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Research Paper

Effect of varying levels of nitrogen on production, economics and energy-use efficiency of direct-seeded rice (*Oryza sativa*) genotypes under upland rainfed ecosystem of Bihar

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ABSTRACT

A field investigation was conducted during the rainy seasons of 2016 and 2017 on clay-loam soil of upland rainfed ecosystem of Bihar, to evaluate the performance of 7 rice (*Oryza sativa* L.) genotypes ('Swarna Shreya', 'IR 84899-B-179-13-1-1-1', 'IR 83929-B-B-291-2-1-1-2', 'IR 84887-B-158-7-1-1-4', 'IR 84899-B-183-20-1-1-1', 'IR 84894-143-CRA-17-1' and 'Rajendra Bhagwati') under 4 levels of nitrogen application, i.e. control, 50% recommended dose of nitrogen (RDN, 60 kg N/ha), RDN (120 kg N/ha) and 150% RDN (180 kg N/ha). Results revealed that increasing levels of nitrogen increased yield attributes and economics of direct-seeded rice genotypes. Among the nitrogen levels significantly higher grain yields (2.90 t/ha) and net returns (₹27×10^3/ha) were recorded with application of 180 kg N/ha. Application of 150% RDN increased the grain yield by 84.7% over the control and 43.6% over the RDN. Crop productivity (25.7 kg/ha/day), dry-matter efficiency (67.5 kg/ha/day) and economic efficiency (₹236/ha/day) were also higher with 180 kg N/ha. Among genotypes, significantly higher grain yield and net returns were shown by 'Swarna Shreya' (2.54 t/ha and ₹44.6×10^3/ha, respectively) but it was on a par with 'IR 84899-B-179-13-1-1-1' (2.43 t/ha and ₹43 × 10^3/ha) and 'IR 83929-B-B-291-2-1-1-2' (2.41 t/ha and ₹42.3 × 10^3/ha). Crop productivity (22.1 kg/ha/day), dry-matter efficiency (64 kg/ha/day) and economic efficiency (₹204 ha/day) were higher with 'Swarna Shreya'. Carbohydrate-equivalent yields (2.27 t/ha) and carbon output (3.40 t CO_2 eq./ha) were significantly higher with application of 180 kg N/ha. Across the genotypes, 'Swarna Shreya' had significantly higher carbohydrate-equivalent yields (1.99 t/ha) and carbon output (3.25 t CO_2 eq./ha), but statistically similar to 'IR 84899-B-179-13-1-1-1' and 'IR 83929-B-B-291-2-1-1-2'. Gross energy output (102.4 × 10^3MJ/ha), net energy returns (74.2 × 10^3MJ/ha), energy intensity in physical terms (3.68 MJ/kg), energy intensity in economic terms (4.48 MJ/₹) and energy-output efficiency (844 MJ/ha/day) were higher with 180 kg N/ha. However, energy profitability and energy productivity showed higher with preceding levels of N. 'Swarna Shreya' had higher gross energy output (97.3 × 10^3 MJ/ha), net energy output (74.7 × 10^3 MJ/ha), energy ratio (4.31), energy profitability (3.31), energy productivity (0.327 kg/MJ/ha), energy intensity in physical terms (3.11MJ/kg), energy intensity in economic terms (4.55 MJ/₹) and energy output efficiency (844 MJ/ha/day). Thus, growing of 'Swarna Shreya' and advanced breeding line 'IR 84899-B-179-13-1-1-1' along with application of 180 kg N/ha is an ideal approach to achieve the optimum crop productivity, monetary returns and energy-use efficiency of direct-seeded rice under the upland rainfed agro-ecosystem of Bihar.

Key words: Direct-seeded rice, Energetics, Productivity, Profitability, Rice genotypes, Rainfed ecosystem

Rice is grown under the diverse ecologies, ranging from irrigated to rainfed, lowland and deep-water ecosystem in country (Kumar *et al*., 2016a,b). It is the important staple food crop for more than half of world's population, provides ~21% of total calories intake. In India, it occupies an area of ~43.8 million ha with a production of ~105 million tones (mt.). Demand for rice growing is increasing every year; its requirement would be ~140 mt by 2025 AD (Kumar *et al*., 2018a,b). To sustain the present food self-sufficiency and to meet the future food requirement, India has to increase the rice productivity by~3% per annum (Kumar *et al.,* 2017a,b). Conventional method of rice establishment is manual transplanting of seedling into puddled the soil, which requires huge water, energy, laborious, that is becoming more scarce and expensive (Kumar *et al*., 2015a,b,c). Direct-seeded rice (DSR) is an emerging and attractive alternative to conventional puddled trans-

