Indian Journal of Agricultural Sciences **93** (10): 1055–1060, October 2023/Article
https://doi.org/10.56093/ijas.v93i10.104538

Effect of nitrogen levels and weed management on weed flora and yield of direct-seeded rice (*Oryza sativa*) in southern part of Punjab

VICKY SINGH[1]*, SEEMA SEPAT[2], JASBIR SINGH[3], ANAND GAUTAM[3] and G S AULAKH[3]

Punjab Agricultural University, Ludhiana, Punjab 141 004, India

Received: 09 September 2020; Accepted: 30 August 2023

ABSTRACT

An experiment was conducted at Krishi Vigyan Kendra, Ferozepur, Punjab during rainy (*kharif*) seasons of 2018 and 2019 to study the effects of nitrogen levels and weed management in direct-seeded rice (*Oryza sativa* L.) (DSR). The results indicated that pendimethalin + bispyribac (W_1) (5.25 and 2.95 m^2) and oxadiargyl + bispyribac (W_2) (6.05 and 3.95 m^2) application reduced the density of narrow-leaved weeds (NLW) and broad-leaf weeds (BLW) followed by oxadiargyl + fenoxaprop (W_3) (7.0 and 4.55 m^2) during both the years. Application of W_1 decreased the total weed biomass by 84–98.2%, respectively compared to weedy check (W_5) (80.1 and 94.8 g/m^2) in both years. Treatment W_1 and W_2 recorded at par values of grain and straw yield followed by W_3. An increase (48.6–72.0%) in grain yield was registered with weed practices compared to weedy check in DSR. W_1 and W_2 significantly recorded higher N uptake in grain (61.45 and 60.85 kg/ha) and total (100.8 and 99.45 kg/ha) followed by W_3 (53.85 and 90.35 kg/ha, respectively). The high infestation of BLW with W_3 resulted in the lowest weed control efficiency (WCE) (46.2–53.9%) among the weed control practices. N at 120 and 150 kg/ha recorded the low density and biomass of NLW and BLW. Application of 120 and 150 kg N/ha enhanced the grain yield (4.89 and 5.25 t/ha) and net returns (55.1 and 60.5 × 10^3 ₹/ha) in both years. No N application recorded lowest N uptake in grain (87.71 kg/ha) and total (80.26 kg/ha) compared to 150 kg N/ha in both years. N levels at 120 and 150 kg/ha recorded higher values of water control efficiency (WCE). Based on the findings, it may be concluded that pendimethalin + bispyribac and oxadiargyl + bispyribac with N 120 kg/ha application can reduce weed flora diversity with higher grain yield of direct-seeded rice in Punjab.

Keywords: Bispyribec-Na, Direct-seeded rice, Nitrogen levels, Weed dynamics

In Direct-seeded rice (DSR), rice (*Oryza sativa* L.) crop is established by sowing the seeds directly in the unpuddled and unsaturated soil (Rao *et al.* 2007). DSR is taken in aerobic and upland conditions and therefore weed composition is diverse in comparison to puddled rice, so the yield reductions are quite common (Singh *et al.* 2016). Research findings indicated that yield reduction up to 35–60% can occur in DSR without suitable and appropriate weed control practices (Rao and Ladha 2013). Single herbicide use cannot provide effective weed control in DSR due to floristically diverse weed communities and development of weed resistance (Brar and Bhullar 2012). In addition, it can also lead to weed flora shifts as well as evolution of herbicide resistant over the years. Besides this, several findings indicated that narrow-leaf weeds are poorly controlled by bispyribac-sodium (Farooq *et al.* 2011). The sequential application of pendimethalin and bispyribac sodium effectively reduced the *Echinochloa* spp. while *Eragrostis spp*. and *L. chinensis* were recorded at higher density in DSR. The use of single herbicides for weed management is prevalent towards narrow-leaf weed spectrum, and therefore the efficacy and compatibility of tank mixtures of different herbicides for diverse weed flora need to be evaluated in DSR. Additionally, nitrogen optimization is essential to achieve higher grain yield (Sepat *et al.* 2022). Zhang *et al.* (2009) reported that anaerobic soil conditions in DSR demands higher N side as the N losses are high via volatilization and denitrification. To achieve higher grain yield in DSR, many researchers reported that 150–180 kg N/ha was optimum in ecologies of Punjab (Singh *et al.* 2007, Thind *et al.* 2018). It is well known that weed infestation can influence the N demand in DSR (Kumawat *et al.* 2017). Limited studies have been conducted on the aspect of the interaction between weed and nitrogen and its effect on the productivity and weed flora of DSR. Therefore, an experiment was conducted to

