International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 20, No. 4, p. 30-40, 2022

RESEARCH PAPER OPEN ACCESS

Identification of suitable integrated weed management approaches for effective weed control in dry direct-seeded basmati rice (*Oryza sativa* L.)

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Key words: Super-basmati, IWM, Yield, Sowing methods, Bispyribac-sodium, Weeds.

http://dx.doi.org/10.12692/ijb/20.4.30-40 Article published on April 17, 2022

Abstract

The dry direct-seeded rice (dry-DSR) can redeem farmers from traditional puddled transplanted rice PTR) due to its fewer water requirements, ease and making rapid sowing feasible. The timely sowing of wheat, mustard, lentil and potato along with high-profit margins but due to heavy weed infestation, and weed-crop competition a failure in weed control which causes a yield loss of 60 to100% depending upon the severity of weed infestation. The experiment was designed under RCBD with four replications having 12 treatments. By integrating different weed control tools viz., hoeing, stale seedbed technique, zero-tillage sowing in stubbles, criss-cross sowing, stale seedbed technique, and bispyribac sodium at 50 g a.i. ha^{-1} applied twice at 21 and 40 days after sowing (DAS). The maximum weed control efficacy (98%) was resulted by the treatment hoeing executed four times viz; 14 days after crop emergence (DAE) (after completion of germination), 25 DAE (tillering), 60 DAE (panicle initiation), and 80 DAE (grain filling) stages of crop growth and development. However, the best treatment in terms of both the effectiveness as well as an economic weed control was criss-cross sowing + bispyribac-sodium 50 g a.i. ha^{-1} applied twice (21 and 40 DAS), which was followed by stale seedbed technique + bispyribac-sodium 50 g a.i. ha^{-1} applied twice as these treatments achieved the highest weed control efficiencies (96 and 95%) along with marginal rates of return (2594 and 2182%), during two years, respectively.

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Introduction

Rice (*Oryza sativa* L.) is one of the principal cereals of the globe (Garg *et al.,* 2020), and over half of the human habitation depends on it for its daily livelihood (Chauhan and Johnson, 2011). Rice is cultivated in 114 countries feeding more than half of the world community, from which Asian farmers contribute more than 90% of the total produce (USDA ERS, 2020). In Pakistan, the fine-grain rice, which is branded as basmati rice, fetches an attractive international price and pays a huge amount in foreign exchange, sharing 3.1% in agriculture value addition and contributing 0.6% in the GDP (Government of Pakistan, 2020). In Pakistan, rice is ranked as the second staple food crop after wheat, an important cash crop and export commodity which earns US$2.2 billion in foreign exchange annually (Government of Pakistan, 2020). Rice is cultivated at about 3,034 m/ha with an annual production of 7.4 Mt (Government of Pakistan, 2020). The traditional method of rice sowing is its nursery transplantation in the puddled soils, which reduces water percolation, controls weeds efficiently due to submerged water conditions along with a good initial seedling stand (Alam *et al.,* 2019). From the opposing point of view, the method of traditional rice nursery transplantation is expensive, time-consuming, and results in delayed and above-optimal age transplantation of its seedlings, producing a smaller number of fertile tillers plant^{-1} (Khaliq and Matloob, 2011). Moreover, the shortage of skilled labor (Mahajan *et al.,* 2009a) and carelessness during manual transplanting of rice seedlings result in low plant density in the field, resulting in low yield (Baloch *et al.*, 2000; Mann and Ashraf, 2001). The rice cultivation through traditional techniques in the puddled soils also demands high water and intensive land preparation to create saturated soil conditions. Moreover, the wheat cultivated after puddled transplanted rice (PTR) requires more tillage operations for land preparation to break the hardpan in the subsoil resulting from soil puddling (Mishra and Singh, 2012). Furthermore, in the rice-wheat cropping system, the yield of wheat is decreased due to degradation in the soil structure and formation of hardpan at a soil depth of 10 to 20 cm due to puddling in the PTR (Behera, 2009).

Water scarcity is a serious issue at the global level due to the high-water contest between agriculture and industry and the situation is further aggravated due to climate change (Hanjar and Qureshi, 2010). It is predicted that in the future, the rice growers will face scarcity of irrigation water (Tuong and Bouman, 2003) and the severe shortage of irrigation water is an overwhelming threat to the sustainability of conventional PTR in the future (Saqib *et al.*, 2015). Under the current scenario, the direct-seeded rice (DSR) seems a feasible substitute in redeeming farmers (Farooq *et al.*, 2011). It has the potential to ensure a water-saving of about 51% along with higher water productivity ranging from 32 to 88% (Bouman *et al.,* 2005). In the dry-DSR technique, the rice seeds are directly sown in a well-prepared or zero-tilled soil and irrigation are managed to maintain the soil moisture at field capacity throughout the crop growing season. It has been pointed out that in DSR, there is 11 to 18% saving of irrigation water (Tabbal *et al.*, 2002) as well as a reduction (11 to 75%) in labor requirements, depending upon the type of direct seeding adopted, season, location and weeds intensity as compared to PTR (Kumar and Ladha, 2011).

