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Research Paper

Evaluation of herbicide mixtures for broad-spectrum weed control and yield in transplanted summer rice (*Oryza sativa*)

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ABSTRACT

An experiment was conducted during the summer seasons of 2018 and 2019 at Cuttack, Odisha, to compare the efficacy of new formulation of penoxsulam 1.02% + cyhalofop-butyl 5.1% in different application rate with the existing ready-mix formulation of penoxsulam 1.02% + cyhalofop-butyl 5.1% (Vivaya). The composition of weed flora showed more prevalence of grasses viz. (43.3%) followed by sedges (29.4%) and broad-leaf weeds (27.3%). *Leptochloa chinensis* (L.) Nees was the most dominant weed (19.6%). Penoxsulam 1.02 % + cyhalofop-butyl 5.1% (135 g/ha) at 15 days after transplanting (DAT) registered effective control of broad-spectrum of weeds. The new formulation and Vivaya were found at par in terms of reduction in weed density and biomass. There were no significant difference between two doses of formulation (120 and 135 g/ha) in controlling weeds. Crop-weed competition in weedy plot reduced the grain yield of rice to the tune of 32.2%. Post-emergence application of penoxsulam 1.02 % + cyhalofop-butyl 5.1% (135g/ha) at 15 DAT resulted in increased grain yield by 32.1% over the weedy check and it was at par with the existing ready-mix formulation. The new formulation has no phyto-toxicity to rice crop. Thus, post-emergence application of ready-mix penoxsulam + cyhalofop-butyl at 135 g/ha could be recommended as an alternative to conventional manual weeding for broad-spectrum weed control in transplanted rice fields.

Key words: Grain yield, Herbicide mixtures, Phyto-toxicity, Transplanted rice, Weed biomass

Planting of rice seedlings on puddled soils is the most common establishment practice in India and about 38.19 million ha area (87% of total rice area) was covered under transplanted rice during 2018–19 (Geotrans Technologies Private Limited, New Delhi 2018). Weeds are considered as the major yield-limiting factor in rice production (Gharde *et al*., 2018). Weed population has to be maintained below the economic threshhold level during early vegetative stage by adopting appropriate weed-management practices for realizing the optimum yield of rice. The composition of weed flora in transplanted rice is highly diverse, comprising grasses, sedges and broad-leaf weeds and their relative abundance is largely influenced by soil seed bank, the growing season and cultural practices adopted. It was reported that the yield reduction in transplanted rice due to crop-weed competition varies from 27 to 68%, depending on growing season and cultural practices (Hossain and Malik, 2017).

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The most common manual weeding in rice is time-consuming, tedious, and no more cost effective (Rao *et al*., 2015). Sometimes, the morphological similarity between the common grasses and rice seedlings makes manual weeding become difficult at early stages of crop growth. Herbicidal weed control is easy and are more energy, labour and cost efficient than manual weed control. Several pre- and post-emergence herbicides provide a good degree of weed control in transplanted rice (Das *et al*., 2012). Pre-emergence herbicides like pretilachlor, butachlor, pyrazosulfuron-ethyl, oxadiargyl were found effective for suppression of early flushes of weeds but most of them are very narrow spectrum, their application window is also only 1–3 days after transplanting (DAT) and failed to control the subsequent flushes of weeds that appeared at later stages of crop growth (Saha *et al.,* 2016). In this context, post-emergence herbicides, viz. azimsulfuron, bispyribac-sodium, ethoxysulfuron, penoxsulam, bensulfuron-methyl, fenoxaprop-p-ethyl etc. are promising for suppressing mixed population of weeds during critical period of crop-weed competition either alone or in different combinations (herbicide mixtures) in rice fields (Saha *et al.,*2016; Munda *et al*., 2019).

