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Chemical weed control of dry direct-seeded rice under zero tillage in central mid-hill region of Nepal

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ABSTRACT

The performance of different herbicides for the weed control of dry direct-seeded rice (DDSR) under zero tillage was evaluated by field experiment during rainy season of 2017 at NARC, Lalitpur, Nepal. The treatments consisted of 8 different herbicidal treatments (pendimethalin 1.0 kg/ha, pendimethalin 1 kg/ha followed by bispyribac-Na 35 g/ha, pendimethalin 1.0 kg/ha followed by (*fb*) tank mix of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha, pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha, pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha, pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under co-culture with *Sesbania*) and a weedy check treatment with 3 replications under randomized complete block design. Result of the experiment revealed significant reduction in the weed density and increase in rice yield due to application of herbicides. Sequential application of pendimethalin (pre) *fb* tank mixture of pyrazosulfuron + bispyribac-Na (post) possess higher weed control efficiency and yielded the highest rice grain yield (3.78 t/ha), which was statistically at par with pendimethalin *fb* 2,4-D under Sesbania co-culture (3.44 t/ha) and pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha (3.09 t/ha). Similarly, application of pendimethalin 1.0 kg/ha (pre) *fb* tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha recorded the highest net returns of NRs. 31,760/ha and B: C ratio of 1.42 resulting to be the most economical and efficient herbicidal treatment option in DDSR under zero tillage.

Rice (*Oryza sativa L.*) is the world's second most important crop following maize, and is the major staple food for more than half of the world's population (Seck *et al.* 2012). Despite of the first position of rice in terms of area, production and consumption in Nepalese context, the present productivity remains very low *i.e.* 3.37 t/ha (MOALD 2017). This lower productivity of rice is not sufficient to meet the increasing demand of population over time. The major reasons are lack of improved cultivation practices, use of old generation seeds, lack of inputs like fertilizers, herbicides, insecticides, irrigation facility, inappropriate and improper weed management practices and poor access to infrastructure and market, *etc.* (Marahatta 2008).

The common method of rice cultivation in Nepal is by puddling followed by transplanting of 20-30 days old seedlings. However, there are several advantages of puddling like enhancing nutrient uptake (*e.g.* P, Fe, Zn) by creating anaerobic condition, reducing weed population (Singh *et al.* 2002), reduction in percolation loss and thus higher water use efficiency, facilitate transplanting and ease seedling establishment (Kirchhof *et al.* 2011). It adversely affects soil physical properties by dismantling soil aggregates, reducing permeability in subsurface layers (Sharma *et al.* 2003), forming hard-pans at shallow depths, which hinders the root development of other crops grown in rice based crop rotation and more emission of methane gas in atmosphere (Tripathi *et al.* 2005) and contributes to global warming (Gao *et al.* 2006). Therefore, the alternate method of planting *i.e.* Dry direct-seeded rice (DDSR) is gaining popularity regarding its high water, labour and energy use efficiencies (Kumar and Ladha 2011).

Dry-DSR is the methods of sowing dry seeds in the conventionally ploughed dry field. Direct-seeded rice removes puddling and drudgery of seedlings transplanting and provides an option to resolve the edaphic conflict, enhance the sustainability of rice based cropping system. DDSR rice matures 1-2 weeks earlier than transplanted rice, thus reducing the risk of terminal drought and allowing earlier planting of succeeding crop in rotation. However, researchers reported the lower yield under DDSR due to uneven or poor crop emergence, inadequate weed control, higher spikelet sterility than in puddled transplanting, higher crop lodging, especially in broadcasting and insufficient knowledge of water and nutrient management (micronutrient deficiencies). Weeds are the major constraint to the success of DSR in general and to DDSR in particular (Kumar *et al.* 2015). It is important to manage the weeds to sustain the yield with the adoption of DDSR. This study was planned and executed aiming to assist to evaluate the efficient and economically viable chemical weed control for higher productivity and profitability of rice under zero tillage DDSR system.