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planted rice (PTR), as it enables the better use of early rains, needs less labour and allows early crop establishment, reduces the risk of drought. Promotion of DSR as a technology had promising results in large-scale demonstration trials in drought-prone ecosystem of eastern India (Kumar *et al*., 2020). Nitrogen requirement of DSR grown with alternate wetting/drying water management may differ from PTR grown in continuous flooding due to differences in N dynamics. Also imbalanced application of nutrition results in to yield stagnation, low nutrient-use efficiency and higher the environmental risk. Since, variation in nutrient response among the rice genotypes offers an opportunity to select and breed for efficient genotypes that can be adopted by the farmers, the present investigation was undertaken.

MATERIALS AND METHODS

A field investigation was conducted during the rainy season of 2016 and 2017 at the ICAR-Research Complex for Eastern Region, Patna (25°30‘N, 85°15‘E and 52 m above mean sea-level) under upland rainfed ecosystem of Bihar. The soil of experimental site was clay loam (42.2% sand, 34.8% silt and 23% clay), low in organic carbon (0.42%), N (218 kg/ha), potassium (228 kg K_2O/ha) and medium in available phosphorus (23 kg P_2O_5/ha). Total rainfall received during the cropping (June–October) was 977 and 840 mm in 2016 and 2017, respectively (Fig.1).

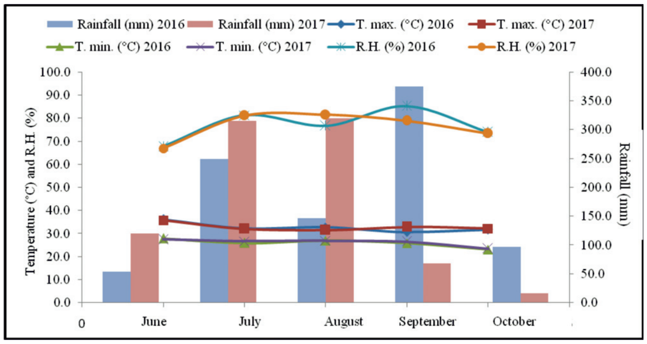

Fig. 1. Weather parameters during the experimentation (RH, relative humidity, T : temperature)

Treatments consisted of 4 levels of nitrogen, viz. control, 50% recommended dose of nitrogen (RDN 60 kg N/ha), RDN (120 kg N/ha) and 150% RDN (180 kg N/ha) as main plot and 7 rice genotypes including 2 released varieties, viz. ‘Swarna Shreya’, ‘IR 84899-B-179-13-1-1-1’, ‘IR 83929-B-B-291-2-1-1-2’, ‘IR 84887-B-158-7-1-14’, ‘IR 84899-B-183-20-1-1-1’, ‘IR 84894 -143-CRA-17-1’ and ‘Rajendra Bhagwati’ as subplot and replicated thrice in split-plot design. Details of direct-seeded rice genotypes were presented in Table 1. Dry seeding of rice genotypes was done manually in rows, 20 cm apart (30 kg/ha) on 8 June and 9 June in 2016 and 2017, respectively. Size of each experimental plot was 5.0 m × 4.0 m. Recommended dose of nitrogen (RDN) represents 120 kg/ha and applied through urea (46% N). Uniform dose of phosphorus and potash was applied @ 60 kg P_2O_5 and 40 K_2O as basal through diammonium phospahate (DAP: 46% P_2O_5 and 18% N) and muriate of potash (MoP, K: 66%), respectively. Nitrogen was applied in 3 equal split, each at basal (50%), maximum tillering (25%) and panicle-initiation stages (25%). Pendimethalin @ 1.0 kg/ha (pre-em.) was applied to manage the initial weed flushes in next day after sowing (DAS) followed by bispyribac-Na @ 30 g/ha at 25 DAS. Hand-weeding was done at 50 DAS to maintaining crop weed-free. For recording dry matter, plants at maturity were cut close to ground in 0.5 m transects at 5 random places within each plot. Samples were first sun-dried and then oven-dried at 65°C. Leaf-area index (LAI) was measured at 60 DAS by removing all the leaves from each of 5 randomly plants and passing them individually through a stationary leaf-area meter. Yield attributes, i.e. number of panicles, grains/panicle, filled grains/unfilled grains (no.) were recorded from 10 random plants from each plot and averaged them. Grain yields were taken from an area of 5 m × 4 m of each plot and expressed in t/ha. Economics of rice was calculated on the basis of minimum support price (MSP). Net income was calculated as difference between gross returns and cost of cultivation. Production and economic efficiency were calculated as suggested

