.0 m/year in the Indo-Gangetic Plains (IGP) of India (Gill *et al*. 2014).

Direct-seeded rice (DSR) has the potential to yield similar to PTR with low requirement of irrigation water (139–474 mm/ha) (Gill and Singh 2008). However, uneven crop stand, high weed infestation and poor understanding on irrigation scheduling criteria, and interactive effects of water and nutrient management are the major issues in the successful cultivation of DSR. Yadav *et al*. (2011) in Punjab reported that increased water stress at 40 kPa can reduce the grain yield (4.2 t/ha), and irrigation regime 10 kPa was the safe limit for obtaining higher yield under light textured soils. The split applications of N at critical growth stages of the crop can influence the yield levels (Gill *et al*. 2014). Ali *et al.* (2015) found that three equal splits of 90 kg N/ha at sowing, maximum tillering, and panicle initiation stage enhanced the grain yield (7.0 t/ha), N uptake (110 kg/ha) and N-use efficiency (23 kg grain kg N/ha) under sandy loam soil in Punjab compared to two N splits at basal and maximum tillering stages of DSR. A detailed study on DSR need to be evaluated under varied climate and soil conditions. Therefore, an experiment was carried out to study the effects of different irrigation and N application practices on yield, net benefit and residual soil fertility in DSR.

MATERIALS AND METHODS

An experiment was conducted during the summer (*kharif*) seasons of 2015 and 2016 at the research farm of ICAR–Indian Agricultural Research Institute, New Delhi, India (28°40' N, 77°12' E, 228.6 m ASL). The climate of Delhi is subtropical and semi-arid with hot and dry summers and cold winters. The mean annual rainfall is 650 mm and 85% of which falls during the rice growing season (June–October). The total rainfall received during the period of experimentation in 2015 and 2016 was 834 and 1147 mm, respectively. The mean pan evaporation during the rice growing period was 698 mm. The mean maximum and

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minimum temperatures were 33 and 22 °C, respectively. The soil of the experimental field was a sandy clay loam up to 30 cm soil depth and is classified as an Inceptisol (Typic Haplustept). The soil *p*H was 7.9, electrical conductivity was 0.45 dS/m and cation exchange capacity of 10.6 cmol/ kg in 0–15 cm depth. The soil has an organic carbon content of 0.34%, permanganate extractable N of 152 kg/ha (Subbiah and Asija 1956), $NaHCO_3$ extractable P of 13.0 kg/ha and NH_4OAc-extractable K of 215 kg/ha (Jackson 1973). The site had grown a puddled transplanted rice-wheat cropping system over the previous 5 years.

The experiment was laid in a split-plot design with three replications. In main plot, three irrigation practices such as 0 kPa – daily irrigation, 10 kPa – irrigation threshold of 10 kPa (irrigation whenever soil water tension at 15 cm soil depth increased to 10 kPa), 20 kPa – irrigation threshold 20 kPa and 40/10 kPa – irrigation threshold of 40 kPa from tillering to flowering and 10 kPa for the remainder of crop growth were taken while N_0 – no N application, three N splits – 120 kg N/ha in three equal splits at sowing, active tillering and panicle initiation, and four N splits – 120 kg N/ha in four equal splits at sowing, active tillering, panicle initiation and flowering were taken in subplots.

The crop cultivar Pusa 1509 was directly drilled at 20 cm row spacing with multi-row crop planter using a seed rate of 30 kg/ha in rotation with zero-till (ZT) wheat. Nitrogen was applied as per treatments while phosphorus (60 kg P_2O_5/ha) and potassium (40 kg K_2O/ha) were applied at the time of sowing as single superphosphate, and muriate of potash, respectively. The AWD treatments were imposed from 21 DAS onwards up to the physiological maturity. The soil water tension was monitored using Irrometer® gauge tensiometer in every morning at 08:00 AM and irrigation water was applied as per irrigation threshold treatments whenever soil water tension increased in 0–15 cm soil depth. Harvesting was done manually, thereafter; produce was left in the field for sun drying about a week. Grain yield as per plot was weighted at moisture content of 12.5 % in grain. Nutrient content at harvest in the plant was determined by drying the samples in a hot air oven at 60°C ± 2°C till a constant dry weight was obtained. Plant samples were analyzed by using Kjeldahl's apparatus for N estimation (Prasad *et al.* 2006). The total N, P and K uptake were estimated by adding N, P and K uptake in grain and straw, respectively. Treatment means separation was done by using Fishers LSD at 5% significance level when F tests indicated that significant differences existed ($p < 0.05$) (Payne 2009).

RESULTS AND DISCUSSION

Yield attributes: Number of effective tillers in 2015, panicle length and test weight in 2015 and 2016, were not influenced by irrigation regimes (Table 1). However, in 2016, the irrigation regime at 0 kPa recorded the highest no. of effective tillers (290.9) followed by 10 kPa (275.6) and 20 kPa (267.8). The adequate availability of water at 0 and 10 kPa favoured the growth and development of rice plant without facing any stress (Gill and Singh 2008). In 2015, numbers of grains/panicle were recorded highest in 0 kPa followed by 10 kPa. However, in 2016, 0 and 10 kPa remained at par followed by 20 kPa. The lowest no. of effective tillers and grains/panicle was recorded at 40/10 kPa. The reduction in the yield attributes at higher moisture tension caused insufficient assimilation of dry matter accumulation in rice (Ramakrishna *et al*. 2007).