Material and methods

Site description

A field trial was organized at Agronomic research area (Latitude 32.13 °N, longitude 72.68 °E and altitude 189 m), Department of Agronomy, College of Agriculture, University of Sargodha, Punjab-Pakistan during the two years 2015 and 2016 at fine silty, mixed hyper-thermic, sodic soils with total average N (0.041 and 0.042%), available P (6.25 and 6.35ppm), and available K (155 and 160ppm). The average temperature and rainfall during the two experimental years were (29.14 °C and 30.6 °C) and (173.1 and 248.9mm), respectively. The Super-basmati variety of rice has been used as a test crop. The crop was sowed in rows 25cm apart on a well pulverized flat seedbed by a hand drill on 4th June and 7th June in the year 2015 and 2016, respectively, at a seed rate of 35 kg ha^{-1}. Nitrogen, phosphorus and potash were used at the rate of 135, 75, and 60 kg ha^{-1} in the form of urea, di-ammonium phosphate (DAP), and sulfate of potash (SOP), respectively.

Experimentation

The experiment was laid out in a randomized complete block design (RCBD) with four replications. The net plot size was 6.0 x 3.0 m. Different ecological cultural methods of weed control were tested alone or in combination with herbicide bispyribac-sodium (BS) at 50g a.i. ha^{-1}, applied once or twice. The treatments tested were W_1 (no weed control), W_2 (Hoeing), W_3 [(BS at 21 days after sowing (DAS)], W_4 (BS at 21and 40 DAS, W_5 (Stale seedbed Technique (SSBT), W_6 (zero-tillage sowing in stubbles (ZT), W_7 (Criss-cross sowing (CCS), W_8 (SSBT + BS at 21DAS), W_9 (ZT + BS at 21DAS), W_{10} (CCS + BS at 21DAS), W_{11} (SSBT + BS at 21 and 40DAS), W_{12} (ZT + BS at 21 and 40DAS), W_{13} (CCS + BS at 21 and 40DAS).

Observations recorded

The data of weed's density was collected by throwing a quadrate of 1m^2 at two different places in each plot at random after 21st day of the treatment applied and at crop harvest. For recording the weed fresh biomass, the shoot tissues of weed harvested by sickle in an area of 1 m^2 by using quadrate randomly at two different points in each plot and were weighed immediately by electronic balance. These samples were sun-dried for one week, and afterward, these samples were dried in an electronic oven at 70°C until a consistent weed dry weight was achieved and then the weed dry weight was recorded carefully. For the estimation of N, P and K content, the oven-dried weed samples were ground in an electric grinder. Then the estimation of N, P, and K content of the weeds was executed by adopting the general procedure as proposed by Williams (1984). The weed dry weight (kg ha^{-1}) was multiplied with N, P, and K content to determine the N, P, and K uptake (kg ha^{-1}). The weed control efficacy (WCE) was calculated as suggested by Kondap and Upadhyay's (1992), which is based on weed dry matter production in control and treated plots designated as W_1 and W_2, respectively.

$$Weed\ control\ efficacy = \frac{W1-W2}{W1} \times 100$$

The relative competitive index (RCI) was calculated as proposed by Jolliffe *et al.,* (1984), using $Y_{weed\text{-}free}$ and Y_{weed}, which indicated the paddy yield in weed-free and in weedy treatments, respectively.

$$RCI = \frac{Y\ weed\ free - Y\ weed}{Yweed-Free} \times 100$$

The data regarding the yield parameters were collected from 10 randomly selected rice plants and then averaged. The number of tillers (m^{-2}) was counted by 1 m^2 quadrate placed randomly at two points in each plot and the productive tillers were counted. The actual paddy yield was derived after an adjustment of paddy yield at a grain moisture content of 14%. The un-threshed rice plants harvested from the whole plot were tied into bundles and weighed by electric field balance to record biological yield in kg plot^{-1}. Afterward, the biological yield in kg plot^{-1} was changed into tons ha^{-1}. Beadle formula (1987) was used to calculate the harvest index (%) as follows:

$$Harvest\ Index = \frac{Economic\ yield}{Biological\ yield} \times 100$$

Statistical analysis

Fisher's Analysis of Variance technique was used for data analysis and the comparison between various treatment means was carried out by using the least significant difference (LSD) test at a significance level of 5% (Steel *et al.*,1997), with the help of Statistix 8.1 (Analytical Computer Software, 2005).