Continuous use of herbicide with same mode of action year after year in the same field may lead to shifting of weed flora and development of herbicide resistance in weed (Kumawat *et al.*, 2018). Thus, rotation of the herbicides with different mode of action and time of application is advocated to minimize the shift in weed flora and development of resistance in weeds. Herbicides having different mode of action when applied either tank-mix or ready-mix results in broad-spectrum weed control and reduces the cost of cultivation of rice (Kabdal *et al.,* 2018). Penoxsulam is a broad-spectrum triazolopyrimidine (ALS inhibitor) rice herbicide, whereas cyhalofop-butyl acts by inhibiting acetyl coenzyme A carboxylase and found good enough to manage grasses in transplanted rice (Sumekar *et al*., 2020). Combination of these two herbicides provides broad-spectrum control of mixed population of weeds with no injury to rice (Lap *et al*., 2013).

To provide more options to the farmers to follow herbicide rotation and to use herbicide mixture for sustainable weed management, there is a need to evaluate the new molecules of herbicides and their combination. Hence new formulations of penoxsulam 1.02% + cyhalofop- butyl 5.1% was evaluated for weed control in transplanted rice.

MATERIALS AND METHODS

The field experiment were carried out at the research farm of ICAR-National Rice Research Institute, Cuttack (20.27° N, 85.56° E and 23.5 m above mean sea-level), located in the 'Eastern and Southern Central Agro-climatic Zone' of Odisha, India, during dry season, 2018 and 2019. The soil of the experimental field was Aeric (Endoaquept) with sandy clay loam in texture (32.1% clay, 17.2% silt, 50.7% sand), bulk density 1.39 g/cm^3, percolation rate 10 mm/d, slightly acidic to neutral in reaction with *p*H (using 1 : 2.5, soil : water suspension) 6.6, cation-exchange capacity (CEC) 15.2 cmol (p+)/kg, electrical conductivity (EC) 0.50 dS/m^2, total carbon 0.78%, available nitrogen 212 kg/ha, available P 17.8 kg/ha and available K 122 kg/ha.

The experiment was arranged in a randomized complete-block design with 3 replications. The treatments consisted of penoxsulam 1.02 % + cyhalofop-butyl 5.1% (new formulation) @ 120 g/ha at 15 days after transplanting (DAT), penoxsulam 1.02% + cyhalofop-butyl 5.1% (new formulation) @ 135 g/ha at 15 DAT, bispyribac-sodium 10% SC @ 25 g/ha at 15 DAT, penoxsulam 1.02% + cyhalofop-butyl 5.1% (Vivaya) @ 120 g/ha at 15 DAT, penoxsulam 1.02% + cyhalofop-butyl 5.1% (Vivaya) @ 135 g/ha at 15 DAT, hand-weeding twice and weedy check.

Water-soaked seeds of rice, variety 'Naveen' (125 days) treated with carbendazim (1.5 g/kg seed) were kept tightly in gunny bags and covered with paddy straw for incubating 24 hours. The sprouted seeds (1–2 mm radical length) were sown in wet nursery during the last week of December. Thirty days old seedlings were uprooted and transplanted in the main experimental field at 15 cm × 15 cm spacing in the last week of January during both the years. The fertilizers were applied @ 80 kg N + 40 kg P + 40 kg K/ha in the form of urea, diammonium phosphate (DAP) and muriate of potash (MoP) respectively. Full amount of phosphorus and two-thirds of potassium were applied as basal. The nitrogen fertilizer was applied in 4 equal splits at 15, 30, 45 and 60 days after transplanting (DAT). The rest one-third of potassium was top-dressed at 60 DAT. Irrigations were applied in the moist field at certain interval after disappearance of water from crop field by following alternate wetting and drying to maintain a 2–3 cm water till the grain-filling stage of the crop.

Weed control treatments were imposed as per the schedule. All the herbicides were applied at saturated soil moisture as per the protocol using knapsack sprayer fitted with flat-fan nozzle at spray volume of 350 litre/ha.