Table 1. Characterization of the promising direct-seeded rice genotypes used during the study

Promising rice genotype	Parents	Year of release and place	Grain type	Plant height (cm)	DFF (days)	Maturity duration (days)
‘Swarna Shreya’	IR78877–208–B–1–1/IRRI 132	2016 , ICAR–RCER, Patna	Long bold	105–110	85–90	115–120
‘IR 84899-B-179-13-1-1-1’	IR78877-208-B-1-1/IRRI 132	Advanced breeding line	Short bold	105–110	85–90	115–120
‘IR 83929-B-B-291-2-1-1-2’	IR78878-53-2-2-2/CT6510-24-1-2	Advanced breeding line	Long slender	105–110	85–90	115–120
‘IR 84887-B-158-7-1-1-4’	IRRI 148 X IR78877-208-B-1-1	Advanced breeding line	Long slender	100–110	85–90	115–120
‘IR 84899-B-183-20-1-1-1’	IR78877-208-B-1-1/IRRI 132	Advanced breeding line	Long slender	105–110	85–90	115–120
‘IR 84894-143-CRA-17-1’	IR77080-B-34-3/IRRI 132	Advanced breeding line	Medium slender	100–105	75–80	110–115
‘Rajendra Bhagwati’	IR 36/Dehradun Basmati	2010, RAU, Pusa	Long slender	105–110	85–90	115–120

DFF: Days to 50% flowering

by Kumar *et al*. (2015a). Dry matter efficiency was computed as suggested by Kumar *et al.* (2018a). Grain yields of rice were converted into carbohydrate equivalent as suggested by *et al.* (2004). Carbon output was calculated based on plant biomass, contains on an average ~ 44% carbon on dry-weight basis (Lal, 2004). Root samples were collected by using root auger up to 30 cm depth at panicle initiation. Thereafter, roots were washed with tap-water in perforated sieve with utmost care, and measured in cm with the help of scale from base of root to tip of the longest root. Total root mass of 3 plants were dipped in water kept in a measuring cylinder for computing root volume by water-displacement method (Kumar and Kumawat, 2014). Analysis of energy coefficient of DSR genotype was done based on the energy equivalents (Devasenapathy *et al.,* 2009). The data were analysed statistically by applying standard techniques. To evaluate the significant difference between 2 treatment means, critical difference at 5% level was worked out.

RESULTS AND DISCUSSION

Growth attributes

Application of increasing levels of N significantly increased growth attributes, i.e. plant height, green leaves, tillers and dry-matter production/row (Table 2). Application of 180 kg N/ha resulted taller plant (108.3 cm), higher green leaves (323.4), tillers (49.9) and dry matter/hill (49.9 g), and per cent increase of these attributes was 15.6, 26, 22.6 and 29.3 over 120 kg N/ha respectively. This might be owing to rapid division and elongation of cells with balanced and adequate supply of N, which seems to be reason behind favourable influence on growth attributes (Kumar *et al*., 2019). Similar trend was also observed in LAI. Increasing level of N (150% RDN) significantly higher root length (27.2 cm), root dry weight (15 g) and root volume (8.27 mm). Increase in root attributes could be attributed to the favourable effect of higher levels of N on soil physical and biochemical conditions (Kumar *et al*., 2016a,b).