Results and discussion

Weed growth

The prevalent weed flora at the research site was false amaranth (*D. arvensis*), jungle rice (*E. colona*), field bindweed (*C. arvensis*), mukia (*Mukia maderaspatana* L. M. Roem), parthenium (*Parthenium hysterophorus* L.), johnson grass (*Sorghum halepense* L.), chinese sprangletop (*L. chinensis*), southern crabgrass (*Digetaria ciliaris*), creeping panic grass (*Echinochloa reptans* L. Roberty), devils weed (*Tribulus terrestris* L.), rice flatsedge (*C. iria*), and variable flatsedge (*C. difformis*) for both years.

All weed control treatments significantly reduced the weed density as compared to control (Table 2). The minimum weed density (97%) was recorded in treatment with hoeing for two years. This treatment is at par with criss-cross sowing + bispyribac-sodium 50 g a.i. ha^{-1} 21 and 40 DAS (95%) and stale seedbed technique + bispyribac-sodium 50g a.i. 21 and 40 DAS (95%) and these treatments were followed by criss-cross sowing + bispyribac-sodium 50g a.i. ha^{-1} 21 DAS (93%) and stale seedbed technique + bispyribac-sodium 50g a.i. ha^{-1} 21 DAS (93%) and bispyribac-sodium 50g a.i. ha^{-1} 21 and 40 DAS (93%), which was followed by bispyribac-sodium 50g a.i. ha^{-1} 21 DAS (89%), ZT sowing in stubbles + bispyribac-sodium 50g a.i. ha^{-1} 21 and 40 DAS (86%), ZT sowing in stubbles + bispyribac-sodium 50g a.i. ha^{-1} 21 DAS (79%), criss-cross sowing (47%), stale seedbed technique (43%), respectively. However, the highest weed density (7%) was noted in ZT sowing in stubbles in the two years. A gradual decline in weed density after 21st day of treatment application might be due to faster as well as effective weed control by the ecological and cultural method of weed control as well as due to the phytotoxicity of bispyribac-sodium against weeds. Khaliq *et al.* (2011) noted a maximum reduction (99%) in weed density with hand weedings twice and (80%) by bispyribac-sodium in dry-DSR.

Table 1. Yield parameters as affected by different weed control methods in dry-DSR.

Treatments	No. of productive tillers (m^{-2})		No. of grains $panicle^{-1}$		1000-grain weight		Grain yield (t ha^{-1})	
Years	2015	2016	2015	2016	2015	2016	2015	2016
No Weed Control	234.8 j	255.7 j	83.4 j	87.8 j	16.8 h	17.2 h	0.38 i	0.41 i
Hoeing	368.1 c	389.7 c	143.0 a	154.0 a	23.0 a	23.5 a	4.11 a	4.28 a
Bispyribac-sodium at 21 DAS	325.7 ef	343.6 fg	107.4 f	110.5 f	21.0 e	21.5 e	2.74 e	2.93 e
Bispyribac-sodium at 21 DAS and 40 DAS	348.2 d	354.3 e	115.6 d	121.3 cd	21.9 c	22.3 c	3.39 c	3.52 c
Stale seedbed technique	305.0 g	310.7 h	101.9 g	104.9 g	18.9 f	19.3 f	0.85 f	0.92 f
ZT	118.5 k	125.6 k	78.9 k	84.0 k	16.7 i	17.0 i	0.29 i	0.33 j
Criss-cross sowing	319.7 f	335.8 g	104.0 g	107.8 fg	18.9 f	19.3 f	0.73 g	0.79 g
Stale seedbed technique + bispyribac-sodium at 21 DAS	331.7 e	347.0 ef	109.8 ef	114.5 e	21.7 d	22.1 d	3.01 d	3.15 d
ZT + bispyribac-sodium at 21 DAS	260.5 i	280.6 i	90.5 i	92.6 i	18.1 g	18.5 g	0.62 h	0.66 h
Criss-cross sowing +bispyribac-sodium at 21 DAS	418.5 b	448.2 b	112.2 e	118.2 de	21.7 d	22.1 d	3.04 d	3.17 d
Stale seedbed technique + bispyribac-sodium at 21 DAS and 40 DAS	359.8 c	370.2 d	119.0 c	124.3 c	22.3 b	22.8 b	3.50 b	3.64 b
ZT + bispyribac-sodium at 21 DAS and 40 DAS	278.6 h	290.0 i	98.8 h	100.0 h	18.3 g	18.6 g	0.72 g	0.79 g
Criss-cross sowing + bispyribac-sodium at 21 DAS and 40 DAS	439.1 a	469.3 a	125.4 b	131.5 b	22.4 b	22.9 b	3.54 b	3.66 b
LSD	11.59	10.53	2.5	3.75	0.12	0.12	0.99	0.82
Contrast comparison								
Control vs all	234.9 vs 322.8**	255.8 vs 338.8**	83.4 vs 108.9**	87.9 vs 113.7**	16.9 vs 20.3**	17.2 vs 20.9**	388.1 vs 2215.0**	418.6 vs 2323.5**
Chemical control vs physical control	345.3 vs 368.1**	362.9 vs 389.8**	109.9 vs 143.1**	114.2 vs 154.1**	20.8 vs 23.0**	21.4 vs 23.5**	2572.0 vs 4112.8**	2693.1 vs 4283.9**
Chemical control vs ecological control	345.3 vs 247.8**	362.9 vs 257.4**	109.9 vs 95.0**	114.2 vs 98.9**	20.8 vs 18.2**	21.4 vs 18.6**	2572.0 vs 630.5**	2693.1 vs 684.4**
Herbicide once vs herbicide twice	334.1 vs 356.5**	354.9 vs 371.0**	105.0 vs 114.8**	109.0 vs 119.3**	20.7 vs 21.0**	21.1 vs 21.7**	2354.3 vs 2789.8**	2481.1 vs 2905.1**