The field experiment was conducted at the Agronomy Farm of Nepal Agriculture Research Council (NARC), Khumaltar, Lalitpur, Nepal from June 2017 to November 2017. Geographically, the experimental site is situated at central Nepal (27^0 392 243 N, 85^0 192 353 E, 1300 masl.) with warm temperate climate. The total rainfall of 755.2 mm was received during the entire period of experiment. randomized complete block design (RCBD) with 9 treatments and 3 replications were set up while execution of the experiment. There were eight treatments regarding herbicides *i.e.* pendimethalin 1.0 kg/ha, pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha, pendimethalin 1.0 kg/ha *fb* tank mix of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha, pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha, pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha, pendimethalin 1.0 kg/ha followed by sulfosulfuron 30 g/ha, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under co-culture with *Sesbania* and a weedy check treatment. Khumal-10 variety of rice was sowed in a gross plot of 12 m^2 (3×4 m) on 7th June 2017. Manual sowing in a continuous line with 20 cm row-to-row distance in a zero tillage field was done. Harvesting was done on 25th October 2017 manually. Biometrical observations on plant height, leaf area index (LAI) and above ground biomass, different yield attributes, grain and straw yield, economics of yield as well as B: C ratio was calculated. Weed parameters, *viz.* weed density, weed index and weed control efficiency (WCE) were also measured. Collected data were analyzed using SPSS and ANOVA was done at 5% level of significance, whereas Microsoft excel was used for graph preparation.

Growth attributes

The taller plant was measured under plot treated with pendimethalin *fb* 2,4-D under *Sesbania* co-culture (136.1 cm) which was statistically superior with all the remaining treatments. Similarly, higher LAI was also found under plot treated with pendimethalin *fb* 2,4-D under *Sesbania* co-culture (2.23). The taller plant under *Sesbania* co-culture attained attractive growth because of nitrogen fixation by *Sesbania* along with smothering of weeds and conserving moisture and thus, more water and nutrients were available for the better growth and development, which resulted in superior growth of rice and hence higher plant height as well as LAI and this result was also agreed by Gaire *et al.* (2013). In pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha applied plots had produced higher above ground biomass (6.5 t/ha) while the lowest biomass was found under weedy check (4.3 t/ha), which was statistically at par with plots treated with pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha (4.7 t/ha), pendimethalin (4.9 t/ha), pendimethalin *fb* penoxsulam (5.3 t/ha) and pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under *Sesbania* co-culture (5.7 t/ha). As intra-specific competition was same in every treatment, inter specific competition between crop and weeds affected the crop biomass. Ottis and

Table 1. Different growth and yield attributes of DDSR as influenced by application of different herbicidal matrices

Treatment	Plant height at harvest (cm)	Leaf area index (LAI)	Above ground biomass (t/ha)	Effective tillers/m^2	Panicle length (cm)	Filled grains/ panicle
Pendimethalin 1.0 kg/ha (pre)	117.5 ^{d}	2.15^{bc}	4.9 ^{cd}	133.3^{abc}	19.9 ^{b}	88.7^{e}
Pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha	123.0 ^{bc}	2.13^{bc}	5.8 ^{abc}	114.3^{bc}	20.9 ^{b}	88.9^{e}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha	118.8 ^{cd}	2.1^{bc}	6.2 ^{ab}	149.0^{ab}	21.5 ^{b}	108.6^{c}
Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	126.8 ^{b}	2.14^{bc}	4.7^{cd}	169.7^{a}	21.9 ^{b}	141.3^{b}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha	124.4 ^{b}	2.13^{bc}	6.5^{a}	118.0^{bc}	20.8 ^{b}	105.9^{c}
Pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha	125.8 ^{b}	2.09^{c}	5.3 ^{bcd}	142.3^{abc}	21.2 ^{b}	104.5^{c}
Pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha	116.4 ^{d}	2.12^{bc}	5.5^{abc}	116.7^{bc}	19.4 ^{b}	96.9^{d}
Co-culture with *Sesbania*, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	136.1 ^{a}	2.23^{a}	5.7^{bcd}	151.3^{ab}	24.7 ^{a}	178.1a
Weedy check	123.6 ^{b}	2.16^{b}	4.3^{d}	106.0 ^{c}	21.8 ^{b}	76.2^{f}
LSD (p=0.05)	4.263*	0.05446**	1.032**	33.16*	2.264*	6.68**

*Significant; **Highly significant. Treatment means followed by common letter(s) are not significantly different among each other based on DMRT at 5% level of significance

Talbert (2007) also stated that other things remaining constant, biomass productions depends upon intra and inter specific competition between the plants.

Yield attributes

Maximum effective tillers/m^2 was found under pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha (169.7) whereas the longest panicle was obtained under pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under *Sesbania* co-culture (24.7 cm). Rest of the treatments was comparable to each other. Statistically similar result was obtained for number of filled grains/panicle in plots treated with pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 35 g/ha, pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha and pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha + byspyribac-Na 25 g/ha. Weedy check plot produced the least number of grains/panicle. Higher the weed density caused the lower effective tillers and lesser filled grains per panicle. Weedy check plot produced the least number of grains/panicledue to the presence of weeds throughout the crop cycle, which caused the depletion of nutrient and less absorption of nutrients by the crop especially during grain filling period. Ehsanullah *et al.* (2014) also reported higher effective tillers per square meter in herbicide applied plot.