Among genotypes, 'IR 83929-B-B-291-2-1-1-2' had the tallest plant (101.6 cm), but at par with 'Swarna Shreya' (97.7 cm), 'IR 84899-B-179-13-1-1-1' (97.9 cm), 'IR 84887-B-158-7-1-1-4' (100.3 cm), 'IR 84899-B-183-20-1-1-1' (96.5 cm) and 'IR 84894-143-CRA-17-1' (96.5 cm), while higher green leaves (289) and tillers/m row (107.9) and LAI (2.55) were recorded with 'Swarna Shreya'. The 'Swarna Shreya' (46.3 g) had higher of dry matter/hill but it was at par with 'IR 84899 -B-179-13-1-1-1' (44.8 g) and 'IR 83929-B-B-291-2-1-1-2' (44.5 g). This might be due to genotypes had vigorous growth and more leaves resulting in higher dry matters. Highest root length (24.5 cm), root dry weight (12.9 g) and root volume (6.5 mm) obtained with 'Swarna Shreya' but statistically similar with 'IR 84899-B-179-13-1-1-1'. This might be due variations in genotypic genetic traits.

Yields attributes

Each subsequent increase in levels of N concurrently reduced days to 50% flowering and maturity (Table 2).

Table 2. Effect of nitrogen levels on growth parameters, root attributes and crop phenology of direct-seeded rice genotypes under upland rainfed condition (pooled data of 2 years)

Treatment	Plant height (cm)	Green leaves/m row* (no.)	Tillers/m row (no.)	Leaf-area index*	Dry matter/hill* (g)	Root length (cm)*	Root volume/ hill* (mm)	Root dry weight/ hill*(g)	DFF (no.)	Days to maturity (no.)
Nitrogen										
Control	85.9	225.0	84.0	1.66	34.5	18.4	4.04	9.2	95.2	121.8
50% RDN	93.7	256.6	97.0	2.38	38.6	22.4	5.05	11.6	92.1	120.4
RDN	101.8	284.3	107.0	2.84	44.2	25.8	6.88	13.7	91.9	118.7
150% RDN	108.3	323.4	118.9	3.03	49.9	27.2	8.27	15.0	88.5	114.8
SEm±	1.5	2.5	1.0	0.02	1.3	0.2	0.06	0.1	0.8	1.2
CD (P=0.05)	4.2	7.2	2.9	0.07	3.8	0.6	0.16	0.3	2.4	3.3
Rice genotype										
'Swarna Shreya'	97.7	289.0	107.9	2.55	39.5	24.5	6.57	12.9	90.6	115.8
'IR 84899-B-179-13-1-1-1'	97.9	274.8	105.7	2.52	44.8	23.5	6.28	12.7	91.4	116.4
'IR 83929-B-B-291-2-1-1-2'	101.6	272.5	103.4	2.50	44.5	23.5	6.15	12.6	90.9	118.0
'IR 84887-B-158-7-1-1-4'	100.3	270.3	101.3	2.48	46.3	23.4	6.06	12.4	92.7	119.0
'IR 84899-B-183-20-1-1-1'	98.9	268.5	99.2	2.46	44.0	23.2	5.95	12.2	91.5	120.0
'IR 84894-143-CRA-17-1'	96.5	266.3	97.8	2.44	38.8	23.1	5.85	12.0	93.1	121.0
'Rajendra Bhagwati'	89.5	265.2	95.5	2.40	34.8	22.8	5.58	11.8	93.5	122.3
SEm±	1.9	3.3	1.4	0.03	1.8	0.3	0.07	0.2	1.1	1.5
CD (P=0.05)	5.5	9.5	3.8	0.09	5.0	0.9	0.21	0.5	3.2	4.3

RDN, (recommended dose of N), 120 kg N/ha; *At panicle initiation stages; DFF, days to 50% flowering

Increased duration of vegetative growth at higher rates of nitrogen might have led to reduction of days to 50% flowering and maturity (Kumar *et al.,* 2019). Panicle (114.8), panicle length (22.9 cm), weight/panicle (2.54 g), filled grains/panicle (114.6) improved significantly with application of 180 kg N/ha. However, significantly less unfilled grain/panicle (6.3) was recorded with application of 180 kg N/ha. Significantly higher total grains/panicle (120.9) and 1,000-grain weight (20.2 g) recorded with 180 kg N/ha. Higher grain filling (94.8%) was recorded with higher levels of applied N (180 kg N/ha), which might be due to adequate supply of nutrition helping in better filling of grains (Kumar *et al.,* 2015c).

