

Seeding rate and herbicides suppress weeds and affect the relative performance of rice (*Oryza sativa*) varieties in dry direct-sown conditions in eastern India

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ABSTRACT

A field experiment was carried out during dry seasons of 2014 and 2015 at Cuttack, Odisha to investigate the effect of seeding rates and weed-control treatments on performance of rice varieties in dry direct-sown rice (*Oryza sativa* L.). Rice varieties 'CR Dhan 304' and 'Naveen' were grown with 4 seeding rates, viz. 20, 30, 40, 50 kg/ha, and herbicide treatments, viz. single application of bispyribac-sodium and combined application of bispyribac-sodium and azimsulfuron along with 2 controls (weed-free and weedy check). The experiment was laid in a split-split plot design. Significantly lower weed density (20 plants/m²) and dry weight (5.33 g/m²) were recorded under 'CR Dhan 304' than 'Naveen' (21.06 plants/m² and 5.61 g/m²). Seeding rate of 50 kg/ha resulted in the highest weed suppression in terms of weed density (4.63 plants/m²) and dry weight (2.82 g/m²). Among the herbicide treatments, the maximum grain yield was recorded with combined application of herbicides (5.8 t/ha), which was at par with weed-free treatment (5.9 t/ha) and significantly higher than the single application of bispyribac-sodium (5.4 t/ha). 'CR Dhan 304' and 'Naveen' varieties recorded net benefit: cost (B:C) ratio of 1.25 and 0.75 respectively. Among the weed-management practices, combined application of herbicides recorded the highest B : C ratio (1.52). Based on our findings, rice variety 'CR Dhan 304' suppressed weeds, and high seeding rate (50 kg/ha) combined with application of herbicides (bispyribac-sodium and azimsulfuron) may be recommended in dry direct-sown rice in coastal plain areas of eastern India.

Key words: Dry direct-sown rice, Grain yield, Rice, Seeding rate, Varieties, Weed-control efficiency

Cultivation of rice during dry season offers a great potential for boosting the production; however, it can be done only where irrigation facility or residual moisture is available. There is a need to develop and test appropriate winter (*rabi*) season tillage practices and establishment methods to promote rice cultivation in *rabi* season (Sarangi *et al.*, 2017). The conventional method of rice crop-establishment during dry season in coastal plains is transplanting which requires a huge amount of water and labour, both of which are gradually becoming scarce and expensive (Chauhan, 2012). Dry direct-sown rice (D-DSR) has shown promise under this scenario and considered as potential alternative to puddled transplanted rice (PTR). This system can save irrigation water up to 18% (Tabbal *et al.*, 2002) and reduces total labour requirement by 11–66% compared to PTR. The increased availability of short-duration rice varieties has further encouraged farmers to explore new methods of rice establishments and

cultivation, viz. System of rice intensification (SRI) in southern and northern India (Dass *et al.*, 2015) and D-DSR in eastern India (Saha *et al.*, 2011). However, weeds pose major biological limitation. The economic benefit from D-DSR remains elusive to the farmers due to severe infestation of weeds.

The competition by weeds under dry seeding is so severe that yield losses may shoot up to 90%. Huge expenditure on labour for weeding dampens the scope of any profit (Chauhan *et al.*, 2015), resulting in concurrent economic loss. Herbicides are considered to be most cost-effective alternative to manual/ mechanical weeding. However, evaluation of cultural weed-control strategies in an integrated way needs to be devised considering the high occurrences of herbicide resistance. Variation among cultivars/ varieties in their ability to compete with weeds has been documented and should be explored further (Zhao, 2006). Higher seeding rate is also one of the approaches that helps increase crop competitiveness against weeds. However, maintaining optimum seeding rate is important keeping in mind plant-to-plant competition as well as additional cost incurred. Higher seeding rates may also cause

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lodging. As the efficacy of herbicides changes with change in crop-management practices, it is hypothesized that appropriate seeding rate, and weed competitive rice varieties may result in higher efficacy of herbicides and eventually higher crop yield. There are limited studies, especially in relation to systematic comparison of weed infestation, efficacy of herbicides, and rice yield with different seeding rates and varieties, particularly in D-DSR during dry season. Therefore, the present study was undertaken to recognize the role of seeding rate and weed competitive variety in suppressing the weeds by use of herbicides and vice-versa under D-DSR in coastal plain areas of eastern India.

