INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
12–405/AKA/2012/14–6–901–907
http://www.fspublishers.org

Full Length Article

Efficient Weeds Control with Penoxsulam Application Ensures Higher Productivity and Economic Returns of Direct Seeded Rice

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ABSTRACT

Severe water scarcity and labor shortage has made the direct seeded rice (DSR) an attractive option for sustainability of rice production systems. However, the severe weed infestation is the major constraint for success of DSR in Pakistan. In this study, two herbicides (penoxsulam [sprayed as early post-emergence, 7 days after sowing at 15 g a.i. ha^{-1}] and pendimethalin [sprayed as pre-emergence at 825 g a.i. ha^{-1}, respectively) were evaluated for effective weed control in DSR planted on ridges or flat soil surface. Herbicides were sprayed with a knapsack hand sprayer using 330 L ha^{-1} volume of spray and a weedy check was maintained as control for comparison. The herbicides were effective in reducing the weed density and dry weight over control in both sowing methods of DSR. Penoxsulam was more effective than pendimethalin for weed control causing substantial increase in grain yield, higher net income, benefit-cost ratio and marginal rate of return. However, there was no difference between sowing methods for weed prevalence, water productivity, grain yield and related traits. In conclusion, early post-emergence application of penoxsulam (15 g a.i. ha^{-1}) in DSR is more beneficial with higher productivity and economic returns owing to effective weeds control.

Key Words: Direct seeded rice; Chemical weed control; Grain yield; BCR; Water productivity

INTRODUCTION

Currently Pakistan is exporting its special brand fine grain aromatic rice to about 100 countries of Asia, Africa and Europe, and earning a massive foreign exchange due to its premium price in global market (REAP, 2012). Under conventional system of rice growing in Pakistan, rice is transplanted manually on puddled fields under flooded conditions (Ehsanullah *et al*., 2007), which requires heavy input of water for nursery raising, puddling operations and to keep a layer of water in rice fields during a major part of crop growth period (Bouman *et al*., 2007). Moreover, higher input of labor is also needed to uproot, transport and transplant the nursery seedlings in this system (Bhushan *et al*., 2007). Therefore, the continuous existence of this conventional system of growing fine grain aromatic rice on puddle soil under flooded conditions is highly vulnerable to sever scarcity of water and acute labor shortage (Farooq *et al*., 2009). In the present scenario, direct seeding of rice (DSR) under aerobic conditions devoid of puddling seemed an eye-catching substitute of this conventional system of rice production (Bhushan *et al*., 2007; Farooq *et al*., 2009).

DSR means the direct planting of rice seeds in the dry soil instead of the conventional methods (CM) that involve the sowing and transplanting of nursery in the flooded fields (Ehsanullah *et al*., 2007; Farooq *et al*., 2011a). DSR possesses pertinent significance in the wake of sever water shortage during the recent two decades (Farooq *et al*., 2009). A significant amount of water can be spared through adoption of DSR instead of CM; as about 35–57% of water savings have been observed in DSR than traditional transplanted rice (Peng *et al*., 2006; Bhushan *et al*., 2007). This saved water may be utilized to bring more area under cultivation for the sake of strengthened food security. Furthermore, the less labor input and early crop maturity adds to the significance of DSR as DSR needs almost 50% less labor compared with conventional transplanted rice system (Singh *et al*., 2008).

Nevertheless, the high weed infestation is the crucial threat to the adoption and sustenance of DSR and other water saving rice cultures (Rao *et al*., 2007). Farmers are reluctant to grow rice as DSR in the wake of high weed