Grain and straw yields and sterility

The use of different herbicidal matrices has significantly influenced the grain and straw yield, and sterility percentage (**Table 2**). The highest grain yield (3.78 t/ha) was observed in pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha and was statistically similar with the yield of pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under *Sesbania* co-culture (3.44 t/ha), pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha (3.35 t/ha) and pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha (3.09 t/ha). The lowest yield was obtained under weedy check plots which might be due to competition from weeds, which reduced LAI and allowed less light transmission producing less biosynthate and ultimately low dry matter production (Parameswari YS and Srinivas A. 2014). Similarly, the highest straw yield was recorded in pendimethalin 1.0 kg/ha *fb* tank mixture of pyrzosulfuron 20 g/ha + bispyribac-Na 25 g/ha (6.5 t/ha), which was statistically at par with pendimethalin *fb* pyrazosulfuron (5.86 t/ha). The weedy check produced the lowermost straw yield (3.39 t/ha), which was statistically at par with pendimethalin 1.0 kg/ha (3.97 t/ha). Parameswari and Srinivas (2014) stated that the huge amount of nitrogen, phosphorous and potassium was removed by the weeds in weedy check plot resulting in lower uptake of nutrients by rice causing low biomass yield.

The average sterility percentage during the experiment was observed to be 8.99% ranging from 7.01% in pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha to 12.66% in pendimethalin 1.0 kg/ha treated plot. Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha resulted in lowest sterility (7.01%), which was statistically at par with pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha (7.02), pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under *Sesbania* co-culture (8.24%), and pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha and bispyribac-Na 25 g/ha (8.43%). The effect of application of herbicides was non-significant to thousand grains weight.

Economics

The cost of cultivation, gross return, net return and B:C ratio as affected by various herbicidal treatments has been presented in **Table 3**. The cost of cultivation was higher for pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under *Sesbania* co-culture. Significantly higher gross return, net return and B:C ratio was found under pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha and bispyribac-Na 25 g/ha.

Table 2. Yield and yield attributes as influenced by different herbicidal matrices application

Treatment	Straw yield (t/ha)	Grain yield (t/ha)	Sterility (%)
Pendimethalin 1.0 kg/ha (pre)	3.97 ^{ef}	1.63 ^{cd}	12.7 ^{a}
Pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha	4.90 ^{cd}	2.58 ^{bc}	9.2 ^{b}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha	6.50 ^{a}	3.78 ^{a}	8.4 ^{bc}
Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	4.70 ^{cde}	2.42 ^{bc}	7.0 ^{c}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha	5.86 ^{ab}	3.35 ^{ab}	7.0 ^{c}
Pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha	4.66 ^{cde}	3.09 ^{ab}	9.5 ^{b}
Pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha	4.50 ^{de}	2.13 ^{bc}	9.6 ^{b}
Co-culture with *Sesbania*, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	5.49 ^{bc}	3.44 ^{ab}	8.2 ^{bc}
Weedy check	3.39 ^{f}	0.97 ^{d}	9.2 ^{b}
LSD (p=0.05)	0.799**	1.09**	1.491**

*Significant; **Highly significant. Treatment means followed by common letter(s) are not significantly different among each other based on DMRT at 5% level of significance

Weed density and weed control efficiency

Different herbicidal treatments significantly reduced the weed density and contributed in the higher grain yield as compared to weedy check. Weed density was increasing up to 30 DAS and started to reduce thereafter mainly due to application of herbicides in the field. Total weed density (narrow, broadleaf and sedges) was found to be higher under weedy check. At 30 DAS, total weed density was the lowest under pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha (183.5 no./m^2). Similarly, at 60 DAS, the lowest weed density was found with pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha (70.5 no./m^2) as compared to other treatments (**Table 4**). The lower weed density in this plot may be due to the better and broad spectrum weed control by applying two different herbicides. WCE also significantly influenced by different herbicidal application (**Table 4**). At 30 DAS, WCE was the highest with pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha (20.56%) and the lowest with pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under co-culture with *Sesbania*. At 60 DAS, WCE in the plot treated with pendimethalin 1.0 kg/ha *fb* y tank mix application of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha was the highest (43.36%), which was also agreed by Kumar *et al.* (2017) while being lowest in the plot with pendimethalin 1.0 kg/ha (21.72%). Similar results were also found by Rao (2005) and Nayak *et al.* (2014) who reported a variable weed control in paddy field with the use of different herbicidal treatments.