Among genotypes, 'Rajendra Bhagawati' took maximum days to 50% flowering (93.5) and maturity (122.3), while 'Swarna Shreya' minimum days to 50% flowering (90.6) and maturity (115.8). This might be owing genotypic genetic traits of respective cultivars. Significantly maximum panicle (104.7), panicle length (24.1 cm) were achieved by 'Swarna Shreya' followed by 'IR 84899-B-183-20-1-1-1' (22.6 cm). Minimum unfilled grains were recorded with 'Swarna Shreya' (6.2) followed by 'IR 84899-B-183-20-1-1-1' (6.7). Higher grain filling was noted with 'Swarna Shreya' (94.7%) and the lowest with 'Rajendra Bhagawati' (89.8%). Genotype 'IR 84899 -B-179-13-1-1-1' resulted significantly higher 1,000-grain weight (21.7 g) but at par with 'Swarna Shreya' (20.7 g). Differential values of yield attributes among the genotypes might be due to genetic traits (Kumar *et al.,* 2018a).

Yields

Pooled data revealed that yield of rice genotypes was significantly higher with higher levels of nitrogen (Table 4). Application of 180 kg N/ha resulted in the highest grain yield (2.90 t/ha) and 84.7, 44 and 16.5% more yields over the control, RDN and 50% RDN respectively. This could be owing to higher vegetative growth in terms of plant height, green leaves and dry matter/plant with increased rate of nitrogen (Kumar *et al.,* 2018b). Significantly higher crop productivity (25.3 kg/ha/day) was recorded with 180 kg N/ha than that to preceding level. Increase in each subsequent levels of N correspondingly improved dry-matter efficiency up to application of highest level of N (150% RDN). This might be owing to higher crop yields. Significantly higher carbohydrate-equivalent yield (2.27 t/ha) and carbon output (3.40 t CO_2 eq./ha) noted with 180 kg N/ha (Fig.2). This might be owing to higher yield and total biomass associated.

Rice genotypes significantly differed in yields parameters among themselves (Table 4). Among the genotypes, markedly higher gain yield was recorded with 'Swarna Shreya' (2.54 t/ha) but at par with 'IR 84899-B-179-13-1-1-1' (2.43 t/ha) and 'IR 83929-B-B-291-2-1-1-2' (2.41 t/ha), respectively. Similar trends were followed for dry matter, crop and economic efficiency. This might be owing to higher yields and monetary returns. Higher carbohy-

Table 3. Effect of nitrogen levels on yield attributes of direct-seeded rice genotypes under upland rainfed condition (pooled data of 2 years)

Treatment	Panicle/m row (no.)	Panicle length (cm)	Weight/ panicle (g)	Filled grains/ panicle (no.)	Ill-filled grains/ panicle (no.)	Total grains/ panicle (no.)	Grain filling (%)	1,000-seed weight (g)
Nitrogen level								
Control	74.3	19.6	1.69	73.9	8.8	82.7	89.4	16.7
50% RDN	88.9	22.4	2.04	92.4	8.1	100.5	91.9	17.5
RDN	96.6	22.1	2.44	109.6	8.7	118.3	92.6	18.3
150% RDN	114.8	22.9	2.54	114.6	6.3	120.9	94.8	20.2
SEm±	1.8	0.8	0.04	2.0	0.5	2.2	–	0.4
CD (P=0.05)	5.2	2.3	0.11	5.7	1.3	6.1	–	1.2
Rice genotype								
'Swarna Shreya'	104.7	24.1	2.28	111.2	6.2	117.4	94.7	20.7
'IR 84899-B-179-13-1-1-1'	102.4	22.6	2.21	100.5	6.7	107.2	93.8	21.7
'IR 83929-B-B-291-2-1-1-2'	100.1	21.4	2.19	99.2	6.9	106.1	93.5	18.9
'IR 84887-B-158-7-1-1-4'	98.3	21.2	2.12	93.6	9.1	102.7	91.1	18.3
'IR 84899-B-183-20-1-1-1'	92	21.1	2.14	94.2	8.5	102.7	91.7	17.3
'IR 84894-143-CRA-17-1'	90.5	21.2	2.07	93.0	9.7	102.7	90.6	16.8
'Rajendra Bhagwati'	88.9	21.1	2.04	77.8	8.8	86.6	89.8	16.5
SEm±	2.4	1.1	0.05	2.7	0.6	2.8	–	0.6
CD (P=0.05)	6.7	3.0	0.15	7.6	1.7	8.1	–	1.6

RDN, (recommended dose of N), 120 kg N/ha drate-equivalent yields (1.99 t/ha) and carbon output (3.25 t CO_2 eq./ha) were recorded with 'Swarna Shryea' but these were on a par with 'IR 84899-B-179-13-1-1-1' and 'IR 83929-B-B-291-2-1-1-2' (Fig. 2). This might be owing to higher yields and total biomass.