To cite this paper: Jabran, K., M. Farooq, M. Hussain, Ehsanullah, M.B. Khan, M. Shahid and D.J. Lee, 2012. Efficient weeds control with penoxsulam application ensures higher productivity and economic returns of direct seeded rice. *Int. J. Agric. Biol*., 14: 901–907

prevalence despite charming benefits of lower water and labor inputs. Decline in yield of DSR is far higher owing to weeds than all other pests. The estimated yield losses due to weeds in DSR were always greater than 10% and resulted in total failure of crop in most of the cases as a result of sever weed-crop competition (Rao *et al.,* 2007). The rice weeds, especially the sedges including *Cyperus rotundus* L., *C. iria* L., *C. difformis* L., *C. esculentus* L. and narrow leaves such as *Echinochloa crusgalli* L., *Echinochloa colona* L. are amongst the worlds' most troublesome and notorious weeds. These weeds make the weed control more difficult in DSR where a layer of standing water is not present to act a mean of weed suppression as in the case of CM. Hence, a higher weed pressure has been reported in DSR than in CM (Mahajan *et al.,* 2009). Further, the semi-saturated soil conditions in DSR are more convenient for the germination and growth of weeds (Singh *et al*., 2008). High weed infestation also robustly lowers the economic returns of DSR and often makes rice cultivation unprofitable.

Establishment methods for DSR can vary owing to land availability for sowing the crop, soil condition and water availability. For cultivating rice through DSR, the rice seeds can either be drilled in the soil at field capacity, or they may be planted in the dry soil with a subsequent immediate irrigation. Sowing of rice seeds on beds or ridges can be the other possible forms of DSR. Ridges may facilitate vigorous root growth to grasp more soil surface and hence enhanced water availability for DSR. Moreover, the weeds emergence and growth pattern for several of these DSR methods has not been studied to the best of our knowledge. As the weeds are major issue in DSR, hence the various sowing methods of DSR may be manipulated to effectively control weeds. Several weed management options can be availed to improve and sustain the productivity of DSR. Manual weed control in DSR is not suitable owing to high costs involved except where it is needed partially. The mechanical weeders are mostly manually operated and can be employed for small scale weed control in DSR. However, the development and testing of tractor drawn weeders having high precision can ease the weed control in DSR. However, several herbicides have been recommended successful for weed management in DSR in various parts of world (Mahajan *et al.,* 2009; Akbar *et al.,* 2011). For instance, application of pendimethalin, pretilachlor and butachlor may suppress the weeds, in DSR, by 70% with improvement in the paddy yield by 7-19% over the control (Akbar *et al.,* 2011). Similarly, Jabran *et al.* (2012) found that the herbicides like bispyribac-sodium, penoxulam and pendimethalin could effectively control the weeds and increase the yield (>50%) in DSR. Hence the herbicides including penoxulam and pendimethalin are likely to possess the potential to control weeds and improve the grain yield in DSR.

Hence, this study was conducted to monitor the weeds proliferation pattern in the DSR sown either on flat seedbed or ridges and evaluating the effectiveness of two herbicides (one pre-emergence & one early post-emergence) for controlling weeds, improving yield, water productivity and economic returns of DSR.

MATERIALS AND METHODS

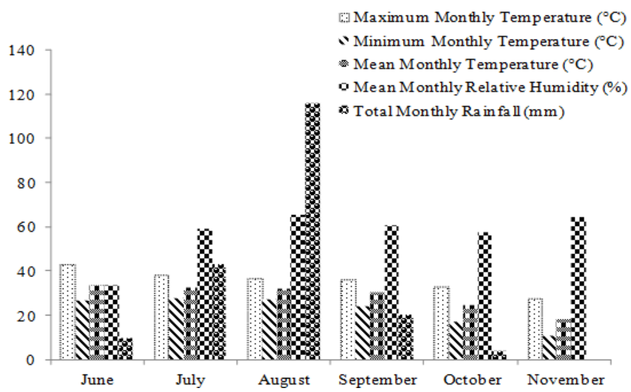
Experimental site description: This study was conducted at area of Directorate of Farms, University of Agriculture Faisalabad, Pakistan. Experimental area was fairly uniform in nature and pre-sowing analysis of soil was conducted in order to assess its fertility standing. The pre-sowing soil analysis indicated that the soil was sandy loam with pH 8.1, EC 0.72 dS m^{-1}, exchangeable sodium 0.30 $mmol_c$/100 g, organic matter 0.83%, total nitrogen 0.054%, available phosphorus 7.12 ppm and available potassium 90 ppm. The weather data, during experimental period, are given in Fig. 1.