The data on weed density and biomass were recorded at 45 and 60 DAT. Weed density was recorded with the help of a quadrate (0.5 m × 0.5 m) placed randomly at 4 places in each plot. Weeds were removed, washed with tap-water, sun-dried, oven-dried at 70°C for 48 h before weighing. The data on actual number of weeds and biomass were transformed to square root for statistical analyses. Weed-control efficiency (WCE) was calculated by using the standard formula and expressed in percentage. Observations (from 10 plants/plot) on crop phytotoxicity in terms of vein clearing, epinasty, hyponasty, wilting and injury to leaf tips and leaf surface were recorded at 1, 3, 5, 7, 10, 15 and 30 days after herbicide application, on 0–10 scale with 0 = no phytotoxicty and 10 = compete mortality.

Grain yield of rice along with other yield components were recorded at harvesting. Sampling was done from an area of 1 m^2 in each plot to determine effect of treatments on yield components. Panicle number was counted in each hill to determine number of panicles/m^2. Plant samples were separated into straws and panicles. Panicles were hand threshed and the filled grains were separated and counted to determine number of grains/panicle. Grain yield was determined from the net area of 6.0 m × 4.0 m (24 m^2) in each plot leaving border rows at harvest. Weed index (WI) was determined to assess % reduction in grain yield due to the presence of weeds under different treatments.

The data were analyzed statistically in Ms-Excel for RBD as per the standard procedures, following the Analyzis of Variance (ANOVA). The differences in the treatment means were tested by using least significant difference (LSD) at 5% level of probability. Weed data were subjected to square-root transformation [$\sqrt{(x + 0.5)}$] before statistical analysis to normalize their distribution.

RESULTS AND DISCUSSION

Weed flora, density, biomass and weed-control efficiency

The weedy check plots were infested with 14 different species of weeds belonging to 8 families during both the years. Among different categories of weeds, grasses were dominant (43.3%) followed by sedges (29.4%) and broad-leaf weeds (27.3%). The most dominant weed species was *Leptochloa chinensis* (L.) Nees (19.6%), followed by *Cyperus difformis* L. (14.9%) and *Echinochloa crus-galli* (L.) P. Beauv. (12.3%). Among the broad-leaf weeds, the average population of *Marsilea quadrifolia* L. was 7.6% followed by *Ludwigia adscendens* (L.) Hara (7.3%) of total weed population.

Manual weeding at 20 and 40 days after transplanting (DAT) recorded the lowest total weed density and biomass due to periodical removal weeds. Weed control with herbicides exhibits efficient and economical weed control when applied at proper dose and time. In our study, significant reduction in weed density was recorded in all the herbicide treatments as compared to the weedy check (Fig. 1). The tested new formulation of herbicide mixture penoxsulam 1.02 % + cyhalofop-butyl 5.1% in both the doses registered significant reduction in weed density at 45 and 60 DAT over the weedy check and was at par with existing formulation Vivaya. Excellent control of the sedges, viz. *Cyperus difformis* L. and *C. iria* L., was recorded by all the herbicide treatments (Fig. 1). Penoxsulam 1.02 % + cyhalofop-butyl 5.1% @ 135 g/ha applied at 15 DAT resulted in the lowest weed density due to effective control of dominant grass species viz., *Echinochloa* species and *Leptochloa chinensis* in transplanted rice (Lap *et al*., 2013; Singh *et al.*, 2019).

Application of new formulation of penoxsulam 1.02 % + cyhalofop-butyl 5.1% was effective in significant reduction in weed biomass (Fig. 2) over the weedy check and it was at par with the existing formulation Vivaya and bispyribac-sodium. It was due to the application of herbicides at right time, i.e. 2–4-leaf stage of weeds that resulted good control of grasses, viz. *Echinochloa crus-galli*, *E. glabrescns* Munro ex Hook. f. and *Leptochloa chinensis* (Lap *et al*., 2013; Singh *et. al.*, 2019) and sedges *Cyperus difformis* and *Cyperus iria* and broad-leaved weeds in transplanted rice. Manual weeding at 20 and 40 DAT showed higher weed-control efficiency (> 90%) during both the years owing to significant reduction of biomass of weeds (Fig 2). Ready-mix application of penoxsulam 1.02 % (w/w) + cyhalofop-butyl 5.1% @ 135 g/ ha was found at par with the bispyribac-sodium in terms of the weed-control efficiency. Deiveegan *et al.* (2017) also found that penoxsulam 1.02 % (w/w) + cyhalofop-butyl 5.1% was comparable with bispyribac-sodium in terms of weed-control efficiency in transplanted rice.

