



Efficacy of pre- and post-emergence herbicides on complex weed flora in direct-seeded rice (*Oryza sativa*) in the eastern plains

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ABSTRACT

The efficacy of different herbicides as tank mixture was evaluated to control diverse and complex weed flora in direct-seeded rice (*Oryza sativa* L.) during 2014-2016 at research farm of ICAR Research Complex for Eastern Region, Patna. Pendimethalin followed by tank mixture of bispyribac + ethoxysulfuron provided better control on diverse weed flora under direct seeded rice (DSR), except some of the typical grassy weeds with a yield of 4.4 tonnes/ha and was followed by tank mixture application of bispyribac + azimsulfuron (4.0 tonnes/ha) with an increment of yield by 83 and 67 % over plots receiving pendimethalin alone (2.4 tonnes/ha). Tank mixture application of bispyribac + 2, 4-D and fenoxaprop + ethoxysulfuron (3.8 t/ ha) also produced 58% more grain yield over pendimethalin treated plots. It was also observed that pendimethalin followed by bispyribac in isolation could not able to control *Trianthema portulacastrum* effectively (69/m²) but when applied in combination with ethoxysulfuron or azimsulfuron has effectively controlled this species (18 and 25/m²). Strong negative correlation ($r = -0.96$, $P < 0.001$) was obtained between weed dry matter at 45 days after sowing and yield during the years of experimentation. With linear regression, it was observed that rice crop likely to produce less than 40% grain yield if weed dry matter is more than 200 g/m². Pendimethalin followed by bispyribac + ethoxysulfuron mixture produced similar grain yield (4.4 tonnes/ha) as that of weed free situation (4.5 tonnes/ha). At farmers' field bispyribac + ethoxysulfuron tank mixture produced significantly higher grain yield (4.3 tonnes/ha) as compared to bispyribac alone (3.3 tonnes/ha) and weedy check (2.2 tonnes/ha) too. The tank mixture of bispyribac with ethoxysulfuron needs further evaluation at different locations as the particular mixture has got potential to control diverse and complex weed flora in direct seeded rice.

Key words: Direct seeded rice, Herbicide mixture, Weed density, Weed dry matter, Weed flora, Yield, Yield attributes

Rice (*Oryza sativa* L.) is the main crop in eastern states of India, which has traditionally been grown by transplanting seedlings into puddled fields. Puddling is expensive in terms of labour, irrigation and energy as well as deteriorates the soil structure and forms compact hard soil layer at the root zone (Upasani *et al.* 2014); all of which have adverse effect on successive crops. In recent years, these states are facing acute shortage of labour and water due to shift of workforce from agriculture to other sectors (Farooq *et al.* 2006). Direct seeding of rice refers to the process of establishing the crop from seeds sown in the field rather than by transplanting seedlings from the nursery. Direct seeding avoids three basic operations, namely, puddling (a process where soil is compacted to reduce water seepage), transplanting and

maintaining standing water. Hence, DSR helps in quick establishment and early harvest than puddled transplanted rice (PTR) and further facilitates timely sowing of successive winter crops (Farooq *et al.* 2008). Consequently, DSR has been emerged as an alternative to the puddled transplanted rice (PTR) and discouraged the cost involved for raising nursery and its further transplanting in the puddled fields (Kumar *et al.* 2012). On the other hand, this method also produces similar grain yield as puddled transplanted rice (Kumar and Ladha 2011) and net benefits are higher with the same available farm power and labour. More area can be sown in much less time by DSR and it has been also shown to have lesser emission of methane gas than PTR fields due to aerobic condition in general and decline in global warming potential (Harada *et al.* 2007). Mishra and Singh (2011) reported 35-55% of water savings in DSR fields that were kept almost near to field capacity as compared to puddled transplanted rice, which was continuously flooded up to 3-5 cm throughout the season. DSR needs only 34% of the total labour requirement and saves 27% of the total cost of transplanted crop (Kamboj *et al.* 2012). Farooq *et al.* (2011) also emphasized higher