MATERIALS AND METHODS

The field investigation was carried out at the Research Farm of the ICAR-National Rice Research Institute, Cuttack (20.5 °N, 86 °E and 23.5 m above mean sea-level), Odisha, India, during the dry seasons of 2014 and 2015. The soil was sandy clay loam, with pH 6.8 (1 : 2.5, soil : water suspension), total carbon 0.76%, available nitrogen 211 kg/ha, available P 16.1 kg/ha and available K 122 kg/ha at the beginning of the experiment.

The experiment was laid out in a split-split-plot design with 3 replications. Two rice varieties, viz. 'CR Dhan 304' and 'Naveen', were assigned to the main plots; 4 seeding rates (20, 30, 40 and 50 kg/ha) to the subplots; and 4 weed-control treatments including 2 herbicides along with weed-free and weedy check to sub-subplots. 'CR Dhan 304' was released in Odisha and West Bengal in 2013 and it showed 13.4% yield advantage over National check ('IR 64'). Since 'CR Dhan 304' (130 days duration) grows vigorously at vegetative stage, it was chosen for studying weed competitiveness. The comparison was made with recommended variety 'Naveen' (120 days duration) which is highly popular variety in coastal plain areas of eastern India, particularly Odisha during dry season. Both the varieties are recommended for irrigated ecosystem. The herbicide treatments consisted of sole application of bispyribac-sodium applied at 30 g a.i./ha, and combined application of bispyribac-sodium (25 g a.i./ha) and azimsulfuron at 22 g a.i./ha. In the present experiment, the efficacy of bispyribac-sodium (sole application) was compared with combined application of bispyribac-sodium and azimsulfuron. Bispyribac-sodium is most widely used post-emergence herbicide in Indian subcontinent to suppress grass weeds along with some sedges. Azimsulfuron is broad-spectrum sulfonylurea herbicide recommended to suppress major grass weeds along with broad-leaf weeds and sedges. Bispyribac-sodium was applied at 7 days after emergence (DAE), whereas application of herbicide mixture (bispyribac-sodium and azimsulfuron) was done at 15 DAE. In the weed-free plots, weeds were removed at

15, 30, 45, and 60 DAE to keep the treatment weed-free.

The field was prepared by ploughing thoroughly with disc plough followed by harrowing with rotavator to get a fine tilth. Rice was sown using a seeding rates of 20, 30, 40 and 50 kg/ha in the first week of January during both the years in 15 cm apart rows. First irrigation was given just after seeding on the same day. A full dose of P₂O₅ (50 kg/ha) and K₂O (50 kg/ha) was applied before sowing during final land preparation and N (100 kg/ha) was applied in 3 equal splits— at 15, 35, and 55 DAE. Herbicides were applied at saturated soil moisture using a knapsack sprayer fitted with a flat-fan nozzle at spray volume of 350 litres/ha and spray pressure of about 200 kPa. All the other recommended agronomic and plant-protection measures were adopted to raise the crop.

Weeds species were identified within 0.5 m × 0.5 m quadrats placed randomly at 2 places in each plot. Weed density was measured species-wise at 30 and 60 DAE. Weeds were cut at the ground level, washed, sun dried, oven dried at 70 °C for 48 h, and then weighed.

The dominant weed species were determined based on the sum dominance ratio (SDR) values expressed as percentage, computed using following equation (Janiya and Moody, 1989).

$$\text{SDR of a weed species} = \frac{[\text{RD} + \text{RDW}]}{2}$$

where relative density, RD = (Density of a given species/total density) × 100 and relative dry weight, RDW = (Dry weight of a given species/ total dry weight) × 100

Weed-control index (%) and weed-control efficiency were calculated as per Das (2008).