Mean values in a column with dissimilar lettering vary significantly ($P < 0.05$) from one another based on the least significant difference (LSD) test, ** indicates significant at $P < 0.05$.

Significantly the lowest weed dry weight was recorded in hoeing treatment during the two years. Followed this treatment were criss-cross sowing technique + bispyribac-sodium 21 and 40 DAS (96%), stale-seedbed technique + bispyribac-sodium 21 and 40 DAS (95%), bispyribac-sodium 21 and 40 DAS (93%), stale-seedbed technique + bispyribac-sodium 21 DAS (93%), bispyribac-sodium 21 DAS (90%), ZT + bispyribac-sodium 21 and 40 DAS, ZT + bispyribac-sodium 21 DAS (85%), criss-cross sowing technique (57%), stale-seedbed technique (51%), while ZT resulted into the maximum weed dry weight.

Table 2. Effect of different weed control methods on weed density and weed dry biomass (m^{-2}) after treatment in dry-DSR.

Treatments	Weed density after treatment ($1m^2$)		Weed dry biomass after treatment ($1m^2$)	
Years	2015	2016	2015	2016
No Weed Control	41.7 b	43.2 b	863.0 b	855.6 b
Hoeing	1.15 I (-97)	1.18 I (-97)	12.3 f (-99)	14.4 g (-98)
Bispyribac-sodium at 21 DAS	4.48 g (-89)	4.80 fg (-88)	87.2 def (-90)	90.3 ef (-89)
Bispyribac-sodium at 21 DAS and 40 DAS	3.11 h (-93)	3.34 gh (-92)	61.9 ef (-93)	62.9 efg (-93)
Stale seedbed technique	23.7 c (-43)	24.5 c (-43)	417.7 c (-52)	419.5 c (-51)
ZT	44.8 a (7)	46.0 a (6)	948.2 a (+10%)	955.0 a (+12)
Criss-cross sowing	21.9 d (-47)	22.4 d (-48)	362.4 c (-58)	365.6 c (-57)
Stale seedbed technique + bispyribac-sodium at 21 DAS	3.10 h (-93)	3.21 gh (-93)	64.7 ef (-93)	62.2 efg (-93)
ZT + bispyribac-sodium at 21 DAS	8.89 e (-79)	8.56 e (-80)	167.2 d (-81)	164.7 d (-81)
Criss-cross sowing +bispyribac-sodium at 21 DAS	2.94 h (-93)	3.05 h (-92)	55.7 ef (-94)	57.0 fg (-93)
Stale seedbed technique + bispyribac-sodium at 21 DAS and 40 DAS	2.12 hi (-95)	2.05 hi (-95)	44.7 f (-95)	43.1 fg (-95)
ZT + bispyribac-sodium at 21 DAS and 40 DAS	6.02 f (-86)	6.12 f (-86)	125.0 de (-86)	127.8 de (-85)
Criss-cross sowing + bispyribac-sodium at 21 DAS and 40 DAS	1.95 hi (-95)	2.04 hi (-95)	35.2 f (-96)	37.1 fg (-96)
LSD	1.22	1.68	80.10	67.63
Contrast comparison				
Control vs all	41.7 vs 10.36**	43.2 vs 10.6**	863.0 vs 198.5**	855.6 vs 200.0**
Chemical control vs physical control	4.08 vs 1.15**	4.15 vs 1.18**	80.2 vs 12.3**	80.69 vs 14.40**
Chemical control vs ecological control	4.08 vs 30.17**	4.15 vs 31.02**	80.23 vs 576.1**	80.69 vs 580.0**
Herbicide once vs herbicide twice	4.85 vs 3.30**	4.91 vs 3.39**	93.72 vs 66.73NS	93.60 vs 67.78*
Weed control by non-ZT vs weed control by ZT	7.17 vs 19.91**	7.41 vs 20.26**	126.9 vs 413.5**	128.0 v 415.8**