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water and system productivity in DSR under aerobic condition as compared to flooded situations. Many Southeast countries like China, Bangladesh, Nepal, Sri Lanka etc. have shifted from PTR to DSR in recent years (Weerakoon *et al.* 2011), largely due to heavy production costs and crisis for labour and water in time. Similar situation is also prevailing in Bihar, where area under DSR is increasing year after year (around eight thousand ha in 2016, out of which 2238 ha under zero tilled direct seeded rice (ZTDSR) which is 85 % more over 2015 (CSISA Annual Report, 2016). The trend shows a clear-cut indication of acceptance of this technology (DSR) among the farmers to meet out the scarcity of water, reduced availability of farm labour and high cost of production. Soil degradation under PTR and acceptability of DSR to mechanization are the drivers of on-farm adaption of direct seeding methods. In case of PTR first weed flush are controlled automatically by ponding water in the rice fields but in DSR fields heavy weed infestation is the major constraint. Critical weed free period for DSR is from 20 to 70 days after sowing (DAS) (Dubey *et al.* 2016). The reduction in yield under DSR is upto 30-90% if weeds are not controlled throughout the season (Kumar

et al. 2016, Singh and Shahi 2015).

Weeds can be effectively managed by hand weeding but it is highly expensive and labour demanding technique. On the other hand, weed management through chemicals is the most practical, remunerative and effective method; hence cultivation of direct seeded rice is also known as herbicidal farming. There is not any single herbicide available in the market which can control this complex and diverse weed flora under DSR and also, sole dependence on any single herbicide can lead to inter and intra-specific shifts as well as evolution of herbicide resistant weed biotypes (Kato and Kato 2014). It is also obvious that effectiveness of some herbicides varies from place to place and weed spp (Bhullar *et al.* 2016).

Ethoxysulfuron and azimsulfuron have been found effective in controlling a wide range of broadleaf weeds and sedges (Walia *et al.* 2008). In a survey conducted in 2014 emphasized that during early years of DSR adaption, weed load in the fields were larger but after more than two years of continuous adaption, weed flora in DSR shifts towards aerobic grasses (Bhullar *et al.* 2016). Therefore, present study was carried out to evaluate the efficiency of

Table 1 Effect of different post- emergence herbicides on weed density (species wise) at 45 DAS (pooled data for 2014-16)

Treatment	Weed density (plants/m ²)										Weed dry matter (g/m ²)		
	Doses (g ai/ha)	<i>E. colona</i>	<i>E. crusgalli</i>	<i>L. chinesis</i>	<i>D. sanguinalis</i>	<i>T. portulacastrum</i>	<i>C. iria</i>	<i>C. difformis</i>	<i>D. aegyptium</i>	<i>E. indica</i>	Grassy weeds	Broad leaved weeds	Sedges
Weed free		0	0	0	0	0	0	0	0	0	0	0	0
Pendimethalin alone	1000	78	96	34	41	69	33	39	22	12	331	128.6	251.0
Pendimethalin fb Bispyribac sodium	25	11	18	33	25	58	11	13	19	11	188.6	37.6	37.6
Pendimethalin fb Bispyribac + ethoxysulfuron	25+35	6	5	7	8	18	6	5	13	9	136.3	5.3	8.0
Pendimethalin fb Bispyribac + Azimsulfuron	25+18	8	8	10	11	25	10	9	19	10	168.0	14.3	16.3
Pendimethalin fb Bispyribac + 2, 4-D sodium	25+500	10	13	16	14	32	9	10	20	15	198.3	10.6	10.0
Pendimethalin fb Fenoxaprop	90	43	52	10	7	37	38	41	8	8	104.6	106.0	184.3
Pendimethalin fb 90 + 35 Fenoxaprop + ethoxysulfuron	90 + 35	14	18	10	8	30	26	30	7	7	86.3	61.6	114.0
Pendimethalin fb 90 + 18 Fenoxaprop + Azimsulfuron	90 + 18	28	32	18	12	35	34	36	10	10	163.0	49.0	134.0
SEm ±		0.6	0.8	0.7	1.1	2	0.6	1.2	0.5	0.3	18.6	2.1	2.2
CD (P=0.05)		1.8	2.4	2.1	3.3	5.9	1.8	3.6	1.5	1.0	59.5	6.7	7.0

Weed free was maintained by pre-emergence application of Pendimethalin followed by 3 manual weeding at 30, 60 and 90 DAS. No hand weeding in all other treatments. Treatment Pendimethalin alone was considered as weedy check.

tank mixtures of different herbicides for control of diverse weed flora in DSR.