Application of three and four N splits remained at par with each other in terms of panicle length, no. of grains/ panicle and test weight in 2015 and 2016, and no. of effective

Table 1 Effect of irrigation and nitrogen management practices on yield attributes and yield of direct-seeded rice during 2015 and 2016

Treatment	Effective tillers (No/m^2)		Panicle length (cm)		No of grains/ panicle		1000-grains weight (g)		Grain yield (t/ha)		Biological yield (t/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Irrigation practice												
0 kPa	273.0	290.9	27.7	28.2	96.6	97.0	23.0	23.5	4.8	5.0	12.2	12.8
10 kPa	265.7	275.6	27.6	27.9	94.4	95.0	22.8	23.2	4.7	4.9	11.8	12.5
20 kPa	253.1	267.8	26.4	26.6	91.8	93.0	22.3	22.8	4.2	4.5	10.8	11.6
40/10 kPa	243.4	246.6	25.4	26.0	91.2	76.0	21.6	21.9	4.0	4.2	10.2	10.9
SEm±	9.5	6.4	0.20	0.16	0.42	0.75	0.20	0.20	0.09	0.07	0.28	0.19
LSD (P=0.05)	NS	19.6	NS	NS	1.46	2.59	NS	NS	0.31	0.22	0.98	0.58
Nitrogen application												
No N	195.7	182.7	24.9	23.3	88.8	65.4	20.5	20.7	2.7	2.6	8.4	7.6
Three N splits	283.4	300.8	27.4	28.5	95.4	102.5	23.0	23.5	4.9	5.3	11.9	13.4
Four N splits	297.3	327.1	28.1	29.8	96.3	102.9	23.8	24.3	5.6	6.0	13.5	14.8
SEm±	7.5	5.0	0.09	0.06	0.24	0.40	0.09	0.17	0.07	0.05	0.21	0.15
LSD (P=0.05)	22.5	16.9	0.27	0.19	0.72	1.19	0.28	0.51	0.21	0.16	0.62	0.46

tillers in 2015 (Table 1). However, in 2016, no. of effective tillers was recorded highest with the application of four splits over three N splits. The adequate supply of N with four N splits increased the accumulation of photosynthates from source to sink, and thereby increased the effective tillers and grains/panicle in rice crop (Kumawat *et al*. 2016).

Yield: A significant variation among different irrigation regimes and N management practices was observed on the grain and biological yield in 2015 and 2016 (Table 1). In general, the yield was increased with declining moisture stress. The grain yield remained similar in 0 and 10 kPa irrigation regimes during 2015 and 2016. In 2015, grain yield remained at par at 20 and 40/10 kPa, but in 2016, the lowest grain yield was recorded in 40/10 kPa among the rest of treatments. Low moisture stress at 0 kPa favoured the yield attributing characters which in turn contributed in higher grain yield formation than high water stress at 40/10 kPa (Yadav *et al*. 2011). Biological yield followed the same trend, and irrigation regime at 0 and 10 kPa remained at par in terms of biological yield in 2015 and 2016.

In 2015, four N splits recorded the highest grain yield over three N split application (Table 1). However, four and three N splits remained at par in terms of grain yield in 2016, biological yield in 2015 and 2016. N is an essential nutrient required for photosynthesis, and balanced and optimum supply during the entire growing season enhanced the grain yield (Kumawat *et al*. 2016). In addition, variation in the partitioning of photosynthates in grain and vegetative organs of different treatments caused a significant variation in yield (Ali *et al.* 2015).

Economics: Irrigation regimes influenced the cost of cultivation except net returns in 2015 and 2016, and B:C ratio in 2015 (Table 2). A higher cost of cultivation was recorded at 0 kPa irrigation regime (40.0 and 42.0 ₹ × 10^3 /ha in 2015 and 2016, respectively) followed by 10 kPa and 20 kPa. The lowest cost of cultivation was recorded at 40/10 kPa (34.0 and 36.0 ₹ × 10^3 /ha in 2015 and 2016, respectively). The increased number of irrigation at 0 kPa and 10 kPa escalated the cost of cultivation as more labour was involved (Thakur *et al*. 2013). Higher gross returns were recorded with 0 kPa irrigation regime which remained at par with 10 kPa. The higher grain and straw yield at 0 and 10 kPa irrigation regimes resulted in higher net returns as compared to other treatments. The better performance of DSR in terms of grain and straw yield compensated the high economic cost of cultivation, therefore, the higher value of B: C ratio was recorded at 10 kPa (1.19 and 1.21 in 2015 and 2016, respectively) than 0 kPa (1.16 and 1.12 in 2015 and 2016, respectively).