Experimental details: The experiment was laid out according to split plot design with net plot size of 6 m x 15 m and replicated three times. Sowing methods and weed control treatments were randomized in main and sub-plots, respectively. Sowing methods included in the study were sowing of the rice seeds on flat seedbed (DSR_1) and on ridges (DSR_2). The weed control treatments included early post-emergence [7 days after sowing (DAS)] application of penoxsulam (Ryzelon 240SC) at 15 g a.i. ha^{-1} and pre-emergence [immediately after sowing] application of pendimethalin (Stomp 330EC) at 825 g a.i. ha^{-1}. Both the herbicides were applied only once at the mentioned timings. The herbicides doses, type and frequency selection was based on personal observations from the previous years' experiments (unpublished data), personal communications and findings of Akbar *et al.* (2011) and Jabran *et al.* (2012). A weedy check (control) was kept un-weeded and maintained as control for comparison. A manually operated knapsack sprayer with flat fan nozzle was used to determine the volume of spray (330 L ha^{-1}) after calibration and used for application of herbicides.

Crop husbandry: The soil was prepared at field capacity by cultivating and planking three times by tractor drawn cultivator and planker for the subsequent sowing of rice seeds in the soil by drill. For DSR_1, the rice seeds were sown on a finely prepared flat soil. For DSR_2, 60 cm spaced ridges were made with the tractor operated ridger. Rice seeds were sown on both sides of ridge. Seed of Shaheen Basmati (75 kg ha^{-1}) was obtained from Soil Salinity Research Institute Pindi Bhattyan having 85% and 12% germination percentage and moisture contents, respectively. Diammonium phosphate (DAP), urea and sulphate of potash (SOP) were used as fertilizer source at 120-75-50 kg NPK ha^{-1}. Whole potassium and phosphorus were added at sowing and nitrogen was applied in three splits. Volume of water applied was recorded by equation QT = AD; where: Q = discharge (ft^3 s^{-1}) rate from flume, T = time (h) for which water to be applied, A = area (acres) to be irrigated and D = depth (inches) of irrigation water. The volume of water in

Fig. 1: Weather data during the whole course of experiment

Source: Agricultural Meteorology Cell, Department of Crop Physiology, University of Agriculture Faisalabad, Pakistan



each of the irrigation was 3 acre inches except the first (pre-soaking) irrigation where it was 4 acre inches. In total 52 acre inches of water (16 irrigations except pre-soaking) were applied to the experiment during the whole crop season in addition to the water received in the form of rainfall.

Measurements: Total number of weeds was counted from a random selected area of 1 m^2 at two places from each plot at 30 days after sowing and averaged to record data of total weeds density. Weed dry weight was recorded by cutting the weeds from designated respective areas at ground level and shifted to laboratory for drying under shade for a period of seven days. The weeds were then placed in oven at 80±2°C until constant weight. Weeds for the respective plots were, then weighted at electric balance to record dry weight (g m^{-2}).

Productive and un-productive tillers were counted from each plot at three places (1 m^2) at random and averaged. Plant height, number of branches per panicle, panicle length and number of grains per panicle were recorded from randomly selected twenty tillers from each plot and averaged. Two random samples of 1000 grains were taken from each seed lot, weighed on an electrical balance and averaged to record 1000-grain weight (g). An area of 3 m × 3 m was demarked, cut manually and threshed to record grain and biological yield. Harvest index was calculated as ratio of grain yield to biological yield expressed in percentage. Water productivity was derived as a ratio of grain yield (kg) and water applied (m^3).

