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RESEARCH ARTICLE

Weed removal and crop nutrient uptake as affected by tillage and herbicides in direct-seeded rice-yellow mustard cropping sequence

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ABSTRACT

A field experiment was conducted during rainy seasons of 2019 and 2020 to evaluate the impact of different tillage and herbicides on the nutrient removal by weeds and productivity of direct-seeded rice (DSR). The treatments consisted two tillage practices, *viz.* zero tillage (ZT) and conventional tillage (CT) in the main plot and six herbicide combinations [oxadiargyl followed by (*fb*) bispyribac-sodium, penoxsulam + cyhalofop-butyl, oxadiargyl *fb* penoxsulam + cyhalofop-butyl, fenoxaprop-p-ethyl + ethoxysulfuron, oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron and pendimethalin *fb* bispyribac-sodium] along with two control treatments (unweeded and weed free check) in the subplots of DSR. Total N, P and K removal by weed in unweeded control was 37.29, 47.12 and 35.86% higher under CT than under ZT. Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron and oxadiargyl *fb* penoxsulam + cyhalofop-butyl registered the lowest total weed biomass, weed nutrient removal and higher nutrient uptake, crop yield and net return of DSR.

Keywords: Direct-seeded rice, Fenoxaprop-p-ethyl + ethoxysulfuron, Penoxsulam + cyhalofop-butyl, Nutrient uptake, Oxadiargyl, Tillage, Weed management

INTRODUCTION

Weeds of various species emerge along with the crop in direct-seeded rice (DSR), in different flushes and are difficult to control since they escape single weed control measure. Weeds have a higher competitive ability than crops and are more efficient in removing nutrients (Blackshaw *et al.* 2003). The removal of nutrients by weeds varies in different locations and this might be due to the type of species and the period of sample collection. Time of sampling is important to understand the total removal of nutrient by weeds since it depends on their biomass. Although, most weed species under DSR emerge at the same time, they do not mature simultaneously due to intra-specific competition and compete with the crop throughout the growing period. *Cyperus iria* (L.) emerges shortly after rice and flowers and produces seeds around a month later. *Ludwigia* sp. thrives in rice fields throughout the crop season. *Ludwigia* plants are initially slow in growth compared to rice, but later biomass increases and this may help *Ludwigia* sp. to compete with other species for light (Chauhan *et al*. 2011). This has wide ecological amplitude and is well-established weed in all the rice ecosystems. The probable reason for its wide ecological amplitude is the adaptation by developing special structure called periderm and pneumatophores like structures (Duary and Mukhopadhyay 1999, Duary *et al*. 2015).

Tillage has an impact on the emergence and growth of weeds. Zero tillage system gathers weed seeds on the soil surface and facilitates weed germination. Tilled soil provides a favourable condition for the establishment of weeds. Herbicides are the most effective and economic way to control the weeds in DSR. But, the application of a single herbicide on a regular basis may cause shift in weed flora. Sole application of single herbicide may not be effective against complex weed flora in DSR. Bispyribac-sodium - a widely used herbicide has already been found to be less effective against many weeds (Mahajan and Chauhan 2013, Chauhan *et al.* 2015, Menon 2019). Thus, combined or sequential application of herbicides is desirable for effective management of complex weed flora in DSR. However, limited information is available on the nutrient removal of various weed species under different tillage and herbicide combination in DSR. The objectives of the present study were to study the effect of combined/sequential application of herbicides on nutrient removal by weeds and crop and productivity of direct-seeded rice (DSR) under different tillage practices in this region of the west Bengal.