In 2015 and 2016, four N splits recorded higher cost of cultivation (42.2 and 44.0 ₹ × 10^3 /ha in 2015 and 2016, respectively) than three N splits (41.0 and 43.0 ₹ × 10^3 / ha in 2015 and 2016, respectively) (Table 2). The highest gross, net returns and B: C ratio were recorded with four N splits (101.9 and 64.6 ₹ × 10^3 /ha and 1.74, respectively) followed by three N splits over the years (90.3 and 53.0 ₹ × 10^3 /ha and 1.42, respectively). Yield advantages and higher income with synchronized N management practices in rice was the main reason for higher net returns and B:C ratio with N split application.

Nutrient uptake: In 2015 and 2016, N, P and K uptake in grain, and total was significantly influenced by irrigation regimes (Table 3). In 2015, at 0 kPa, N uptake in grain and total was recorded higher which remained at par with 10 kPa. But, in 2016, similar values of N uptake in grain were recorded at 0, 10 and 20 kPa. P and K uptake in grain and total remained at par with 0 and 10 kPa in 2015 and 2016. The optimum water regime enhanced the flow of nutrients

Table 2 Effect of irrigation and nitrogen management practices on the economics of direct-seeded rice during 2015 and 2016

Treatment	Cost of cultivation (₹ × 10^3 /ha)		Gross returns (₹ × 10^3 /ha)		Net returns (₹ × 10^3 /ha)		B:C ratio	
	2015	2016	2015	2016	2015	2016	2015	2016
Irrigation scheduling								
0 kPa	40.0	42.0	87.2	85.5	46.8	45.1	1.16	1.12
10 kPa	38.0	40.0	83.2	84.1	45.2	46.1	1.19	1.21
20 kPa	36.4	38.0	75.3	78.3	38.9	41.7	1.07	1.15
40/10 kPa	34.0	36.0	69.5	72.4	35.5	38.4	1.04	1.13
SEm±	-	-	2.98	1.92	2.98	1.92	0.08	0.01
LSD (P=0.05)	-	-	10.32	7.69	NS	NS	NS	0.05
Nitrogen application								
No N	28.2	30.0	44.7	47.8	7.4	10.5	0.20	0.28
Three N splits	41.0	43.0	90.2	90.3	53.0	55.0	1.42	1.42
Four N splits	42.2	44.0	101.5	102.2	64.3	62.9	1.73	1.75
SEm±	-	-	1.56	0.83	1.56	0.83	0.04	0.01
LSD (P=0.05)	-	-	4.69	2.48	4.69	2.48	0.12	0.04

Table 3 Effect of irrigation and nitrogen management practices on nutrient uptake in direct-seeded rice during 2015 and 2016

Treatment	N uptake (kg/ha)				P uptake (kg/ha)				K uptake (kg/ha)			
	Grain		Total		Grain		Total		Grain		Total	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Irrigation scheduling												
0 kPa	64.3	68.1	105.4	116.5	7.1	7.6	13.7	14.7	14.3	13.1	129.7	139.5
10 kPa	62.0	66.5	100.4	112.8	6.8	7.4	13.0	14.0	13.3	14.7	121.9	134.3
20 kPa	55.8	62.1	90.1	101.7	6.0	6.8	11.5	12.9	11.6	12.8	110.2	121.8
40/10 kPa	49.2	53.9	80.8	87.4	5.5	6.0	10.7	11.7	10.3	11.4	103.3	112.9
SEm±	1.41	1.96	2.43	3.13	0.11	0.21	0.26	0.29	0.44	0.67	3.95	3.36
LSD (P=0.05)	4.34	5.8	8.41	10.83	0.39	0.74	0.90	1.01	1.53	NS	10.66	11.63
Nitrogen application												
No N	30.4	30.3	56.1	52.1	3.4	3.6	7.4	7.2	6.4	6.6	83.9	75.2
Three N splits	64.8	73.0	103.4	122.3	7.3	8.0	13.5	15.2	13.7	14.5	122.0	144.2
Four N splits	78.2	84.6	123.0	139.4	8.4	9.2	15.8	17.6	17.0	17.9	143.0	161.9
SEm±	1.09	1.16	1.82	1.50	0.09	0.13	0.17	0.17	0.20	0.27	2.50	3.59
LSD (P=0.05)	3.46	3.95	5.46	4.48	0.28	0.39	0.52	0.52	0.60	0.81	7.49	10.76

from the soil to crop, and thereby increased dry matter production and grain yield ascribed to accelerated transport and uptake of nutrients (Thakur *et al*. 2013).

N split enhanced the N uptake in grain and total (68.9 and 112.9 kg/ha, respectively) compared to no N application (30.4 and 54.1 kg/ha, respectively) (Table 3). N splits registered an increase of N uptake in grain and total by 18.14 and 16.26 %, respectively, than three N splits (68.9 and 131.2 kg/ha, respectively). A sufficient and synchronized supply of N during pre and post-anthesis period resulted in higher N accumulation in rice grain (Ali *et al*. 2015). The balanced application of nutrients improved the availability of nutrients, and thereby increased nutrient uptake by the crop (Ramakrishna *et al*. 2007). Based on the findings, it may be concluded that irrigation regime of 10 kPa with four application could be a better alternative to 0 kPa and three N splits to enhance productivity and profitability in direct-seeded rice.

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