MATERIALS AND METHODS

Field experiments were conducted during rainy seasons of 2014 to 2016 at the research farm of ICAR Research Complex for Eastern Region, Patna and on farmers' fields of Naubatpur block, Patna. The soil at experimental field was clay loam with a pH of 7.1 having 197 kg available N, 16 kg available P and 211 kg available K/ha. At farmers' fields (3 fields) the soil texture varied from loam to clay loam having 188 kg available N, 14.8 kg available P and 207 kg available K/ha with a pH of 6.8. The experimental sites at research farm as well as farmers' fields) were under rice-wheat cropping system for previous three years. Nine weed control treatments, viz. pendimethalin alone (1 kg a.i./ha as pre emergence), pendimethalin followed by bispyribac-sodium @25 g a.i./ha alone and as tank mixture with azimsulfuron (18 g a.i./ha), ethoxysulfuron (35 g a.i./ha) and 2,4-D (500 g a.i./ha), pendimethalin followed by fenoxaprop-p-ethyl (90 g a.i./ha) alone and tank mixture with azimsulfuron (18 g a.i./ha) as well as ethoxysulfuron (35 g a.i./ha) were replicated thrice in a randomized complete block design. Pendimethalin alone was applied as pre emergence (PE) and rest all herbicides were applied as post-emergence (PoE) within 18-20 DAS in 400 l/ha water. The treatment pendimethalin alone has been considered as weedy check in research plots of on-station trial. Further, in weed free check, weeds were controlled by applying pendimethalin as PE and three hand weeding at 30, 60 and 90 DAS. No hand weeding was done in all other treatments in research plots whereas in farmers' field one hand weeding at 45 DAS was performed in all treatments except weedy check. At three farmers' fields, five treatments, viz. pendimethalin alone, pendimethalin followed by bispyribac-sodium alone and as tank mixture with azimsulfuron, ethoxysulfuron and 2,4-D were used in similar dose as that of applied at research plots. The herbicides were sprayed in rice fields with flat nozzle fitted in a knapsack sprayer.

Rice variety Pusa 1176 (135 days crop duration) was sown during 14 - 21 June in all the three years of experimentation both at research plots as well as in farmers' fields. Sowing was done through a seed drill fitted with an inclined plate system @ 25 kg seed/ha at 20 cm row spacing. Recommended dose of NPK was applied in all fields in three equal splits. The field was irrigated thrice after sowing and rest moisture was maintained through rainfall. The data were recorded by using standard procedures and yield was calculated on net plot basis (20 m²). The crop was harvested in the first week of November in each year.

RESULTS AND DISCUSSION

Weed flora

Sedges and grassy weeds are the dominant weed flora in DSR. *Cyperus rotundus* L., *Cyperus iria* L., *Cyperus*

difformis L., *E. colona* L., *E. crus-galli*, *Leptochloa chinensis* (L.), *Dactyloctenium aegyptium* (L.), *Digitaria sanguinalis* (L.), *Eleusine indica* (L.), *Cynodon dactylon* (L.), *Brachiaria reptans* (L.), *Trianthema portulacastrum* L. were the major weeds in research plots while *Cyperus rotundus* L., *Cyperus iria* L., *Cynodon dactylon* (L.), *Trianthema portulacastrum* L., *Panicum rigidulum*, *Digitaria sanguinalis* (L.), and *Ludwigia parviflora* were reported as major weed species on farmers' field. *Cyperus iria*, *Cyperus rotundus*, *Echinochloa colona*, *Leptochloa chinensis*, *Echinochloa crus-galli*, *Digitaria sanguinalis*, *Eleusine indica* are the dominant weeds in rice crop in the eastern India. Joshi *et al.* (2013) also reported more diverse weed flora in DSR as compared to PTR and that is the reason that a wider range of herbicides and their mixtures would be required to control this diverse weed population effectively.