The lowest weed density and weed dry weight was noted in treatment with criss-cross sowing + bispyribac-sodium 21 and 40 DAS, might be credited to the highest bio-efficacy as well as phytotoxic behavior of herbicide as ALS inhibitor (Lycan and Heart, 2006). Colbach *et al.* (2014) also described that homogeneity between rows and plants resulted in reduced weed-crop competition in DSR. Muhammad *et al.* (2016) reported a reduction in the weed dry biomass in treatments with physical weed control as compared to weed control by bispyribac-sodium in DSR. Khaliq *et al.* (2011) recorded minimum weed dry biomass when the herbicides were applied in a sequence rather than applied once in DSR.

All contrasts between different weed control measures proved to be significant regarding the weed density and weed dry weight in dry-DSR in two years. Muhammad *et al.* (2016) also stated a significant decline in the dry biomass of weeds by different cultural and chemical weed control methods in the dry-DSR. Safdar *et al.* (2010) reported minimum dry biomass (2.34 gm^{-2}) of weeds, while the maximum weed biomass (12.0 gm^{-2}) in weedy-check plots. The weed control efficiencies of various weed control measures have been shown in (Fig. 1). Maximum weed control efficiency (98%) was achieved by hoeing, while the criss-cross sowing + bispyribac-sodium 50 g ai ha^{-1} 21 and 40 DAS, stale seedbed technique + bispyribac-sodium 50 g ai ha^{-1} 21 and 40 DAS, criss-cross sowing + bispyribac-sodium 50 g ai ha^{-1} 21 DAS, stale seedbed technique + bispyribac-sodium 50 g ai ha^{-1} 21 DAS, bispyribac-sodium 50 g ai ha^{-1} 21 and 40 DAS, bispyribac-sodium 50 g ai ha^{-1} 21 DAS, ZT + bispyribac-sodium 50 g ai ha^{-1} 21 and 40 DAS, ZT + bispyribac-sodium 50 g ai ha^{-1} 21 DAS, criss-cross sowing, stale seedbed technique followed this treatment in the respective order for the first and second year, respectively. The minimum weed control efficiency was attained in ZT sowing in stubbles in both of the years, respectively. A significant decline in dry weight of weeds by different weed control methods when compared to un-weeded control seemed due to a decrease in the fresh weight of weeds. Our results are similar to Gogoi *et al.* (2000), who declared a significant decline in dry biomass (12.2 g m^{-2}) due to different weed control strategies, such as two hand weedings, one hoeing and the application of different herbicides. The minimum N uptake by the weeds (0.48 and 0.57 kg ha^{-1}) for the first and second year, respectively, was attained in the treatment with hoeing and this treatment was found statistically at par to bispyribac-sodium 50g a.i. ha^{-1} at 21 and 40DAS, stale seedbed technique + bispyribac-sodium 50g a.i. ha^{-1} at 21DAS, criss-cross sowing + bispyribac-sodium 50g a.i. ha^{-1} at 21DAS, stale seedbed technique with bispyribac-sodium 50g a.i. ha^{-1} at 21 and 40DAS, and criss-cross sowing + bispyribac-sodium 50g a.i. ha^{-1} at 21 and 40DAS, in two years, respectively. However, the maximum N uptake by the weeds (28.0 and 29.6 kg ha^{-1}) for the first and second year, respectively, was noted in the treatment with ZT sowing in stubbles.

Table 3. Weed NPK uptake (kg ha^{-1}) at harvest as affected by different weed control methods in dry-DSR.