[1]Punjab Agricultural University, Ludhiana, Punjab; [2]ICAR-Indian Institute of Maize Research, Ludhiana, Punjab; [3]Krishi Vigyan Kendra, Ferozepur, Punjab Agricultural University, Punjab.
*Corresponding author email: vickysinghpau@gmail.com

study the impact of various weed management practices and nitrogen levels on weed dynamics, productivity and profitability of DSR.

MATERIALS AND METHODS

An experiment was conducted during the rainy (*kharif)* seasons of 2018 and 2019 at Krishi Vigyan Kendra of Ferozepur (30°54'33 N, 74°39'50 E, 243 MSL) in Punjab. The climate of the experimental site is subtropical, semi-arid with hot, dry summers and cold winters. The mean annual rainfall of the study area is 484 mm and 85% of which falls during the rice growing season (June-October). The total rainfall received during the period of experimentation was 732 and 446 mm in 2018 and 2019, respectively. The soil of the experimental field was sandy clay loam up to 30 cm soil depth. The soil *p*H was 8.0 and electrical conductivity was 0.45 dS/m in 0–15 cm depth. The soil has an organic carbon content of 0.62%, permanganate extractable N of 152 kg/ha, $NaHCO_3$ extractable P of 11.0 kg/ha and NH_4OAc-extractable K of 135 kg/ha (Jackson 1973). The experiment was laid in a split-plot design with 3 replications. In the main plot, 5 weed management practices, viz. pendimethalin (0.75 kg/ha) as pre-emergence application (PE) followed by (*fb*) bispyribac-sodium 0.025 kg/ha as post-emergence (PoE) (W_1); oxadiargyl 0.09 kg/ha PE *fb* bispyribac-sodium 0.025 kg/ha) PoE (W_2); oxadiargyl 0.09 kg/ha as PE *fb* fenoxaprop-p-ethyl with a safener 0.07 kg/ha PoE (W_3); weed free check (W_4); and weedy check (W_5) while 4 nitrogen management levels, viz. 0 (no N); 100 (N_1), 120 (N_2) and 150 (N_3) kg N/ha were taken in sub-plots. The herbicides were applied using a knapsack sprayer that delivered around 500 litre/ha spray solution for PE and 375 litre/ha for PoE herbicides through a flat fan nozzle.

A crop cultivar PR 114 was taken in both the years. Rice crop was direct seeded in the field using a seed-cum-fertilizer drill after appropriate field ploughing. All the recommended package of practices except nitrogen and weed management were followed in DSR. For weed sampling, two quadrats of 50 cm × 50 cm were randomly placed in each plot at 45 DAS to determine the density and biomass of narrow-leaf and broad-leaf weeds. Weed biomass was recorded after drying the weed samples at 70°C in an oven for 48 h. The observations on effective tiller/m^2, no of grains/panicle and test weight (1000-grains) were recorded. Weed control efficiency (%) was recorded as:

$$\frac{\text{Weed density in weedy check-weed density in treated}}{\text{Weed density in weedy check}} \times 100$$

Weed density and biomass data were square-root-transformed before performing ANOVA because of high variance. Water productivity was calculated with the ratio of grain yield to water used during growing period of crop and expressed in kg/m^3. 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

Weed density and biomass: In DSR, *Echinochloa crus-galli* (L.) P. Beauv.*, Echinochloa colona* (L.) Link., *Leptochloa chinensis* and *Dactyloctenium aegyptium* (L.) Wild., *Eleusine indica* (L.) Gaertn and *Digitaria sanguinalis*

Table 1 Effects of nitrogen levels and weed management on density and biomass of weed, and water use efficiency