The leaf-area index of rice at maximum tillering stage was also worked out.

Days to physiological maturity was estimated as 30 days after 50% of the spikelets in the panicle have flowered. Grain yield along with other yield components were recorded at harvesting at 14% moisture content in seed. Sampling was done from an area of 1m² in each plot to determine yield components, grain and straw yields. Panicle number from 1m² sample was counted to determine number of panicles/m². Filled grains of 10 randomly selected panicles were counted to determine number of grains/panicle. Economics of treatments were computed on the basis of prevailing market price of 2015 of inputs and outputs in Indian rupees under each treatment. The total cost of cultivation was calculated on the basis of different operations performed and materials used for raising crop.

The data were statistically analyzed in split-split-plot design using analysis of variance (SAS Software pack-

ages, SAS EG 4.3) and means of treatments were compared based on critical difference (CD) test at $P=0.05$. Weed density and biomass data were subjected to square-root transformation and the transformed values were used in analysis. All the analyses were made using mean data over 2 years.

RESULTS AND DISCUSSION

Weed composition and species-dominance pattern

The weed flora in the experimental plots had a mixed population of grasses, sedges and broad-leaf weeds. There was dominance of grasses which included *Echinochloa colona* (L.) Link, *Leptochloa chinensis* (L.) Nees and *Digitaria sanguinalis* (L.) Scop. Besides grasses, the other weed species that showed dominance at early vegetative stage (30 DAE) were *Cyperus difformis* L. and *Sphenoclea zeylanica* Gaertn (Table 1). Among different weed species, *E. colona* and *L. chinensis* exhibited the highest summed dominance ratio (SDR) i.e. 25.00 and 26.37 at 30 and 60 DAE respectively. Broad-leaf weeds, viz. *Alternanthera philoxeroides* (Mart.) Griseb., *Eclipta prostrata* L. and *Phyllanthus niruri* L. were also recorded at 60 DAE. Higher SDR was recorded for *S. zeylanica* (19.04) than *C. difformis* (9.30) at 60 DAE. The SDR of weed species at 30 DAE followed the order of *E. colona* > *L. chinensis* > *D. sanguinalis* > *C. difformis* > *S. zeylanica*. The SDR of weed species at 60 DAE followed the order of *L. chinensis* > *E. colona* > *S. zeylanica* > *D. sanguinalis* > *C. difformis* > *E. prostrata* > *A. philoxeroides* > *P. niruri*.

Effect on weeds

Rice variety 'CR Dhan 304' recorded significantly lower weed density and weed dry weight than 'Naveen' (Table 2). Plant height and leaf-area index (LAI) are important plant characteristics reported to be associated with weed competitiveness and weed-suppressing ability (Mahajan and Chauhan, 2013). 'CR Dhan 304' showed

9.4 and 22.5% higher plant height and LAI than 'Naveen', respectively, which contributed to its high weed-suppressing ability (Table 3). Plant height indicated early vegetative growth and high plant vigour which played important role in the weed suppression.

Among the seeding rates, 50 kg/ha resulted in the lowest weed density and weed dry weight compared to 20, 30 and 40 kg/ha. High leaf-area index at 50 kg/ha seeding rate (Table 3) led to early canopy cover thereby suppressing the weeds effectively. High seeding rates facilitate quick canopy closure, which help suppress weeds more effectively. At low seeding rates, crop plants take more time to close their canopy, which encourages weed growth (Guillermo *et al.*, 2009). Increased seeding rate from 25 to 100 kg/ha reduced weed dry weight by 40–58% (Mahajan and Chauhan, 2013).

Among the weed-control treatments, combined application of bispyribac-sodium and azimsulfuron recorded weed density at par with weed-free check. Early post-emergent application of bispyribac-sodium showed significantly higher weed density, indicating the failure to suppress broad-spectrum of weeds. Singh *et al.* (2016) reported that, sequential and combined applications of herbicides provided better weed control by way of lowering the weed density and dry weight compared to single application of either pre-or post-emergence herbicide.