Growth attributes

Significant increase in plant height was recorded in all

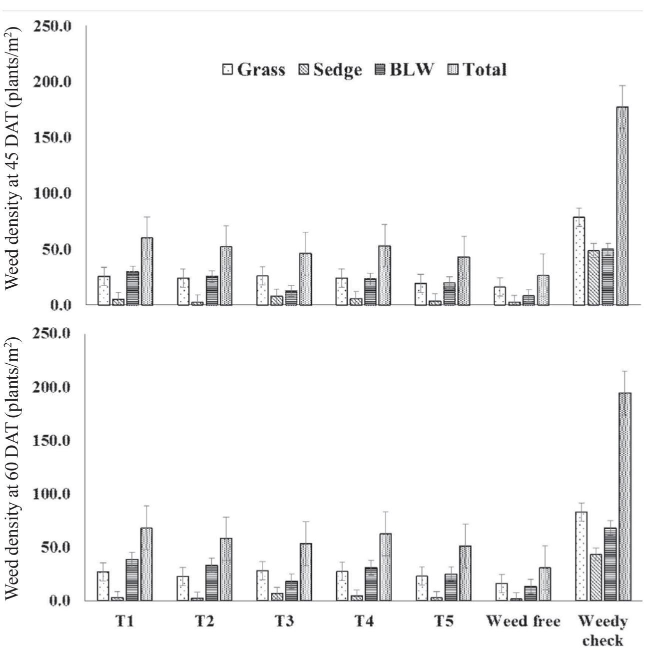

Fig. 1. Weed density at 45 and 60 days after transplanting (DAT) as influenced by weed control methods (pooled data of 2 years) (Details of treatments are given under Materials and Methods)

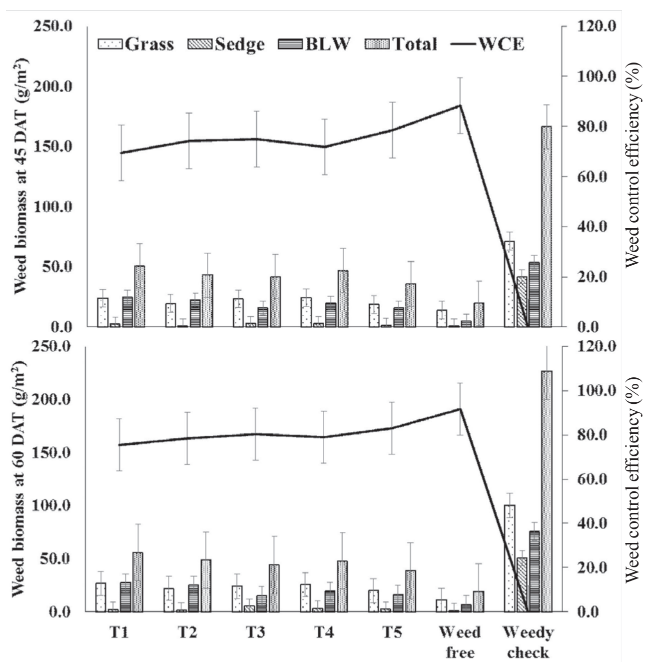

Fig. 2. Weed biomass and weed-control efficiency at 45 and 60 days after transplanting (DAT) as influenced by weed control methods (pooled data of 2 years) (Details of treatments are given under Materials and Methods)

the plots treated with herbicides in different herbicide combinations owing to comparatively less crop-weed competition for resources in comparison to weedy check (Fig. 3). Because of better control of weeds at proper time, the manually weeded plots showed relatively higher plant height. However, there was no significant differences in plant height among the weed-control treatments. Days to 50% flowering and crop maturity did not show any significant influence either by the weeds or by different weed-control treatments.