Treatment	Weed density (no/m^2)						Weed biomass (g/m^2)						Weed control efficiency (%)		Water use efficiency (kg grain/m^3)	
	Broad-leaf		Narrow-leaf		Total		Broad-leaf		Narrow-leaf		Total					
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Weed management																
W_1	3.1	2.8	4.4	6.1	7.5	8.9	19.3	12.8	24.2	34.5	43.5	47.3	68.9	68.5	1.58	1.58
W_2	3.2	4.7	4.3	7.8	7.5	12.5	22.8	18.2	25.5	35.3	48.3	53.5	63.8	51.6	1.59	1.59
W_3	5.1	4.0	6.1	7.9	11.2	11.9	29.0	20.7	28.8	38.7	57.8	59.4	46.2	53.9	1.47	1.52
W_4	0	0	0	0	0	0	0	0	0	0	0	0	100	100	1.62	1.60
W_5	8.9	10.2	11.9	15.6	20.8	25.8	31.1	30.9	48.0	63.9	80.1	94.8	0	0	0.93	0.83
SEm±	0.62	0.56	0.52	0.35	0.80	0.76	0.60	0.67	1.02	0.92	0.94	0.98	1.32	1.22	0.07	0.09
LSD (P=0.05)	1.92	1.78	1.64	1.83	2.52	2.39	1.89	2.11	3.20	2.89	2.99	3.11	4.21	3.89	0.21	0.28
Nitrogen level																
N_0	6.2	8.5	8.8	14.7	15.0	23.2	31.9	28.7	40.8	44.9	72.7	73.6	39.9	38.2	0.98	0.89
N_1	4.4	4.3	6.2	6.9	10.6	11.2	17.3	11.3	22.2	34.3	39.5	45.6	55.2	58.0	1.53	1.58
N_2	2.0	2.0	2.2	4.0	4.2	6.0	13.2	12.4	18.4	28.5	31.6	40.9	65.7	63.0	1.64	1.60
N_3	3.8	2.5	4.0	4.4	7.8	6.9	19.4	13.7	20.6	30.2	40.0	43.9	62.3	60.0	1.62	1.60
SEm±	0.38	0.42	0.40	0.44	0.58	0.56	0.45	0.53	0.68	0.63	0.58	0.88	1.32	0.62	0.04	0.03
LSD (P=0.05)	1.20	1.32	1.28	1.40	1.82	1.76	1.43	1.68	2.16	1.99	1.87	2.80	2.78	1.98	0.12	0.09

Treatment details are given under Materials and Methods.

(L.) Scop. were the major narrow-leaf weed (NLW) while *Eclipta prostrata* (L.), *Sonchus oleraceus* (L.) and *Commelina benghalensis* (L.) were the major broad-leaf weeds (BLW) observed during 2018 and 2019. In general, NLW density was higher in 2019 over 2018 (Table 1). However, density and biomass of BLW remained static in both years. W_5 recorded higher density and biomass of NLW, BLW and total weed flora in 2018 and 2019. Among the weed control practices, W_1 and W_2 recorded lower density and biomass of NLW, BLW and total weed followed by W_3. W_1 (7.5 and 8.9 no/m^2) and W_2 (7.5 and 12.5 no/m^2) recorded lowest density of total weeds almost at par with W_4. W_1 and W_2 reduced the density of total weeds by 177.3 and 189.9%, respectively compared to W_5 (20.8 and 25.8 no/m^2) in 2018 and 2019. It was found that W_1 controlled the wide range of weeds flora including NLW and BLW, and therefore reduction in total weed density and biomass was recorded in DSR. A reduction in NLW density was observed with W_3 application, but *Echinochloa crus-galli* remained high in both years. Likewise, *D. aegyptium* density recorded high in W_2 treatment. Water control efficiency (WCE) was found highest with the weed free check followed by W_1 (68.9%) and W_2 (60.23%) due to efficient control of diverse weed flora in 2018 and 2019. The high infestation of BLW with W_3 resulted in lowest WCE (46.2–53.9%) among the weed control practices.

In 2018 and 2019, N application influenced the density and biomass of NLW, BLW and total (Table 1). The optimum N application suppressed the weed growth owing to increase the growth and yield attributes of rice crop (Hitesh *et al.* 2018). Hence, N at 120 and 150 kg/ha application recorded the low density and biomass of NLW and BLW compared to N 100 kg/ha. N level at 120 kg/ha reduced the density of total weeds by 29.30 and 39.10% compared to no N application (72.7 and 73.6 in 2018 and 2019, respectively). N levels at 120 and 150 kg/ha recorded higher values of WCE followed by 100 kg/ha in both years.