Treatments	N uptake		P uptake		K uptake	
Years	2015	2016	2015	2016	2015	2016
No Weed Control	24.5 b	25.9 b	2.75 b	2.38 b	26.6 a	25.6 b
Hoeing	0.48 g	0.57 h	0.08 h	0.10 j	0.46 g	0.55 g
Bispyribac-sodium at 21 DAS	3.09 ef	3.17 fg	0.49 f	0.54 g	2.80 ef	3.00 ef
Bispyribac-sodium at 21 DAS and 40 DAS	2.36 efg	2.44 gh	0.39 fg	0.41 gh	2.08 fg	2.14 fg
Stale seedbed technique	13.8 c	14.2 c	1.87 c	1.94 c	12.9 b	12.5 c
ZT	28.0 a	29.6 a	3.28 a	2.91 a	28.3 a	28.2 a
Criss-cross sowing	11.5 c	11.2 d	1.41 d	1.48 d	10. c	11.2 c
Stale seedbed technique + bispyribac-sodium at 21 DAS	2.35 efg	2.30 gh	0.40 fg	0.40 gh	2.11 fg	2.08 fg
ZT + bispyribac-sodium at 21 DAS	5.87 d	5.93 e	0.91 e	0.99 e	5.46 d	5.23 d
Criss-cross sowing +bispyribac-sodium at 21 DAS	1.94 fg	2.01 gh	0.29 fg	0.33 hi	1.78 fg	1.84 fg
Stale seedbed technique + bispyribac-sodium at 21 DAS and 40 DAS	1.70 fg	1.62 gh	0.29 g	0.28 hi	1.48 fg	1.47 fg
ZT + bispyribac-sodium at 21 DAS and 40 DAS	4.73 de	4.87 ef	0.77 e	0.84 f	4.29 de	4.48 de
Criss-cross sowing + bispyribac-sodium at 21 DAS and 40 DAS	1.31 fg	1.37 gh	0.22 gh	0.25 ij	1.15 fg	1.24 fg
LSD	2.57	2.13	0.03	0.15	1.98	2.0
Control vs all	24.5 vs 6.44**	25.9 vs 6.62**	2.75 vs. 0.87**	2.39 vs. 0.88**	26.65 vs 6.14**	25.64 vs 6.17**
Chemical control vs physical control	2.92 vs 0.48**	2.97 vs 0.58**	0.47 vs. 0.09**	0.51 vs. 0.11**	2.64 vs 0.46**	2.68 vs 0.55**
Chemical control vs ecological control	2.92 vs 17.8**	2.97 vs 18.3**	0.47 vs. 2.19**	0.51 vs. 2.11**	2.64 vs 17.38**	2.68 vs 17.32**
Herbicide once vs herbicide twice	3.32 vs 2.53*	3.35 vs 2.58*	0.53 vs. 0.42*	0.57 vs. 0.45**	3.04 vs 2.25**	3.04 vs 2.33*
Weed control by non-ZT vs weed control by ZT	4.29 vs 12.8**	4.33 vs 13.4**	0.61 vs. 1.66**	0.64 vs. 1.59**	3.96 vs 12.70**	4.01 vs 12.63**

The contrast comparisons between different weed control techniques showed significance regarding weeds N uptake in the two years. Weeds being a heavy competitor, nourish strongly on nutrients as compared to crops. A higher weed N uptake in our study was noticed in treatment with ZT sowing in stubbles, which may be credited to a higher weed dry weight in that treatment. On the other hand, a decrease in weeds N uptake due to different weed control techniques may be due to a decline in weed biomass on an area basis (Table 3). The lowest P uptake by the weeds (0.08 and 0.10 kg ha^{-1} for the first and second year, respectively) was noted in hoeing, which was found statistically at par with that of criss-cross sowing + bispyribac-sodium 50g a.i. ha^{-1} at 21 and 40DAS, criss-cross sowing + bispyribac-sodium 50 g a.i. ha^{-1} at 21DAS, and stale seedbed technique + bispyribac-sodium 50g a.i. ha^{-1} at 21 and 40DAS, stale seedbed technique + bispyribac-sodium 50g a.i. ha^{-1} at 21 DAS, and bispyribac-sodium 50g a.i. ha^{-1} at 21 and 40DAS in two years, respectively. Contrastingly, the maximum value of P uptake (3.28 and 2.91 kg ha^{-1}) for the first and second year, respectively, was documented in treatment with ZT sowing in stubbles. More P uptake by the weeds in plots with ZT was apparently due to a higher weed biomass production. Though, a reduction in weed's P uptake by various weed control methods might be due to a reduction in weed biomass. The K uptake by the weeds decreased significantly by different weed control methods adopted in dry-DSR. The minimum K uptake of the weeds (0.46 and 0.55 kg ha^{-1}) in two years, respectively, was noted in hoeing that was statistically at par to criss-cross sowing + bispyribac-sodium 50g a.i. ha^{-1} at 21 and 40DAS, stale seedbed technique + bispyribac-sodium 50g a.i. ha^{-1} at 21 and 40DAS, criss-cross sowing + bispyribac-sodium 50g a.i. ha^{-1} at 21DAS, bispyribac-sodium 50g a.i. ha^{-1} at 21 and 40DAS, and stale seedbed technique + bispyribac-sodium 50g a.i. ha^{-1} at 21DAS in both of the years, respectively. Contrastingly, the maximum K uptake of the weeds (28.35 kg ha^{-1} for the first year and 28.20 kg ha^{-1} for the second year) was recorded in ZT sowing in stubbles. All contrast comparisons constructed among diverse weed control strategies regarding uptake of K were proved to be significant in both of the years.