Weed index

The weed index ranged the lowest with pendimethalin *fb* tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha (-2.23%) to the highest in weedy check plot (58.13%). It means the reduction in yield due to presence of weed was 58.13% in the experiment. Sharma (2013) also reported that 65% yield reduction in DDSR was due to weed in Chitwan condition. Weedy check produced the higher weed index as compared to other treatments due to presence of invasive (species that is not native to a specific location) number of weeds as never removed from the plot that was statistically at par with the pendimethalin treated plot.

Table 3. Economic analysis on cost of cultivation, gross return, net return and B:C ratio as influenced by different herbicidal matrices application

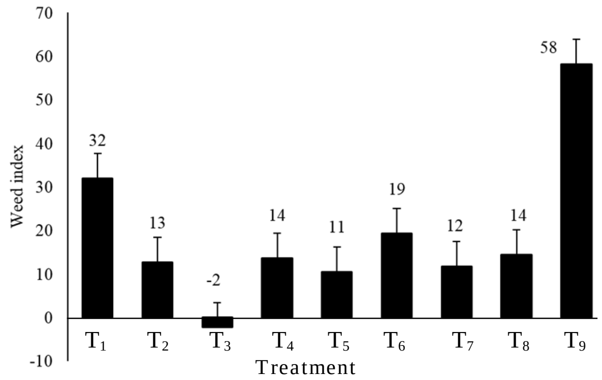
Treatment	Total cost of cultivation ($x10^3$ `/ha)	Gross return ($x10^3$ `/ha)	Net return ($x10^3$ `/ha)	B:C ratio
Pendimethalin 1.0 kg/ha (pre)	67.47^g	92.29^f	24.31^c	1.36^c
Pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha	73.31^d	103.47^b	30.16^b	1.41^b
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha	75.64^b	107.40 ^{a}	31.76^a	1.42^a
Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	74.53^c	95.39e	20.86^f	1.28^f
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha	73.24^d	96.46^d	23.22^d	1.32^d
Pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha	72.28^e	95.26^e	22.98^d	1.32^d
Pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha	74.74^c	96.67^d	21.93^e	1.29^e
Co-culture with *Sesbania*, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	76.31^a	101.06^c	24.74^c	1.32^d
Weedy check	64.47^g	51.60^g	-12.87^g	0.81^g
LSD (p=0.05)	0.5740**	0.4948**	0.7170**	0.0116**

*Significant; **Highly significant. Treatment means followed by common letter(s) are not significantly different among each other based on DMRT at 5% level of significance

Table 4. Weed density and weed control efficiency as influenced by different herbicidal matrices application

Treatment	Weed density (no./m^2)		Weed control efficiency (%)	
	30 DAS	60 DAS	30 DAS	60 DAS
Pendimethalin 1.0 kg/ha (pre)	249.2 ^{b}	141.1 ^{b}	12.4 ^{bc}	21.7 ^{e}
Pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha	197.2 ^{d}	92.9 ^{e}	20.6 ^{a}	36.6 ^{b}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha	183.5 ^{e}	70.5 ^{g}	11.20 ^{c}	43.4 ^{a}
Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	206.0 ^{cd}	101.7 ^{d}	14.1 ^{bc}	32.4 ^{c}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha	203.9 ^{d}	112.7 ^{c}	16.1 ^{b}	33.3 ^{c}
Pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha	218.1 ^{c}	102.2 ^{d}	12.9 ^{bc}	27.5 ^{d}
Pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha	195.5 ^{de}	78.3 ^{f}	13.9 ^{bc}	37.2 ^{b}
Co-culture with *Sesbania*, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	208.9 ^{cd}	78.9 ^{f}	11.2 ^{c}	32.9 ^{c}
Weedy check	317.5 ^{a}	169.4 ^{a}	-	-
LSD (p=0.05)	13.01 **	7.099**	3.383 *	1.034 **

*Significant; **Highly significant. Treatment means followed by common letter(s) are not significantly different among each other based on DMRT at 5% level of significance



T_1- Pendimethalin 1.0 kg/ha; T_2- Pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha; T_3- Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha; T_4- Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha; T_5- Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha; T_6- Pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha; T_7- Pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha; T_8- Co-culture with *Sesbania*, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha; T_9- Weedy check

Figure 1. Weed index of different herbicidal matrices application

It was concluded that the herbicides contributed significantly to the growth and yield of the crop by providing adequate weed control and, hence, reducing the competition occurred by dense weed growth. Pre-emergence application of pendimethalin 1.0 kg/ha followed by application of tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha as post-emergence herbicide was found effective to control against diverse weed flora, produced higher grain yield and proved to be more economic in return in dry direct seeded rice. It could be advocated that the chemical weed control in dry DSR would be a new direction for research and development in Nepalese rice production system.

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