On-station trial

Weed density: In the present study, it was observed that application of pendimethalin as pre-emergence herbicide checked the germination and establishment of grassy weeds to some extent at initial stage, viz. *E. colona*, *E. crus-galli*, *Digitaria sanguinalis*, *Cynodon dactylon* and reduced their densities by 72% at 15 DAS in all the plots and kept DSR plots free from weeds at least for first 2 weeks or up to rice seed germination and its establishment. Similar observations were also made by Chauhan and Johnson (2011). Herbicides used in DSR have a narrow weed control spectrum and do not provide full season weed control. The persistence of pendimethalin is short and could not be able to check germination of grassy weeds and its establishment for larger period (Farooq *et al.* 2011). The most drawback of this herbicide is that it could not be able to control sedges like *Cyperus rotundus*, *Cyperus iria*, *Panicum rigidulum* and *Trianthema portulacastrum* and large seeded broad leaf weed population which restricts its broader usefulness. Further after 45 days it was observed that pendimethalin followed by bispyribac-sodium had effectively controlled *Echinochloa* and *Cyperus* spp. but less effective on aerobic grassy and broad-leaf weeds like *Dactyloctenium aegyptium*, *L. chinensis* and *T. portulacastrum*. Sequential application of pendimethalin and bispyribac sodium was found to control *Echinochloa* spp. up to a large extent (Singh *et al.* 2015). Pendimethalin followed by tank mixture application of bispyribac + ethoxysulfuron improved the control of grassy weeds up to some extent, but showed very good control on sedges and other broad-leaf weeds. This tank mixture also reduced the population of *L. chinensis* by 79% and improved the efficacy of controlling other grassy weeds by 12-20% as compared to pendimethalin followed by bispyribac alone. Gill *et al.* (2013) also reported the effectiveness of tank mixture of bispyribac + ethoxysulfuron on sedges and broad-leaf weeds. Regarding other combinations it was observed that tank mixture application of bispyribac + azimsulfuron and bispyribac + 2,4-D had also controlled weeds like *Echinochloa* spp, *Cyperus* spp. and *T. portulacastrum* but could not control most of the grassy weeds. Pendimethalin

followed by fenoxaprop significantly reduced the densities (36-70%) of *D. aegyptium*, *L. chinensis*, *Digitaria sanguinalis* and *Eleusine indica*; however, it was not able to control *Echinochloa* spp. up to a satisfactory level as compared to pendimethalin followed by bispyribac alone. The tank mixture of fenoxaprop + ethoxysulfuron had controlled *Echinochloa* spp. effectively as this mixture acted to be synergistic for the control of *Echinochloa* spp. up to 83% but failed in controlling the sedges population. Tank mixture application of fenoxaprop + azimsulfuron reduced the efficacy in controlling *E. colona* by 24% and *L. chinensis* by 78% indicating antagonism.

Weed dry matter: Weed dry matter (WDM) at 45 DAS varied significantly among weed control treatment during all the crops season (Table 2). Among the plots treated with single post emergence herbicide, pendimethalin + bispyribac-sodium alone had highest grass dry matter (188.6 g/m²), which was quite higher than the plots treated with pendimethalin followed by fenoxaprop alone (104.6 g/m²). The tank-mixture applications of different herbicides did not reduce weed dry matter significantly in case of grasses except sedges and broad leaf weed dry matter, while tank mixture application of bispyribac + ethoxysulfuron has effectively reduced weed dry matter of sedges and broad leaf weeds (8 and 5.3 g/m², respectively). It was followed by tank mixture application of bispyribac + 2,4-D and then by bispyribac + azimsulfuron to reduce weed dry matter of sedges and broad leaf weeds during all the three years of experimentation (Table 1). Application of PE herbicide followed by tank mixture of PoE herbicide has also been advised by Chauhan and Abugho (2012).