Statistical and economic analysis: Fisher's analysis of variance technique and LSD test at 5% probability were used to analyze the data and compare the differences among treatment's means, respectively (Steel *et al*., 1997). Economic analysis for the treatments was worked out by calculating the total income, variable expenditures and total expenditures. Variable expenditure was subtracted from total income to get net field benefits (US$ ha^{-1}). Similarly, net returns (US$ ha^{-1}) were calculated by subtracting the total expenditures from total income. Benefit cost ratio was computed by dividing total income by total expenditure. Marginal analysis was done in accordance with the procedure of CIMMYT (1988).

RESULTS

The weed emergence was similar for the two sowing methods of direct seeded rice (DSR) (Table I). Similarly, the dry matter gained by the weeds was also similar for both the sowing methods of DSR (Table I). Nevertheless, the herbicides were effective in suppressing weeds compared with the weedy check (control; Table I). Total weeds density and total weeds dry weight were reduced by the application of herbicides compared with the control treatment (Table I). Total weeds density (number m^{-2}) was reduced by 79.88 and 73.1% by the application of penoxsulam (15 g a.i. ha^{-1}) and pendimethalin (825 g a.i. ha^{-1}), respectively (Table I). Similarly, the total weeds dry weight was reduced by 82.01 and 75.96% by the application of penoxsulam (15 g a.i. ha^{-1}) and pendimethalin (825 g a.i. ha^{-1}), respectively (Table I). The interactive effects of DSR sowing methods and weed control treatments were also significant on the total weeds density and total weeds dry weight (Table I). Maximum total weeds density and dry weight were recorded in the weedy check treatment under both the sowing methods of DSR (Table I). Penoxsulam (15 g a.i. ha^{-1}) was more effective than pendimethalin (825 g a.i. ha^{-1}) in controlling weeds under both the sowing methods (Table I).

DSR on flat as well as the ridges did not differ statistically for water productivity, unproductive tillers, grain yield and yield related parameters; whereas herbicides application significantly affected the grain yield and related parameters (Table II). Maximum and statistically similar plant height, branches per panicle, productive tillers, 1000-grain weight, grain yield, biological yield, harvest index and water productivity were recorded for the experimental units applied with the herbicides penoxsulam (15 g a.i. ha^{-1}) and pendimethalin (825 g a.i. ha^{-1}) while minimum of these parameters were noted for the weedy check (Table II). Grains per panicle were recorded maximum for plots applied with penoxsulam (15 g a.i. ha^{-1}) followed by the plots applied with pendimethalin (825 g a.i. ha^{-1}) while minimum number of grains per panicle was recorded for the weedy check (Table II). Weedy check had the highest non-productive tillers followed by penoxsulam (15 g a.i. ha^{-1}) and pendimethalin (825 g a.i. ha^{-1}), respectively (Table II). The experimental units applied with the herbicides penoxsulam (15 g a.i. ha^{-1}) and pendimethalin (825 g a.i. ha^{-1}) exhibited 88.5 and 76.2% higher grain yield, respectively over weedy check (Table II).

The interactive effects of sowing methods and weed control treatments were also significant on most of the yield related parameters (Table II). Minimum plant height was recorded for the weedy check of ridge sown rice (DSR_2) followed by the weedy check of flat sown rice (DSR_1) and

Table I: Effect of penoxulam and pendimethlin on total weeds density and total weeds dry weight under direct seeded rice

Treatments	Total weeds density (m^{-2})	Total weeds dry weight ($g\ m^{-2}$)
Direct seeded rice sowing methods (DSR)		
Sowing of rice seeds in the flat soil (DSR_1)	16.03	146.10
Sowing of rice seeds on the ridges (DSR_2)	14.32	140.80
LSD value (p 0.05)	**NS**	**NS**
Weed control treatments (W)		
Penoxsulam at 15 g a.i. ha^{-1} (W_1)	6.23 B (79.88)	54.50 B (82.01)
Pendimethalin at 825 g a.i. ha^{-1} (W_2)	8.33 B (73.10)	72.83 B (75.96)
Weedy check (control) (W_3)	30.97 A	303.00 A
LSD value (p 0.05)	**2.34**	**19.03**
Interaction between DSR X W		
$DSR_1 \times W_1$	6.33 c (79.86)	57.00 bc (81.18)
$DSR_1 \times W_2$	10.33 b (67.13)	78.00 b (74.28)
$DSR_1 \times W_3$	31.43 a	303.30 a
$DSR_2 \times W_1$	6.13 c (79.90)	52.00 c (82.82)
$DSR_2 \times W_2$	6.33 c (79.25)	67.67 bc (77.64)
$DSR_2 \times W_3$	30.50 a	302.70 a
LSD value (p 0.055)	**3.31**	**24.87**