Like weed density and weed dry weight, weed-control efficiency (WCE) and weed-control index (WCI) showed similar trend in response to applied treatments. Among the varieties, 'CR Dhan 304' recorded significantly higher WCE and WCI compared to 'Naveen'. Seeding rate of 50 kg/ha recorded, 39, 13 and 11% higher WCE over 20, 30 and 40 kg/ha respectively. In terms of WCI, the values were 7, 6 and 3% higher with 50 kg/ha compared to 20, 30 and 40 kg/ha seeding rates respectively. Between the 2 herbicide treatments, combined application of bispyribac-sodium and azimsulfuron revealed higher WCE and WCI than single application of bispyribac-sodium. Similarly,

Table 1. Weed composition in weedy plots and their summed dominance ratio (SDR \pm SE)

Scientific name	Family name	Weed type	30 DAE	60 DAE
<i>Echinochloa colona</i> (L.) Link	Poaceae	Grass	25.00 \pm 2.84	19.27 \pm 2.82
<i>Leptochloa chinensis</i> (L.) Nees	Poaceae	Grass	21.41 \pm 4.24	26.37 \pm 3.14
<i>Digitaria sanguinalis</i> (L.) Scop.	Poaceae	Grass	16.27 \pm 3.53	12.42 \pm 2.15
<i>Cyperus difformis</i> L.	Cyperaceae	Sedge	15.32 \pm 3.94	9.30 \pm 1.82
<i>Alternanthera philoxeroides</i> (Mart.) Griseb.	Amaranthaceae	Broad-leaf	-	4.49 \pm 1.14
<i>Sphenoclea zeylanica</i> Gaertn.	Sphenocleaceae	Broad-leaf	13.75 \pm 2.82	19.04 \pm 2.28
<i>Eclipta prostrata</i> L.	Asteraceae	Broad-leaf	-	4.62 \pm 1.12
<i>Phyllanthus niruri</i> L.	Euphorbiaceae	Broad-leaf	-	2.48 \pm 0.7
Others	-	-	8.22 \pm 1.24	1.56 \pm 0.5

DAE, Days after emergence

Singh *et al.* (2016) reported maximum weed dry weight reduction (82–91%) with combined bispyribac-sodium and azimsulfuron applied after a pre-emergence herbicide application. Significant interaction among the varieties, seeding rates and weed-control treatments indicate that the use of all the 3 factors effect each other and contribute towards weed suppression (Table 2). Likewise, Chauhan (2012) suggested that use of any single measure is unlikely to be feasible as a stand-alone technology for weed control but rather it may be a valuable component of integrated measures.

Effect on plant growth, yield and economics

‘CR Dhan 304’ rice recorded significantly higher plant height, LAI, days to physiological maturity, panicles/m², grains/panicle, 100-grain weight, grain yield and straw yield than ‘Naveen’ (Table 3), indicating genetic and phenotypic superiority of ‘CR Dhan 304’ in suppress weeds. ‘Naveen’ is a short-duration variety which is expected to suppress the weeds at early stage particularly due to its high growth rate. However, low tillering capacity of

‘Naveen’ could be the reason for poor weed suppression compared to ‘CR Dhan 304’.

Among the seeding rates, 50 kg/ha resulted in significantly higher plant growth and yield parameters than the other seed rates of 20, 30 and 40 kg/ha. However, Nwokuwu *et al.*, (2015) reported that, adequate resources at lower seed rate help in better plant growth and resultant grain yield. Similarly, Zhang and Yamagishi (2010), reported more panicles/m², grains/panicle and grain yield at low seed rate in rice. The deviation in our study is a result of high weed pressure at lower seed rates. Increasing rice seeding rates suppress weed growth and reduce grain yield losses due to weeds in weedy plots (Chauhan *et al.*, 2011).