Yield and yield attributes: Application of pendimethalin followed by tank mixture of bispyribac and ethoxysulfuron resulted at par with weed free plots in respect of number of effective tillers, grain number and 1000-grain weight during all the years of experimentation (Table 2). Mean value of three years data reflected that tank mixture combination of

bispyribac and ethoxysulfuron recorded similar rice grain and straw yield (4.4 and 5.3 tonnes/ha) to the plots kept weed free throughout the season (4.5 and 5.4 tonnes/ha), whereas weedy plots which received pendimethalin alone, produced least grain and straw yield (2.4 and 3.3 tonnes/ha), respectively due to more weed biomass in the plots which affected the vegetative and reproductive phases of rice crop adversely. Further, pendimethalin followed by tank mixture application of bispyribac+ azimsulfuron produced higher grain and straw yield (4.0 and 5.0 tonnes/ha) over rest of the treatments. Application of pendimethalin followed by fenoxaprop+ ethoxysulfuron produced similar grain yield, straw yield and other yield attributes as that of pendimethalin followed by bispyribac+ 2,4-D. Application of pendimethalin followed by tank mixture of bispyribac and ethoxysulfuron produced 83% more grain yield than pendimethalin treated plots which were considered as weedy check. The reduction in yield due to weed infestation under DSR is reported up to 50-80% and it can be reached to 100% if weeds are not controlled throughout the season (Kumar et al. 2016).

From this study, a strong negative correlation ($r=-0.96$, $P<0.01$) was obtained between weed dry matter at 45 DAS and rice grain yield during 2014-2016 (Fig 1). The results advocated the poor competitiveness of rice crop to weed and need to control them effectively during the whole growing period to get an optimum yield of rice. Gathala et al. (2011) also found negative correlation between weed dry matter and grain yield of direct seeded rice. According to the linear regression, rice crop is likely to produce less than 40% grain yield if weed dry matter is more than 200 g/m. The tank mixture application of bispyribac + ethoxysulfuron, bispyribac + azimsulfuron, fenoxaprop + ethoxysulfuron or bispyribac + 2,4- D recorded lowest weed dry matter (76-135 g/m) at 45 DAS, which was equivalent to > 56% reduction as compared to plots receiving pendimethalin/ the weedy check.

Table 2 Effect of different post-emergence herbicide and tank mixture adaptation on yield and yield attributes (Pooled data of 2014-16)

Treatment	Dose (g a.i./ha)	Effective tillers/m ²	Grains/panicle	1000-grain wt (g)	Grain yield (t/ha)	Straw yield (t/ha)
Weed free		262	47	23.7	4.5	5.4
Pendimethalin alone	1000	186	31	22.8	2.4	3.3
Pendimethalin fb bispyribac sodium	25	230	41	23.0	3.6	4.7
Pendimethalin fb bispyribac + ethoxysulfuron	25+ 35	258	46	23.7	4.4	5.3
Pendimethalin fb bispyribac + azimsulfuron	25+ 18	247	43	23.4	4.0	5.0
Pendimethalin fb bispyribac + 2, 4-D sodium	25+500	240	41	23.2	3.8	4.8
Pendimethalin fb fenoxaprop	90	235	40	23.1	3.6	4.7
Pendimethalin fb fenoxaprop + ethoxysulfuron	90+35	245	40	23.2	3.8	4.9
Pendimethalin fb fenoxaprop + azimsulfuron	90+18	223	38	22.9	3.4	4.5
SEm ±		2.0	0.6	0.27	0.05	0.06
CD(P=0.05)		5.8	1.79	0.80	0.14	0.18

Weed free treatment was maintained by pre-emergence application of pendimethalin followed by 3 manual weeding at 30, 60 and 90 DAS. No hand weeding in all other treatments. Treatment pendimethalin alone was considered as weedy check.