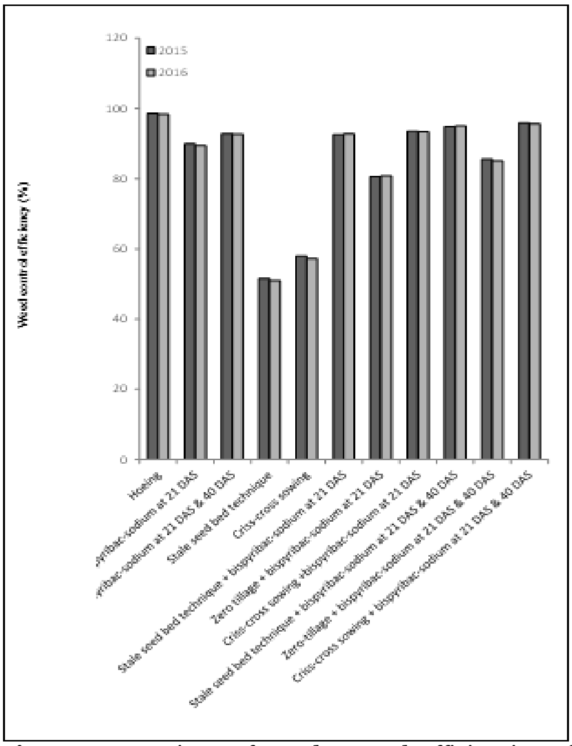

Fig. 1. Comparison of weed control efficiencies of different weed control methods in dry-DSR in two years.

Lower weed biomass production led to lower NPK uptake by the weeds (Puniya *et al.*, 2007). Our research findings are comparable with that of Shelar (2014), who noted a minimum depletion of weeds NPK in plots where weeds were removed by hoeing in DSR. Our results are analogous to Singh *et al.* (2013), who described that weed nutrient depletion was at its lowest (16.1 N, 7.3 P, 20.5 K kg ha^{-1}) due to an application of carfentrazone-ethyl, while it was highest (39.6 N, 17.9 P, 31.3 K kg ha^{-1}) in un-weeded (control) in rice. Gowda *et al.* (2009) also reported maximum depletion of P and K (13.5 and 27.0 kg ha^{-1}, respectively) in un-weeded (control) plots in DSR (Table 3).

Rice yield and yield components

Productive tillers

When compared with control, the maximum number of productive tillers m^{-2} of rice (439.1 in the first year and 469.3 in the second year) was noted in criss-cross sowing with bispyribac-sodium twice while the treatment criss-cross sowing with bispyribac-sodium once, hoeing, and stale-seedbed technique with bispyribac-sodium twice, were ranked at 2nd, 3rd and 4th positions in both years, respectively. Further, the minimum productive tillers m^{-2} (118.5 and 125.6) were counted in ZT sowing in stubbles for the two consecutive years, respectively. Kankal *et al.* (2015) reported that the maximum number of tillers/ 0.25 m^2 (37.43) of DSR in weed-free treatments over control. These results are further supported by Shelar (2014), who reported the highest number of tillers (m^{-2}) in weed-free plots when compared to un-weeded (control) in DSR. Ashraf *et al.* (2016) also counted the highest tillers m^{-2} when criss-cross planting geometry was adopted in the transplanted rice.

Number of grains panicle^{-1}

The highest number of grains panicle^{-1} (143 in the first year and 154 in the second year) was registered in hoeing, while a combination of criss-cross sowing and bispyribac sodium twice (125 and 131), stale seedbed technique and bispyribac-sodium twice (119 and 124) and bispyribac-sodium twice (115 and 121) followed this treatment in two years. Muhammad *et al.* (2016) stated that the number of grains panicle^{-1}of rice were higher in plots with physical weed control in comparison to chemical weed control (bispyribac-sodium).