Response to combined application of bispyribac-sodium and azimsulfuron herbicides was also consistent across the growth and yield parameters. However, the differences in growth parameters, viz. plant height, LAI and days to physiological maturity was statistically non-significant. Significant interaction between varieties means at same or different levels of weed-control treatment means was recorded in terms of plant height, LAI, panicles/m²

Table 2. Effect of varieties seeding rate and herbicide on weed density (plants/m²)* and dry weight (g/m²)*, weed-control efficiency (%) and weed control index (%). (mean data of 2 years)

Treatment	Weed density at 30 DAE*	Weed density at 60 DAE*	Weed dry weight (g) at 30 DAE*	Weed dry weight (g) at 60 DAE*	Weed-control efficiency at 60 DAE*	Weed-control index at 60 DAE*
<i>Genotypes (G)</i>						
‘CR Dhan 304’	4.99 (20.16)	6.58 (36.96)	2.81 (5.33)	5.31 (23.13)	70.14	86.14
‘Naveen’	5.09 (21.06)	6.67 (38.06)	2.87 (5.61)	5.33 (23.32)	62.06	84.55
SEM±	0.003	0.01	0.01	0.003	0.11	1.75
CD (P=0.05)	0.01	0.03	0.03	0.01	0.47	NS
<i>Seed rate (SR)</i>						
20 kg/ha	5.37 (23.71)	6.93 (41.34)	2.98 (6.15)	5.57 (25.70)	54.24	82.97
30 kg/ha	5.11 (21.25)	6.63 (37.57)	2.96 (6.05)	5.28 (22.84)	66.71	83.19
40 kg/ha	5.06 (20.79)	6.48 (35.76)	2.87 (5.61)	5.25 (22.56)	67.93	86.35
50 kg/ha	4.63 (17.05)	6.45 (35.40)	2.82 (5.38)	5.19 (21.99)	75.50	88.85
SEM ±	0.04	0.01	0.02	0.01	0.18	1.05
CD (P=0.05)	0.1	0.03	0.05	0.03	0.52	3.11
<i>Weed-control treatment (T)</i>						
BPS	4.10 (12.96)	5.61 (26.11)	2.08 (2.49)	3.93 (11.76)	62.52	82.46
BPS + AZM	4.02 (12.39)	5.16 (21.71)	1.84 (3.38)	3.28 (7.72)	69.67	88.23
Weedy check	7.01 (42.38)	9.10 (73.96)	4.80 (18.49)	8.76 (68.22)	-	-
Weed free	4.01 (12.32)	5.14 (21.52)	1.81 (3.27)	3.08 (6.65)	-	-
SEM±	0.01	0.03	0.08	0.04	0.26	1.03
CD (P=0.05)	0.03	0.09	0.23	0.11	0.55	2.19
<i>Interaction CD (P=0.05)</i>						
G × SR	0.04	0.04	0.08	0.02	0.78	8.33
G × T	0.12	0.11	NS	0.13	NS	NS
SR × T	0.05	0.04	0.09	0.03	0.93	NS
G × SR × T	0.13	0.12	0.30	0.14	1.32	NS

*, Square root-transformed data; original data in parentheses; DAE, days after emergence; BPS, Bispyribac-sodium; AZM, Azimsulfuron (Means are separated by critical difference (CD))

and grain and straw yield. However, the interaction was non-significant in terms of days to physiological maturity and grains/panicle, as these parameters are mainly governed by genetic factors. Among the yield attributes, num-

ber of panicles/m² was significantly higher with sequential application of herbicides. Similarly, the maximum yield was recorded with combined application of herbicides (5.8 t/ha) which was at par with weed-free treatment (5.9 t/ha)

Table 3. Effect of genotype, seed rate and herbicide on plant height (cm), leaf-area index (LAI), days to physiological maturity, yield components, grain and straw yield of rice (mean data of 2 years)