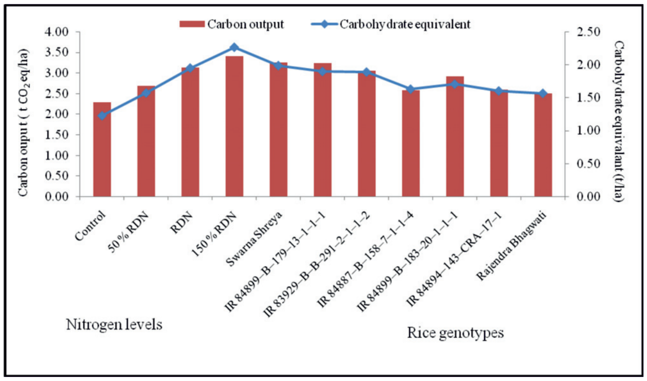

Fig. 2. Carbon output and carbohydrate-equivalent yield of direct-seeded rice genotypes as influenced by varying levels of nitrogen (pooled data of 2 years)

Economics

Higher levels of N (180 kg N/ha) resulted significantly higher gross returns (₹49.8×10^3/ha), net returns (₹27.0×10^3/ha), benefit: cost ratio (2.18) and economic efficiency (₹236/ha/day). This might be owing to higher yields and monetary returns. Among genotypes, 'Swarna Shryea' resulted higher gross returns (₹44.6×10^3/ha), net returns (₹23.5×10^3/ha) and benefit: cost (B: C) ratio (2.08) but statistically it was at par with 'IR 84899-B-179-13-1-1-1' and 'IR 83929-B-B-291-2-1-1-2' (Table 4). Similar trends were also followed in economic efficiency. Rajendra Bhagwati' had the lowest gross returns (₹34.9×10^3/ha), net returns (₹13.8×10^3/ha) and B: C ratio (1.65), which might be due to poor yields and net returns.

Energy-use efficiency

Energy inputs increased with the increasing levels of N, which might be due to more N consumed with respective treatments (Table 5). Among the levels of N, significantly higher gross energy output (102.4×10^3 MJ/ha) and net energy returns (74.2×10^3 MJ/ha) were noted with 180 kg N/ha. Energy intensity in physical terms (3.68 MJ/kg), energy intensity in economic terms (4.48 MJ/₹) and energy-output efficiency (844 MJ/ha/day) increased with increasing levels of N (150% RDN) due to higher biomass production (Bohra and Kumar, 2015). Each subsequent increasing level of N caused significant decline in energy ratio, energy profitability and energy productivity. This might be due to more consumption of energy inputs.

Among the rice genotypes, 'Swarna Shreya' had significantly higher gross energy input (97.3× 10^3 MJ/ha), net energy returns (74.7×10^3 MJ/ha), energy ratio (4.31), energy profitability (3.31), energy productivity (0.327 kg/MJ/ha) and energy output productivity (844 MJ/ha/day) com-