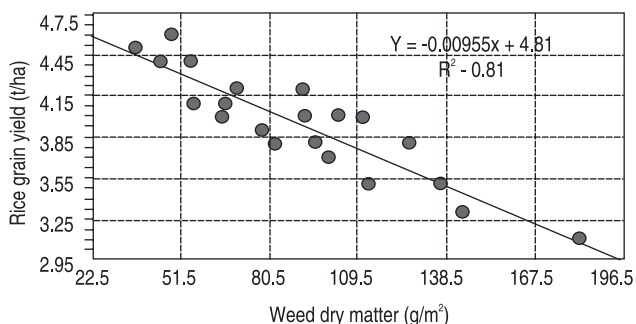


Fig 1 Relationship between weed dry matter at 45 DAS and direct-seeded rice grain yield.

0.7 tonne/ha more grain yield than weedy check. The result of this study advocates that in absence of POE herbicide, the combination of PE herbicide and one hand weeding at 45 DAS, could increase the grain yield by 32 % and may be one of the options for getting remunerative yield of rice as compared to weedy check.

On the basis of above finding it can be concluded that tank mixture of bispyribac+ ethoxysulfuron @ 25 + 35 g a.i./ha provided effective control on diverse weed population under DSR and may be recommended to the farmers who are adopting DSR technique. Further, it would be better to make a conclusion that in absence of PoE herbicide one should

Table 3 Effect of different POE herbicides and tank mixture application on weed at 45 DAS and grain yield in farmers’ field (Pooled data from 2014-16)

Treatment	Dose (g a.i./ha)	Weed control over weedy check at 45 DAS							Grain yield (t/ha)
		<i>E. colona</i>	<i>E. crus-galli</i>	<i>C. rotundus</i>	<i>C. iria</i>	<i>D. sanguinalis</i>	<i>T. portulacastrum</i>	<i>L. parviflora</i>	
Weedy Check		166	97	35	67	29	88	16	2.2
Pendimethalin alone	1000	128	63	28	49	23	77	15	2.9
Pendimethalin fb bispyribac alone	25	39	23	21	16	15	71	11	3.3
Pendimethalin fb bispyribac + ethoxysulfuron	25+35	13	9	8	10	9	21	8	4.3
Pendimethalin fb bispyribac + azimsulfuron	25+18	17	11	12	14	12	28	14	4.0
Pendimethalin fb bispyribac + 2, 4-D sodium	25+500	22	14	11	15	8	33	5	3.9
SEm ±		1.0	0.4	0.3	1.1	0.7	1.3	0.8	0.03
CD(P=0.05)		3.1	1.2	0.9	3.3	2.0	4.0	2.5	0.1

No hand weeding in weedy check treatment. All other treatments received one hand weeding at 45 DAS along with respective herbicides.

Farmers' field trial

Weed density: Pendimethalin has resulted in optimal control of grassy weed, viz. *E. colona*, *E. crus-galli*, *L. chinensis* etc. weed species. Up to 15 DAS (data not presented). Follow-up application of bispyribac and ethoxysulfuron as tank mixture has effectively reduced weed density and obviously biomass (Table 3). Further, it was observed that bispyribac when sprayed alone was not able to control the population of *T. portulacastrum* effectively (71/m²) but when applied in combination with ethoxysulfuron or azimsulphuron, has effectively controlled its population (21 and 28/m²).

Rice-grain yield: Application of pendimethalin as PE and tank mixture application of POE herbicides, i.e. bispyribac+ ethoxysulfuron has reduced the weed population effectively and produced an optimum yield of rice (4.3 tonnes/ha) which was followed by tank mixture application of bispyribac+ azimsulfuron (4.0 tonnes/ha) and bispyribac + 2,4-D (3.9 tonnes/ha) Application of pendimethalin followed by tank mixture application of bispyribac with ethoxysulfuron, azimsulfuron and 2,4-D recorded 60, 57 and 54% increase in grain yield, respectively (Table 3) as compared to weedy check (2.2 tonnes/ha) .

Trials conducted at farmers' field with pendimethalin as PE herbicide + one hand weeding at 45 DAS also produced

go for hand weeding at 7-8 weeks of sowing necessarily to get an optimum yield of rice crop. Bispyribac has got potential to effectively control aerobic and aquatic weeds in DSR, so this herbicide should be tested with some other PoE herbicide in combination to get more effective control on diverse weed population throughout the country.

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