Means not sharing the same letter within a column differ significantly from each other at P = 0.05 according to LSD test
Values given in parenthesis indicate percent decrease over control
DSR_1 and DSR_2 mean sowing of direct seeded rice on flat seedbed and ridges, respectively; and W_1, W_2 and W_3 mean early post-emergence application of penoxsulam at 15 g a.i. ha^{-1}, pre-emergence application of pendimethalin at 825 g a.i. ha^{-1} and weedy check (un-weeded), respectively

Table II: Effect of penoxulam and pendimethlin on the yield and related traits under direct seeded rice

Treatments	Plant height (cm)	Branches per panicle	Non-productive tiller (m^{-2})	Productive tiller (m^{-2})	Grains per panicle	1000-grain weight (g)	Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)	Water Productivity (kg m^{-3})
Direct seeded rice sowing methods (DSR)										
DSR_1	96.17	8.58	15.94	299.80	56.92	19.19	2515.00	8613.00	28.71	0.47
DSR_2	90.36	8.18	15.03	303.40	54.77	18.94	2622.00	8940.00	28.82	0.49
LSD value (p 0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Weed control treatments (W)										
W_1	102.70 A	8.70 A	13.50 B	340.30 A	65.48 A	19.18 AB	3125 A (88.5)	9402 A	33.18 A	0.58 A
W_2	99.00 A	8.40 A	10.33 C	333.00 A	60.62 B	20.55 A	2922 A (76.2)	9092 A	32.09 A	0.54 A
W_3	78.05 B	8.03 B	22.63 A	231.50 B	41.43 C	17.47 B	1658 B	7837 B	21.02 B	0.31 B
LSD value (p 0.05)	**9.34**	**NS**	**1.13**	**36.38**	**4.08**	**2.15**	**397.7**	**407.6**	**3.85**	**0.073**
Interaction (DSR × W)										
$DSR_1 \times W_1$	102.20 ab	9.17 a	14.33 c	360.70 a	64.67 ab	19.17 ab	3100 a (85.9)	9419 a	32.80 a	0.58 a
$DSR_1 \times W_2$	106.40 a	8.50 ab	12.00 d	332.00 a	61.53 ab	20.37 a	2778 a (66.6)	8772 b	31.63 a	0.52 a
$DSR_1 \times W_3$	79.90 cd	8.07 b	21.50 b	206.70 b	44.57 c	18.03 ab	1667 b	7648 c	21.71 b	0.31 b
$DSR_2 \times W_1$	103.20 ab	8.23 ab	12.67 d	320.00 a	66.30 a	19.20 ab	3150 a (90.9)	9385 a	33.57 a	0.59 a
$DSR_2 \times W_2$	91.63 bc	8.30 ab	8.67 e	334.00 a	59.70 b	20.73 a	3067 a (85.9)	9411 a	32.54 a	0.57 a
$DSR_2 \times W_3$	76.20 d	8.00 b	23.77 a	256.30 b	38.30 d	16.90 b	1650 b	8025 c	20.34 b	0.31 b
LSD value (p 0.055)	**13.21**	**1.05**	**1.60**	**51.45**	**5.77**	**3.04**	**562.5**	**576.4**	**5.45**	**0.103**