Table 4. Effect of nitrogen levels on yield and economics of direct-seeded rice genotypes under upland rainfed condition (pooled data of 2 years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Crop productivity (kg/ha/day)	Dry-matter efficiency (kg/ha/day)	Gross returns (×10^3 ₹/ha)	Net returns (×10^3 ₹/ha)	Benefit: cost ratio (₹/ha/day)	Economic efficiency (₹/ha/day)
Nitrogen level									
Control	1.57	3.24	4.80	12.9	42.7	28.5	10.2	1.56	84
50% RDN	2.02	4.37	6.38	16.8	50.8	36.0	14.6	1.69	122
RDN	2.49	5.22	7.71	21.1	60.1	43.6	21.5	1.97	182
150% RDN	2.90	5.78	8.68	25.3	67.5	49.8	27.0	2.18	236
SEm±	0.04	0.11	0.14	0.4	1.3	0.72	0.72	0.03	6
CD (P=0.05)	0.12	0.30	0.39	1.2	3.6	2.04	2.04	0.10	18
Rice genotype									
'Swarna Shreya'	2.54	5.28	7.82	22.1	64.0	44.6	23.5	2.08	204
'IR 84899-B-179-13-1-1-1'	2.43	5.39	7.82	20.9	63.4	43.0	21.9	2.01	189
'IR 83929-B-B-291-2-1-1-2'	2.41	4.84	7.26	20.6	59.0	42.3	21.1	2.00	180
'IR 84887-B-158-7-1-1-4'	2.08	4.10	6.18	17.8	49.7	36.8	15.6	1.72	133
'IR 84899-B-183-20-1-1-1'	2.18	4.83	7.01	18.2	55.2	38.7	17.6	1.81	147
'IR 84894-143-CRA-17-1'	2.05	4.17	6.22	17.0	48.9	35.9	14.7	1.68	123
'Rajendra Bhagwati'	2.00	3.94	5.94	16.5	46.7	34.9	13.8	1.65	114
SEm±	0.06	0.14	0.18	0.5	1.7	0.95	0.95	0.04	8
CD (P=0.05)	0.16	0.40	0.52	1.6	4.7	2.70	2.70	0.13	24

RDN, (recommended dose of N), 120 kg N/ha

Table 5. Effect of nitrogen levels on energetics of direct-seeded rice genotypes under upland rainfed condition (pooled data of 2 years)

Treatment	Energy input ($\times10^3$ MJ/ha)	Gross energy output ($\times10^3$ MJ/ha)	Net energy returns ($\times10^3$ MJ/ha)	Energy use efficiency	Energy profitability	Energy productivity (kg/MJ/ha)	Energy intensity in physicalterms (MJ/kg)	Energy intensity in economic terms (MJ/₹)	Energy output efficiency (MJ/ha/day)
Control	16.4	68.0	51.6	4.15	3.15	0.317	3.22	3.72	594
50% RDN	21.0	80.3	59.3	3.83	2.83	0.291	3.54	3.77	679
100% RDN	24.6	93.8	69.2	3.81	2.81	0.289	3.71	4.25	793
150% RDN	28.2	102.4	74.2	3.63	2.63	0.274	3.68	4.48	844
SEm±	-	1.68	1.68	0.08	0.08	0.006	0.08	0.08	16
CD (P=0.05)	-	4.75	4.75	0.21	0.21	0.016	0.22	0.22	45
Rice genotypes									
'Swarna Shreya'	22.6	97.3	74.7	4.31	3.31	0.327	3.11	4.55	844
'IR 84899-B-179-13-1-1-1'	22.6	96.7	74.1	4.26	3.26	0.324	3.19	4.52	834
'IR 83929-B-B-291-2-1-1-2'	22.6	91.5	70.0	4.19	3.19	0.318	3.24	4.35	778
'IR 84887-B-158-7-1-1-4'	22.6	77.6	55.1	3.45	2.45	0.262	3.90	3.65	657
'IR 84899-B-183-20-1-1-1'	22.6	86.9	64.4	3.86	2.86	0.293	3.45	4.08	727
'IR 84894-143-CRA-17-1'	22.6	77.8	55.3	3.48	2.48	0.264	3.89	3.66	646
'Rajendra Bhagwati'	22.6	75.0	52.4	3.44	2.44	0.261	3.99	3.56	616
SEm±	-	2.22	2.22	0.10	0.10	0.008	0.10	0.10	22
CD (P=0.05)	-	6.29	6.29	0.28	0.28	0.022	0.29	0.29	61

RDN, (recommended dose of N), 120 kg N/ha; *At panicle initiation stages; DFF, days to 50% flowering

pared to the other genotypes (Table 5). However, energy intensity in physical terms (3.99 MJ/kg) was recorded higher with 'Rajendra Bhagawati'. Higher energy-use efficiency of rice genotypes was mainly attributed to higher yields with use of low energy-input utilization (Kumar *et al.,* 2018a).

From the above study, it may be concluded that growing of 'Swarna Shreya' and advanced breeding line 'IR 84899-B-179-13-1-1-1' along with application of 180 kg N/ha is an ideal approach to achieve the higher crop productivity, monetary returns and energy use efficiency of direct seeded rice under upland rainfed agro-ecosystem of Bihar.

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