Yield attributes: In 2018 and 2019, weed management practices recorded significant influence on yield attributes, viz. no. of effective tillers/m^2, no. of filled grains/panicle and panicle weight except test weight in DSR (Table 2). Application of W_1 and W_2 remained at par with respect to no. of effective tillers/m^2, no of filled grains/panicle and panicle weight. W_1 application increased the effective tillers (35.3 and 22.5%) and filled grains/panicle (33.0 and 33.3%) over weedy check. The low occurrence of weeds in treated plots enhanced the yield attributes as rice crop faced low competition for space and nutrients (Rao *et al.* 2007). No. of effective tillers/m^2 and no. of filled grains/panicle were recorded highest in W_4, and remained lowest in W_5 during study period. N levels significantly enhanced the no. of effective tillers, no. of filled grains/panicle, panicle weight and test weight compared to no N application (Table 2). Application of 120 and 150 kg N/ha remained at par with yield attributes followed by 100 kg N/ha and no N application. High infestation of weeds with no N application and N at 100 kg/ha reduced the growth and vigour of rice crop (Thind *et al.* 2018), and thereby reduction in effective tillers/plant was noticed.

Yield: In 2018 and 2019 (Table 3), W_4 recorded the highest grain (5.0 and 5.4 t/ha) and straw yield (6.15 and 6.50 t/ha) in DSR. The weed free environment increased the nutrient uptake in rice crop thereby enhanced the grain yield (Rao and Ladha 2013). W_1 and W_2 recorded at par values of grain and straw yield followed by W_3. In 2018 and 2019, W_5 recorded the lowest grain (2.79 and 3.50 t/ha)

Table 2 Effects of nitrogen levels and weed management on yield attributes in direct-seeded rice

Treatment	No of effective tillers/m^2		No of filled grains/panicle		Panicle weight/plant (g)		Test weight (g)	
	2018	2019	2018	2019	2018	2019	2018	2019
Weed management								
W_1	280	300	130	144	1.75	2.00	22.8	23.9
W_2	280	292	128	143	1.59	1.90	21.9	23.0
W_3	272	278	120	128	1.55	1.84	21.1	22.5
W_4	295	305	141	147	1.89	2.00	21.4	23.0
W_5	207	245	100	108	1.42	1.42	20.2	22.0
SEm±	7.30	7.72	4.06	4.73	0.03	0.02	0.38	0.42
LSD (P=0.05)	22.9	24.2	12.7	14.8	0.09	0.07	NS	NS
Nitrogen level								
N_0	213	230	91	108	1.25	1.50	18.6	21.0
N_1	264	289	122	139	1.72	1.85	21.8	22.5
N_2	284	308	140	144	1.78	1.95	23.1	24.0
N_3	306	309	142	145	1.80	2.00	24.8	24.0
SEm±	5.94	6.13	3.04	3.57	0.01	0.01	0.35	0.38
LSD (P=0.05)	18.70	19.2	9.5	11.2	0.03	0.02	1.10	1.19

Treatment details are given under Materials and Methods.

Table 3 Effects of nitrogen levels and weed management on nutrient uptake, yield and economics of direct-seeded rice