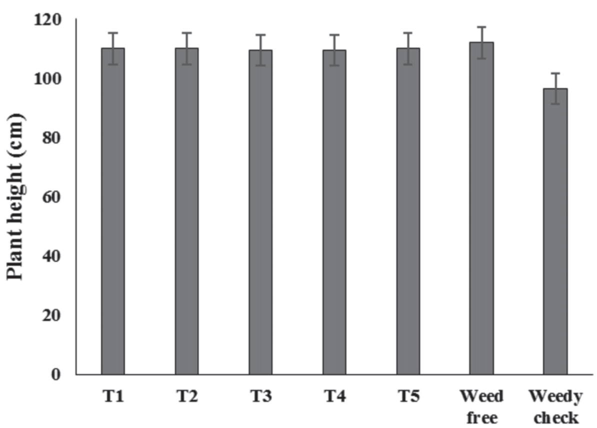

Fig. 3. Plant height of rice at harvesting stage as influenced by weed-control methods (pooled data of 2 years) (Details of treatments are given under Materials and Methods)

Yield attributes and yield

Persistence of weeds throughout the crop-growth period in weedy plots recorded significant reduction in panicle length and spikelet/panicle (Table 1). Higher panicle length (25.2 cm) and spikelets/panicle (144.2) were recorded in manual weed control plots because of least crop-weed competition owing to better control of weeds. All the herbicide-treated plots were at par in terms of panicle length and spikelets/panicle. Similar trend was recorded in grain-filling percentage. It was reduced significantly in weedy check as compared to other weed- control treatments. Reduced number of spikelets and filled grains/panicle in weedy check ultimately reflected in panicle weight. Weed infestation in weedy plot resulted in lower panicle weight compared with the other weed-control treatments. The highest panicle weight (3.17 g) was recorded in manually weeded plots because of higher panicle length, spikelet/panicle and grain-filling percentage. Application of new formulations of penoxsulam 1.02 % + cyhalofop-butyl 5.1% (135 g/ha) at 15 DAT registered panicle weight at par with the bispyribac-sodium and existing formulation Vivaya.

Crop-weed competition reduces input-use efficiency, grain yield and quality of produce. The productive tillers/unit area, grains/panicle and grain weight influences the final grain yield of transplanted rice. Weed-control measures have significant influence on yield attributes like panicles/m^2 and grains/panicle (Saha *et al.,* 2016). In present study, weedy plots recorded the lowest panicles/unit area and number of grains/panicle due to prolonged crop-weed competition. Manual weeding at 20 and 40 DAT registered higher number of panicles/unit area, grains/panicle and 1000-grains weight owing to comparatively less weed pressure during the period of critical crop-weed competition. Application of new formulation of penoxsulam 1.02 % + cyhalofop-butyl 5.1% @ 135 g/ha at 15 DAT significantly increased all the yield attributes over weedy check, but it was comparable with the existing formulation (Vivaya) and bispyribac-sodium (Table 2).

Table 1. Effect of weed-control practices on growth and yield attributes of rice (pooled data of 2 years)