Means not sharing the same letter within a column differ significantly from each other at P = 0.05 according to LSD test
Values given in parenthesis indicate percentage increase over control
DSR_1 and DSR_2 mean sowing of direct seeded rice on flat seedbed and ridges, respectively; and W_1, W_2 and W_3 mean early post-emergence application of penoxsulam at 15 g a.i. ha^{-1}, pre-emergence application of pendimethalin at 825 g a.i. ha^{-1} and weedy check (un-weeded), respectively

both the treatments were at par with each other for the plant height (Table II). Maximum plant height was recorded for the DSR_1 applied with pendimethalin (825 g a.i. ha^{-1}; Table II). Maximum branches per panicle were recorded for DSR_1 applied with penoxsulam at 15 g a.i. ha^{-1} while minimum branches per panicle were recorded for the weedy check of both the sowing methods (Table II). Highest non-productive tillers were recorded for the weedy check of DSR_2 followed by the weedy check of DSR_1 (Table II). Minimum non-productive tillers were recorded for the DSR_2 applied with pendimethalin at 825 g a.i. ha^{-1} (Table II). DSR_1 and DSR_2 applied with both the tested herbicides had similar productive tillers while weedy check of both of the sowing methods had lowest and statistically similar productive tillers (Table II). Number of grains per panicle was noted maximum for DSR_2 applied with penoxsulam at 15 g a.i.

ha^{-1}, while the DSR_1 plots applied with both the herbicides were at par with this treatment (Table II). Minimum number of grains per panicle was noted for the weedy check of DSR_2 followed by the weedy check of DSR_1 (Table II). DSR_1 and DSR_2 applied with pendimethalin at 825 g a.i. ha^{-1} had the highest and statistically similar 1000-grain weight while minimum 1000-grain weight was recorded for the weedy check of DSR_2 (Table II). Weedy check plots of both the sowing methods had lowest grain yield, harvest index and water productivity, while DSR_1 and DSR_2 plots applied with both the herbicides had the highest and statistically similar grain yield, harvest index and water productivity (Table II). A sizeable rise in grain yield of about 85.9 and 90.9% respectively was observed under both sowing methods of DSR with penoxsulam (15 g a.i. ha^{-1}) application (Table II). DSR_1 and DSR_2 applied with penoxsulam at 15 g a.i. ha^{-1} and DSR_2 applied with pendimethalin at 825 g a.i. ha^{-1} had the highest biological yield while the weedy check plots of both the sowing methods had the lowest biological yield (Table II).

Economic analysis indicated that DSR planted on ridges had a slight edge on flat seedbed as indicated by a bit higher net economic returns and BCR (benefit-cost ratio) value (Table III). Among the applied herbicides, highest net field benefits, net returns and benefit-cost ratio was recorded for penoxsulam (15 g a.i. ha^{-1}; Table III). Weedy check had lowest net field benefits and BCR and a negative value for the net returns, which depicted DSR to be unprofitable without effective weed control (Table III). With respect to interaction between planting methods of DSR and weed control treatments, maximum economic returns tied with higher BCR of DSR was exhibited by penoxsulam (15 g a.i. ha^{-1}) application under both sowing methods (Table III). Negative values of economic returns and BCR values less than 1 for weedy check plots under both sowing methods depicted that DSR was unprofitable without effective weed control either sown on flat seedbed or ridges (Table III). According to marginal analysis, ridge sowing and penoxsulam (15 g a.i. ha^{-1}) application was the best with 301.2 and 3900.95% rate of marginal return over their respective controls (Table IV). With respect to interactive effect, penoxsulam (15 g a.i. ha^{-1}) application seemed the best with 14000 and 2690% rate of marginal return by sowing DSR on flat seedbed and ridges respectively (Table IV).