Treatment	N uptake (kg/ha)				P uptake (kg/ha)				K uptake (kg/ha)				Yield (t/ha)				Cost of cultivation ($\times 10^3$ ₹/ha)		Net returns ($\times 10^3$ ₹/ha)	
	Grain		Total		Grain		Total		Grain		Total		Grain		Straw					
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Weed management																				
W_1	59.5	63.4	97.9	103.7	10.6	12.0	14.5	16.1	13.9	15.6	111.7	120.38	4.80	5.20	5.82	6.20	30	32	54	60
W_2	58.8	62.9	96.4	102.5	10.0	11.2	13.9	15.5	13.9	15.3	112.3	120.1	4.78	5.11	5.86	6.20	30	32	53.7	58.5
W_3	49.0	58.7	83.5	97.2	8.8	11.3	12.7	15.4	11.9	14.7	97.9	114.1	3.98	4.89	5.15	5.92	28.5	30.5	37.7	56.1
W_4	62.0	67.0	103.8	109.2	10.0	12.4	14.2	16.7	15.0	16.2	117.7	125.4	5.00	5.40	6.15	6.50	35.2	37.2	55.8	58.4
W_5	28.8	39.2	52.6	62.8	5.0	7.1	8.1	9.6	8.0	8.1	68.4	80.7	2.79	3.50	3.82	4.60	27	29	21.8	33
SEm±	1.5	1.1	1.9	1.6	0.9	0.6	1.0	0.9	1.3	1.2	2.1	1.8	0.04	0.04	0.07	0.06	-	-	1.54	1.76
LSD (P=0.05)	4.8	3.8	6.1	5.2	2.8	1.9	3.2	2.9	4.3	3.8	6.7	5.9	0.13	0.12	0.21	0.19	-	-	4.82	5.5
Nitrogen level																				
N_0	32.0	38.8	55.8	65.3	5.8	7.8	8.6	10.6	7.0	8.2	72.2	85.0	3.20	3.92	4.32	5.00	29	31	27	38.4
N_1	50.4	60.0	86.6	97.2	8.4	11.0	11.9	15.0	12.6	15.0	103.3	114.0	4.20	5.00	5.40	6.00	30.2	32.2	43.3	56.3
N_2	60.5	64.8	100.5	104.5	10.1	11.7	14.3	15.9	14.9	15.8	113.5	122.4	4.80	5.10	5.80	6.20	30.4	32.4	55.1	60.5
N_3	63.6	69.3	104.9	113.4	11.3	12.6	15.3	17.0	15.7	16.8	117.3	127.1	4.89	5.25	5.91	6.30	30.9	32.9	53.1	57.4
SEm±	1.1	0.9	1.6	1.2	0.6	0.3	0.7	0.4	1.1	0.9	1.6	1.3	0.06	0.05	0.06	0.03	-	-	0.72	0.79
LSD (P=0.05)	3.6	2.9	4.8	3.8	2.0	0.9	2.1	1.1	3.6	2.9	5.3	4.0	0.19	0.16	0.18	0.11	-	-	2.27	2.49

Treatment details are given under Materials and Methods.

and straw yield (3.82 and 4.6 t/ha) in DSR. Here, sequential application of W_1 effectively controlled the density of *Echinochloa sp*. and *D. sanguinalis* while the *Eragrostis* sp. and *L. chinensis* were recorded higher in DSR (Brar and Bhullar 2012). No N (Table 3) application gave the lowest grain (3.20 and 3.92) and straw yield (4.32 and 5.0 t/ha). Application of 120 and 150 kg N/ha recorded at par values of grain and straw yield in DSR. N at 120 kg/ha increased the rice grain yield by 52.8 and 33.9% compared to no N application. A significant interaction effect of weed and nitrogen levels was found on grain yield of DSR in 2019 (Fig 1). Here, W_4 along with 150 and 120 kg N/ha recorded higher grain yield followed by W_1 with N at 150 and 120 kg/ha and W_2 with N at 150 and 120 kg/ha. N application enhanced the cell division, and thereby growth and vigour of rice crop and weed free environments in DSR resulted in to higher grain yield (Kumawat *et al.* 2017). In addition, a high correlation ($r^2 = 0.99$) was found with nitrogen application between total weed density and grain yield in both years (Fig 2). Grain yield reduced by 0.54 kg/ha in 2018 and 0.89 kg/ha in 2019 with the increase of 10 m^2/ha total weed density.

Economics: Weed management practices significantly influenced the cost of cultivation and net returns in 2018 and 2019 (Table 3). Application of the W_1 and W_2 reduced the cost of cultivation compared to W_4. On the other hand, weedy check recorded the lowest cost of cultivation (27.0 and 29.0 × 10^3 ₹/ha in 2018 and 2019) as no weed control measures were done. In weedy check, high infestation of weeds reduced the grain yield so the lowest net returns were obtained. Pendimethalin + bispyribac and oxadiargyl + bispyribac recorded higher net returns followed by oxadiargyl + fenoxaprop and unweeded control. In herbicides treated plots, higher yield produced with low cost of cultivation which enhanced the net returns. The different levels of N significantly influenced the cost of cultivation and net returns compared to no N application in 2018 and 2019 in DSR (Table 3). N at 120 and 150 kg/ha increased the grain yield, and therefore recorded higher net returns (Sepat *et al*. 2022) compared to no N application.