Treatment	Days to 50% flowering	Panicle length (cm)	Panicle weight (g)	Spikelets/ panicle	Grain filling (%)
T_1, Penoxsulam 1.02 % + cyhalofop-butyl 5.1% (new source) @ 120 g/ha at 15 DAT	100.0	23.7	2.91	136.9	91.1
T_2, Penoxsulam 1.02 % + cyhalofop-butyl 5.1% (new source) @ 135 g/ha at 15 DAT	99.5	24.0	2.88	135.1	92.4
T_3, Bispyribac-sodium 10% SC @ 25 g/ha at 15 DAT	99.5	24.1	2.93	136.9	91.6
T_4, Penoxsulam 1.02 % + cyhalofop-butyl 5.1% (Vivaya) @ 120 g/ha at 15 DAT	101.0	23.7	2.96	135.4	91.4
T_5, Penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD (Vivaya) @ 135 g/ha at 15 DAT	100.0	23.9	2.95	137.3	91.7
T_6, Hand-weeding twice	100.0	25.2	3.17	144.2	92.2
T_7, Weedy check	99.5	21.6	2.53	130.7	74.8
SEm±	1.12	0.22	0.04	1.41	0.89
CD (P=0.05)	NS	0.59	0.11	3.82	2.41

DAT, Days after transplanting

Table 2. Influence of weed-control practices on yield attributes, yield of rice and weed index (pooled data of 2 years)

Treatment	Panicles/ m^2	Grains/ panicle	1000-grains weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Weed index
T_1, Penoxsulam 1.02 % + cyhalofop-butyl 5.1% (new source) @ 120 g/ha at 15 DAT	323	125	22.7	5.53	6.20	10.6
T_2, Penoxsulam 1.02 % + cyhalofop-butyl 5.1% (new source) @ 135 g/ha at 15 DAT	333	125	22.9	5.64	6.26	8.9
T_3, Bispyribac-sodium 10% SC @ 25 g/ha at 15 DAT	331	125	22.7	5.64	6.24	9.0
T_4, Penoxsulam 1.02 % + cyhalofop-butyl 5.1% (Vivaya) @ 120 g/ha at 15 DAT	321	124	22.7	5.45	6.15	12.0
T_5, Penoxsulam 1.02 % + cyhalofop-butyl 5.1% OD (Vivaya) @ 135 g/ha at 15 DAT	342	125	22.8	5.68	6.27	8.3
T_6, Hand-weeding twice	377	132	23.3	6.2	6.83	0.0
T_7, Weedy check	284	99	20.8	4.27	5.03	32.2
SEm±	10.44	1.27	0.25	0.13	0.13	-
CD (P=0.05)	28.10	3.40	0.67	0.36	0.37	-

DAT, Days after transplanting

The lowest grain yield (4.27 t/ha) was recorded in the weedy check due to reduction in number of panicles/unit area and grins/panicle. The highest grain yield (6.20 t/ha) was achieved with manual weeding at 20 and 40 DAT. Ready-mix post-emergent application (15 DAT) of penoxsulam1.02% + cyhalofop-butyl 5.1% at 135 g/ha resulted in the good control of all three categories of weeds in transplanted rice and increase in grain and straw yields over weedy check. Efficacy of penoxsulam 1.02% + cyhalofop-butyl 5.1% for broad-spectrum weed control in transplanted rice and increase in yield was also reported by Hossain and Malik (2017), Yadav *et al*. (2018) and Sumekar *et al*. (2020).

Plots treated with penoxsulam + cyhalofop-butyl showed lower grain yield than manual weeding due to poor control of broad-leaf weeds like *Ludwigia adscendens* and *Ludwigia octovalvis* (Jacq.) P.H. raven. Menon *et al.* (2016) also reported poor efficacy of this herbicide combination against *Ludwigia parviflora* in transplanted rice. But the herbicide mixture was comparable with the standard herbicide bispyribac-sodium in transplanted rice (Radhamani, 2019). The extent of yield loss due to weed competition in weedy check was 32.2%. Among the herbicidal treatments, penoxsulam 1.02% + cyhalofop-butyl 5.1% (new formulation) at 135 g/ha showed the lower weed index of 8.9% and comparable with bispyribac-sodium.

Results of the present investigation indicated that penoxsulam + cyhalofop (ready-mix) @ 135 g/ha applied at 15 DAT could be an alternative option for effective and economic control of broad-spectrum weeds and enhancement of yield in transplanted rice.

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