Treatment	Plant height (cm)	LAI at 60 DAE	Days to physiological maturity	Panicles/m ²	Grains/panicle	100-grain weight	Grain yield (t/ha)	Straw yield (t/ha)	Harvest Index
<i>Genotypes (G)</i>									
'CR Dhan 304'	121.42	4.23	122.00	285.08	131.33	2.53	5.39	6.78	0.44
'Naveen'	110.92	3.48	108.83	251.92	129.25	1.98	4.27	4.80	0.47
MSE \pm	0.33	0.09	1.85	2.36	0.22	0.01	0.09	0.08	0.01
CD (P=0.05)	1.42	0.37	7.97	10.14	0.95	0.04	0.40	0.33	0.03
<i>Seed rate (SR)</i>									
20 kg/ha	112.17	3.64	119.00	252.17	128.17	2.23	4.30	5.29	0.45
30 kg/ha	114.33	3.76	119.83	257.17	129.67	2.25	4.41	5.40	0.45
40 kg/ha	114.83	3.89	121.67	277.00	130.83	2.27	5.11	6.00	0.46
50 kg/ha	117.33	4.13	121.17	287.67	132.50	2.27	5.49	6.47	0.46
SE \pm	1.41	0.09	1.09	1.21	3.99	0.01	0.15	0.10	0.01
CD (P=0.05)	4.18	0.27	NS	3.58	NS	0.03	0.46	0.3	NS
<i>Weed-control treatment (T)</i>									
BPS	118.13	4.05	121.75	275.88	130.25	2.28	5.40	6.19	0.47
BPS + AZM	119.75	4.15	123.88	284.50	132.75	2.29	5.80	6.46	0.47
Weedy check	106.13	3.37	115.63	245.13	127.88	2.21	3.29	4.73	0.41
Weed free	120.05	4.18	124.11	288.22	134.71	2.30	5.92	6.49	0.48
SE \pm	1.10	0.06	1.64	2.70	1.43	0.02	0.11	0.14	0.01
CD (P=0.05)	2.69	0.14	4.03	6.64	3.51	0.04	0.26	0.34	0.03
<i>Interaction CD (P=0.05)</i>									
G \times SR	NS	NS	NS	10.92	NS	0.05	NS	0.49	NS
G \times T	3.37	0.39	NS	12.23	NS	0.06	0.48	0.50	NS
SR \times T	NS	NS	NS	11.40	NS	NS	0.62	0.63	NS
G \times SR \times T	NS	NS	NS	NS	NS	NS	NS	NS	NS

BPS, Bispyribac-sodium; AZM, azimsulfuron

Table 4. Effect of variety, seed rate and herbicide on economics of rice (mean data of 2 years)

Treatment	Cost of cultivation ($\times 10^3$ ₹/ha)	Gross returns ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Net benefit: cost ratio
<i>Genotypes (G)</i>				
'CR Dhan 304'	38.7	86.9	48.2	1.25
'Naveen'	38.7	67.7	29.0	0.75
<i>Seed rate (SR)</i>				
20 kg/ha	38.1	69.1	31.0	0.81
30 kg/ha	38.5	70.8	32.3	0.84
40 kg/ha	38.9	81.5	42.6	1.10
50 kg/ha	39.3	87.6	48.3	1.23
<i>Weed-control treatment (T)</i>				
BPS	35.4	85.8	50.4	1.42
BPS + AZM	36.5	91.8	55.3	1.52
Weedy check	32.4	54.2	21.8	0.67
Weed free	50.4	93.5	43.1	0.85

BPS, Bispyribac-sodium; AZM, azimsulfuron

and significantly higher than single application of bispyribac-sodium (5.4 t/ha).

The maximum net returns (₹55,343/ha) was obtained with combined application of bispyribac-sodium and azimsulfuron and the minimum (₹21,792/ha) with weedy check. Among the varieties, 'CR Dhan 304' recorded substantially higher returns (₹48,182/ha) compared to 'Naveen' (₹28,989/ha). Seed rate of 50 kg/ha recorded considerably higher net returns than lower seed rates of 20, 30, and 40 kg/ha. The net benefit: cost (B:C) ratio followed the same trend wherein the maximum value was recorded with combined application of herbicides (Table 4).

Thus, choice of varieties, optimum seed rate and selection of herbicide have major role in weed suppression and higher grain yield in D-DSR. Weed-competitive varieties like 'CR Dhan 304', high seed rate (50 kg/ha) and combined application of bispyribac-sodium and azimsulfuron may be recommended in D-DSR in coastal plain areas of eastern India.

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