DISCUSSION

Water and labor shortage has made it inevitable to investigate and adopt the direct cultivation of rice instead of conventional flooded transplanting. Nevertheless, the severity of weed infestation leads to the total failure of direct seeded rice (DSR) in many instances. Results of this study depict that DSR is heavily affected by the weeds and the weed prevalence, however, was similar for the both sowing methods of DSR. Hence, careful weed management strategies would be desired for DSR sown under various sowing methods. Heavy weed infestation is the major cause of substantial yield reduction of DSR (Farooq *et al*., 2011a) and therefore, an important obstacle in its commercial adoption on large scale (Rao *et al*., 2007). Chemical weed control by the application of selective herbicides often proved very effective in suppressing weeds with sizeable boost in the productivity of variety of arable crops including DSR (Mahajan *et al.,* 2009; Razzaq *et al.,* 2010; Farooq *et al*., 2011a).

The weed flora of the experimental site consisted of narrow leaves (*Echinochloa colona* L., *Echinochloa crusgalli* L., *Dactyloctenium aegyptium* L.) and sedges (*Cyperus rotundus* L., *Cyperus difformis* L.) while no broad leaved weeds were noted in the experiment. Although both the tested herbicides caused substantial reduction in total weeds density and dry weight over control but early post emergence application of penoxsulam was found to be more effective. Lower efficacy of pendimetahlin for suppressing total weed density and total weed dry weight than the penoxsulam may be due to the presence of sedges (*C. rotundus* & *C. difformus*) in the experimental site; as pendimethalin has been reported to be less effective against sedges (Jabran *et al.,* 2010b). As pendimethalin only kills the germinating weeds and less effective against sedges while penoxulam can be effective in controlling sedges, broad leaved weeds and grasses, hence penoxulam might had offered more promising weed control than the pendimethalin.

Adoption of any technique or treatment on commercial basis to get proper consideration by the farmers totally depends on its economic feasibility and in current scenario sever scarcity of the resources makes the comparison of economic outputs more important. Results of the study clearly depicted that the application of both herbicides in general and early post emergence application of penoxsulam in particular, significantly improved the economic returns owing to higher grain output than weedy check by suppressing the weeds (Table III). Although, the herbicides had minor expenditures, however, their application caused substantial increase in yield leading to sizeable elevation in total net income and benefit-cost ratio (BCR) (Table III; Razzaq *et al*., 2012). Moreover, the penoxsulam was less expensive than pendimethalin, however, it earned comparatively higher benefits due to higher weed suppression and increase in yield and therefore observed higher marginal rate of return of 14000 and 2690% of DSR planted on flat seedbed and ridges respectively (Table IV). The negative value of the net economic returns and BCR less than 1 for the weedy check treatment under both sowing methods of DSR suggested that without proper weed control, the DSR system was totally unprofitable (Table III).

Overall, the values of net return and benefit cost ratio were not attractive. That was due to overall low productivity of DSR. This predicates the use of integrated weed

Table III: Effect of penoxulam and pendimethlin on economic returns under direct seeded rice

Treatments	Variable cost (US$ ha^{-1})	Permanent cost (US$ ha^{-1})	Total cost (US$ ha^{-1})	Gross income (US$ ha^{-1})	Net field benefits (US$ ha^{-1})	Net return (US$ ha^{-1})	Benefit-cost ratio (BCR)
Direct seeded rice sowing methods (DSR)							
DSR_1	0.0	833.3	833.3	1047.9	1047.9	214.6	1.26
DSR_2	11.1	833.3	844.4	1092.5	1081.4	248.1	1.29
Weed control treatments (W)							
W_1	15.3	833.3	848.6	1302.1	1286.8	453.5	1.53
W_2	20.8	833.3	854.1	1217.5	1196.6	363.2	1.43
W_3	0.0	833.3	833.3	690.8	690.8	-142.5	0.83
Interaction (DSR ×W)							
$DSR_1 \times W_1$	15.3	833.3	848.6	1291.7	1276.4	443.1	1.52
$DSR_1 \times W_2$	20.8	833.3	854.2	1157.5	1136.7	303.3	1.36
$DSR_1 \times W_3$	0.0	833.3	833.3	694.6	694.6	-138.8	0.83
$DSR_2 \times W_1$	26.4	833.3	859.7	1312.5	1286.1	452.8	1.53
$DSR_2 \times W_2$	31.9	833.3	865.3	1277.9	1246.0	412.6	1.48
$DSR_2 \times W_3$	11.1	833.3	844.4	687.5	676.4	-1590.3	0.81