Nutrient uptake and water use efficiency: In DSR, N, P and K uptake in grain and total was significantly influenced with weed management practices (Table 3). W_1 and W_2 significantly recorded higher N uptake in grain (61.45 and 60.85 kg/ha) and total (100.8 and 99.45 kg/ha) followed by W_3 (53.85 and 90.35 kg/ha, respectively) in 2018 and 2019. W_4 had highest N, P and K uptake as no competition for water and nutrient was faced by DSR throughout the growing period over the years. In contrary, W_5 recorded lowest N, P and K uptake which prove that nutrient uptake is severely affected with abundance of weeds in DSR. In general, imposition of herbicide treatments increased the N uptake in grain and total by 80.37 and 74.69% compared to W_5. In W_5, a decrease of P uptake by 96.8% in grain and 66.0% in total was found compared to weed practices. On the other hand, an increase of 70.49% in grain and 66.17% in total P uptake was found with weed management practices over weedy check. The similar response was found with K uptake in grain and total. An increase of 71–91.9% was registered with K uptake in grain and 48.6–60.8% with total K uptake was found due to weed management practices as compared to W_5. In DSR, WUE was found higher with W_1 (1.58 kg/m^3) and W_2 (1.59 kg/m^3) followed by W_3 (1.49 kg/m^3) as the herbicide application significantly reduced the density of weeds. Application of 150 and 120 kg/ha

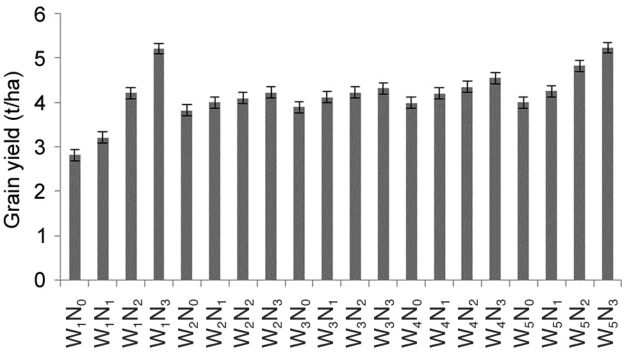
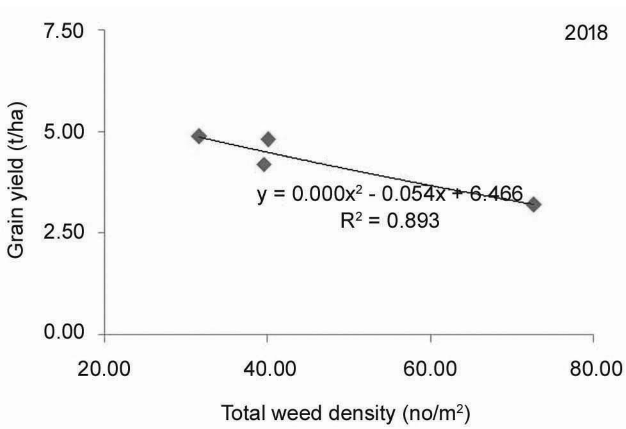


Fig 1 Interaction effect of weed practices and nitrogen levels on grain yield of DSR during 2019.



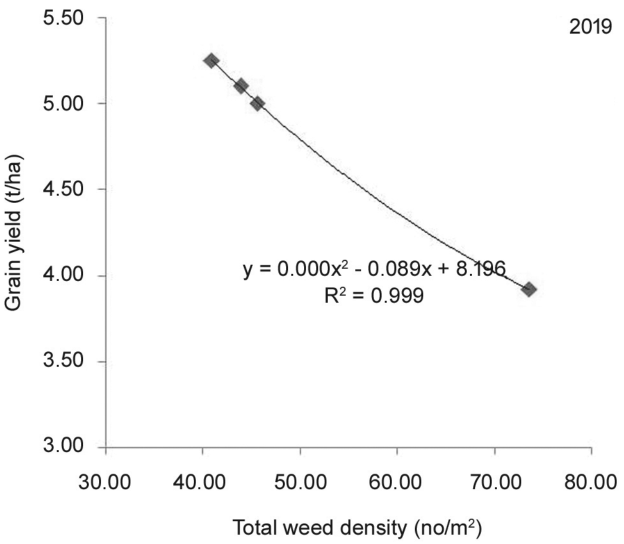


Fig 2 Relationship between total weed density and grain yield of rice during 2018 and 2019.