Thousand grain weight

Among the different integrated approaches to control the weeds in this study, the highest 1000-grain weight of rice (23.0 and 23.5g) for the first and second year, respectively was recorded in plots with hoeing, and this treatment differed significantly from all the other weed control treatments in the two years. Contrastingly, a minimum of 1000-grain weight of rice (16.7 and 17.0g) was obtained from plots with ZT as a weed control treatment. The different contrast comparisons among different weed control methods regarding the 1000-grain weight of rice, the contrast among all use control measures.

The maximum 1000-grain weight of rice was accomplished due to the production of more assimilates due to minimum weed-crop competition during the phase of grain filling (Table 1). Bhurer *et al.* (2013) reported a maximum 1000-grain weight of rice when the weeds in DSR were controlled by an ecological (stale-seedbed technique) along with chemical weed control twice (pendimethalin Fb bispyribac-sodium) and ecological (stale-seedbed technique) along with chemical weed control once (bispyribac-sodium) and chemical weed control twice when compared with the weedy-check.

Grain yield

A statistically significant incline in the grain yield of rice was noted due to various weed control techniques alone and in combinations, as compared to weedy-check. Among all weed control methods used, the best weed control method was found to be hoeing as it resulted in the maximum grain yield of rice (4.11 t ha^{-1}) for the first year. In the second year, again hoeing demonstrated to be the best delivering the highest rice grain yield (4.28 t ha^{-1}), while, criss-cross sowing with bispyribac-sodium twice at second (3.66 t ha^{-1}), stale-seedbed technique with bispyribac-sodium applied twice at third (3.64 t ha^{-1}), positions, respectively. Contrastingly, the minimum grain yield of rice (0.29 and 0.33 t ha^{-1}) was recorded from the treatment with ZT in both of the years were proved to be statistically significant throughout both experimental years (Table 1).

The comparison of herbicide efficiency indices (HEI) related to various weed control methods has been demonstrated (Fig. 2). Data indicated that the highest HEI (203 and 232 in the first and second year, respectively) were attained by criss-cross sowing + bispyribac-sodium at 21 and 40 DAS which was followed by stale seedbed technique + bispyribac-sodium at 21 and 40 DAS with HEI values of 158 and 198 during the first and second year, respectively.

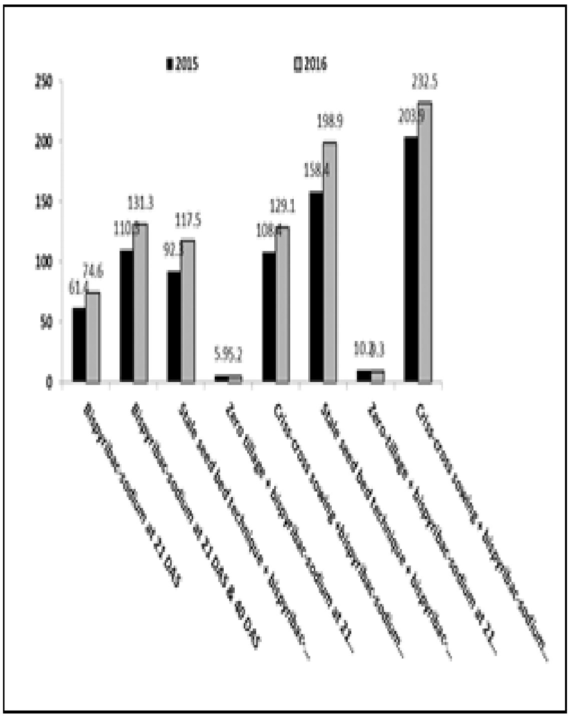

Fig. 2. Herbicide efficiency indices (HEI) of different weed control treatments in dry-DSR for two years.

Sharma and Singh (2008), during the assessment of integrated weed management strategies in DSR recorded the maximum paddy yield (5.5 t ha^{-1}) in criss-cross planting technique + one hand weeding + herbicide treatment which was followed by herbicide once + one hand weeding (5.3 t ha^{-1}), this treatment was followed by hand weeding twice (5.0 t ha^{-1}), which was followed by criss-cross sowing technique + one hand weeding (3.8 t ha^{-1}) while the lowest grain yield of rice (0.7 t ha^{-1}) was noted in un-weeded check.

Acknowledgment

We thank the higher authorities of the College of the Agriculture University of Sargodha for the technical assistance.

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