DSR_1 and DSR_2 mean sowing of direct seeded rice on flat seedbed and ridges, respectively; and W_1, W_2 and W_3 mean early post-emergence application of penoxsulam at 15 g a.i. ha^{-1}, pre-emergence application of pendimethalin at 825 g a.i. ha^{-1} and weedy check (un-weeded), respectively
The income was estimated using the prevailing average market price of rice in Pakistan
Variable cost included the expenditures for the respective herbicides and the weed free treatment
Permanent cost included the expenditures spent for field preparation, seed, sowing, fertilizing, irrigation, crop protection measures and harvesting
Net field benefits and net income were calculated by subtracting variable cost and total cost respectively, from the income
Benefit-cost ratio (BCR) was computed by dividing the income with total expenditure

Table IV: Effect of penoxulam and pendimethlin on the marginal analysis under direct seeded rice

Treatment	Variable cost (US$ ha^{-1})	Net field benefits (US$ ha^{-1})	Change in cost (US$ ha^{-1})	Change in net benefits (US$ ha^{-1})	Marginal rate of return (%)
Direct seeded rice sowing methods (DSR)					
DSR_1	0	1047.9	-	-	
DSR_2	11.1	1081.4	11.1	33.5	301.8
Weed control treatments (W)					
W_3	0	7.7	-	-	
W_1	15.3	14.3	15.3	6.6	3900.95
W_2	20.8	13.3	5.5	-	D
Interaction between DSR ×W					
$DSR_1 \times W_3$	0.0	694.6	-	-	
$DSR_2 \times W_3$	11.1	676.4	11.1	-	D
$DSR_1 \times W_1$	15.3	1276.4	4.2	600.0	14285.7
$DSR_1 \times W_2$	20.8	1136.7	5.5	-	D
$DSR_2 \times W_1$	26.4	1286.1	5.6	149.4	2667.9
$DSR_2 \times W_2$	31.9	1246.0	5.5	-	D

DSR_1 and DSR_2 mean sowing of direct seeded rice on flat seedbed and ridges, respectively; and W_1, W_2 and W_3 mean early post-emergence application of penoxsulam at 15 g a.i. ha^{-1}, pre-emergence application of pendimethalin at 825 g a.i. ha^{-1} and weedy check (un-weeded), respectively
Change in cost is the extra or marginal cost calculated by subtracting the cost of a treatment from the cost of the preceding treatment after arranging the treatments in the increasing cost order
Change in benefit is the extra or marginal benefit obtained after subtracting the benefit of a certain treatment from the benefit of the preceding treatment after arranging the treatments in the increasing cost order; Marginal rate of return was calculated by dividing the change in benefit with the change in cost and expressed in percentage
D=dominated due to lower benefits than preceding treatments

management strategies and more economical weed control techniques (Jabran *et al.,* 2008). However, special attention must be imparted to the fact that integration of various weed control methods must not compromise on the cost effectiveness. Further, in the wake of chronic effects of herbicides on the environment and the development of herbicide resistance in weeds, it would be desired to use other means of weed control along with careful use of herbicides (Jabran *et al.,* 2010a; Farooq *et al.,* 2011b, c).

In conclusion, early post emergence application of penoxsulam for the two sowing methods seemed more beneficial with high productivity and economic returns owing to effective weeds control. Although, sowing of DSR on ridges seemed a bit more economical but it was statistically at par with flat seedbed with respect to weeds control and grain yield along with all other yield related traits. Moreover, without proper weed control, cultivation of rice under DSR system seemed unprofitable.

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(Received 12 July 2012; Accepted 15 September 2012)