recorded at par values of N uptake followed by 100 kg N/ha in DSR. No N application recorded lowest N uptake in grain (87.71 kg/ha) and total (80.26 kg/ha) compared to 150 kg N/ha in both years. Application of 120 and 150 kg/ha recorded higher values of P uptake in grain and total followed by 100 kg N /ha during 2018 and 2019. Nitrogen plays an important role in formation of dry matter via photosynthesis therefore uptake of nutrient enhanced with fertilization in DSR (Farooq *et al.* 2011). An increase of 56.9% was registered for total P uptake with 120 kg N/ha compared to no N application. An increase of 49.98% was observed with 120 kg N/ha for total K uptake over to no N in DSR. The optimum N application with less density of weeds decreased the water demand in rice (Zang *et al*. 2009). Based on the findings, it may be concluded that pendimethalin at 0.75 kg/ha or oxadiargyl at 0.09 kg/ha application as pre-emergence followed by bispyribac at 0.025 kg/ha as post-emergence with nitrogen at 120 kg/ha can reduce the weed intensity with higher grain yield in direct-seeded rice.

REFERENCES

Brar H S and Bhullar M S. 2012. Dry-seeded rice productivity in relation to sowing time, variety and weed control. *Indian Journal of Weed Science* 44(**3**): 193–95.

Farooq M, Siddique K H M, Rehman H M U, Aziz T, Lee D and Wahid A. 2011. Rice direct seeding: experiences, challenges and opportunities. *Soil and Tillage Research* 111: 87–98.

Hitesh S, Sepat S, Babu S and Das T K. 2018. Weed and nitrogen management effects on weed flora and productivity of transplanted rice (*Oryza sativa*) in North-Eastern region of India. *Indian Journal of Agronomy* 63(**4**): 513–16.

Jackson M L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi, India.

Kumawat A, Sepat S, Kumar D, Singh S, Jinger D, Bamboriya S D and Verma A K. 2017. Effect of irrigation scheduling and nitrogen application on yield, grain quality and soil microbial activities in direct-seeded rice. *International Journal of Current Microbiology and Applied Sciences* **6**(5): 2855–60.

Payne R W. 2009. GenStat. Wiley Interdisciplinary Reviews: Computational Statistics 1, no. 2: 255–58.

Rao A N, Johnson D E, Sivaprasad B, Ladha J K and Mortimer A M. 2007. Weed management in direct-seeded rice. *Advances in Agronomy* **93**: 15–355.

Rao A N and Ladha J K. 2013. Economic weed management approaches for rice in Asia. *(In) Proceedings of the 24th Asian-Pacific Weed Science Society Conference*, October 22–25, Bandung, Indonesia, pp. 500–09.

Sepat S, Pavuluri K, Singh V, Kumawat A and Kumar D. 2022. Effect of irrigation and nitrogen on yield, nutrient uptake and water productivity of direct-seeded rice in India. *Journal of Plant Nutrition* **45**(19): 3004–15.

Singh Y, Gupta R K, Singh B and Gupta S. 2007. Efficient management of fertilizer nitrogen in wet direct-seeded rice (*Oryza sativa*) in northwest India. *The Indian Journal of Agricultural Sciences* 77(**9**): 561–64.

Singh V P, Dhyani V C, Banga A, Kumar A, Satyawali K and Bisht N. 2016. Weed management in direct-seeded rice. *Indian Journal of Weed Science* 48(**3**): 233–46.

Thind HS, Singh Y, Sharma S, Goyal D, Singh V and Singh B. 2018. Optimal rate and schedule of nitrogen fertilizer application for enhanced yield and nitrogen use efficiency in dry-seeded rice in north-western India. *Archives of Agronomy and Soil Science* **64**(2): 196–207.

Zhang L, Lin S, Bouman B A M, Xue C, Wei F, Tao H, Yang H, Wang D Z and Dittert K. 2009. Response of aerobic rice growth and grain yield to N fertilizer at two contrasting sites near Beijing, China. *Field Crops Research* **114**: 45–53.