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MATERIALS AND METHODS

A field experiment was conducted at Agricultural Farm of Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, Birbhum, West Bengal during two consecutive rainy seasons of 2019 and 2020 in a fixed plot without disturbing the layout. The soil in the experimental field was sandy loam (*Ultisol*) with a pH of 5.80, 0.62% organic carbon, 253 kg/ha available N, 19 kg/ha P and 135 kg/ha K. Zero tillage (ZT) and conventional tillage (CT) in main plot and eight weed management practices in sub-plots were assigned in a split-plot design replicated thrice. The weed management treatments consisted: pre-emergence application (PE) of oxadiargyl 90 g/ha followed by (*fb*) post-emergence application (PoE) of bispyribac-sodium at 25 g/ha, penoxsulam + cyhalofop-butyl (ready-mix) PoE 180 g/ha, oxadiargyl at 90 g/ha *fb* penoxsulam + cyhalofop-butyl (ready-mix) 180 g/ha, fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) PoE at 90 +15 g/ha, oxadiargyl at 90 g/ha *fb* fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) at 90+15 g/ha, pendimethalin PE at 1000 g/ha *fb* bispyribac-sodium at 25 g/ha, weed free check and unweeded control. Glyphosate at 1.0 kg/ha was applied before sowing of crops under ZT. Before sowing rice with CT, the final land preparation was done using a rotavator. Rice cultivar *'MTU-1010'* was chosen for the study. The crop was fertilized with 80-40-40 kg/ha of N, P and K. Basal dose of nutrients was drilled through 10-26-26. Full quantity of P and K and 1/5th of N (16 kg/ha) was applied as basal on the day of sowing in DSR. Remaining quantity of N (64 kg/ha) was applied through urea in two equal splits at 25 and 50 DAS. The area of fresh green leaves for each treatment was measured by using leaf area meter (LICOR Model LI 3000CAP). Leaf area index (LAI) was computed using the formula as suggested by Evans (1972). Herbicides were applied with a battery-powered knapsack sprayer equipped with a flat-fan nozzle with 500 l/ha of water. Plant samples were collected at harvest for the estimation of nutrient, whereas weed samples were collected at their maturity [*Cyperus iria* (L.) at 30 DAS, *Digitaria sanguinalis* (L.) Scop., *Echinochloa colona* (L.) Link, *Fimbristylis miliacea* (L.) Vahl, *Spilanthes calva* DC., *Eclipta alba* (L.) and *Cyanotis axillaris* D. Don ex Sweet at 60 DAS and *Ludwigia parviflora* (Jacq.) Raven and *Alternanthera philoxeroides* (Mart.) Griseb. at 90 DAS]. Samples were dried in a hot air oven at 70 ^{0}C for 48 hours before chemical analysis. Total nitrogen was estimated using the Kjeldahl method from acid digestion, total phosphorus was estimated using the Vanado molybdate yellow colour method from diacid extract and total potassium was estimated using the flame photometric method from diacid extract as suggested by Jakson (1973). The uptake of N, P and K by crops and removal by weeds was estimated by multiplying crop yield with the corresponding % composition of N, P and K. Weed data were subjected to square root $\sqrt{x+0.5}$ transformation and the transformed data was used for analysis. Statistical analysis of the data was done as described by Gomez and Gomez (1984) at a 5% level of significance. The original data have been given in parentheses in each table along with the transformed values.

RESULT AND DISCUSSION

Weeds in direct-seeded rice and their nutrient uptake

Direct-seeded rice was infested with *Digitaria sanguinalis* (L.) Scop., *Echinochloa colona* (L.) Link, *Paspalum notatum* Flüggé among the grasses; *Eclipta alba* (L.), *Spilanthes calva* DC., *Ludwigia parviflora* (Jacq.) Raven, *Alternanthera philoxeroides* (Mart.) Griseb. and *Oldenlandia corymbosa* (L.) among broad-leaved; *Cyperus iria* (L.) and *Fimbristylis miliacea* (L.) Vahl among sedges and *Cyanotis axillaris* D. Don ex Sweet (monocot). Malik *et al.* (2021) also observed similar type of weed flora in DSR under lateritic soil of West Bengal. At maturity on a dry weight basis, *E. alba* (2.30%) recorded the highest N content (**Table 1**) followed by *S. calva* (2.18%). The phosphorus content was highest in *C. axillaris* (0.48%) and *E. alba* (0.47%). *Spilanthes calva* accumulated 5.48% K followed by *C. axillaris* (4.71%). Among weeds, the lowest N, P and K contents were obtained with *E. colona*.

Effect of tillage and herbicides on weed biomass and nutrient removal

The total biomass of all weed species at maturity was significantly lower in ZT (21.12 g/m^2) than in CT (31.79 g/m^2) in the first year (**Table 2**). However, in second year tillage had no effect on total weed biomass. Sequential application of oxadiargyl *fb* fexoxaprop-p-ethyl + ethoxysulfuron, oxadiargyl *fb* penoxsulam + cyhalofop-butyl, oxadiargyl *fb* bispyribac-sodium and pendimethalin *fb* bispyribac-sodium recorded the lowest total weed biomass. Penoxsulam + cyhalofop-butyl (ready-mix) and fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) significantly reduced the total weed biomass over unweeded control in first year. But, after one cropping cycle, sole application of penoxsulam + cyhalofop-butyl (ready-mix) recorded the highest total weed biomass, followed by unweeded control and fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) alone. The combination of cyhalofop-butyl and penoxsulam was poor against *L. perennis* as reported by Menon (2019). Pendimethalin *fb* bispyribac-sodium used in sequence was more effective than pendimethalin alone for controlling weeds (Patel *et al.* 2018).

During the second year, significant variation was not observed between tillage treatments in terms of the N, P and K removal by weeds in DSR (**Table 2**) as total weed biomass did not differ significantly between tillage practices in DSR. Although total nutrient removal was unaffected by tillage, interaction revealed that *D. sanguinalis* and *F. miliacea* removed N, P and K more efficiently under CT than under ZT (**Figure 1**). Total N, P and K removal was 37.29, 47.12, and 35.86% higher under CT than under ZT in the unweeded control (**Figure 1**). Among weed management treatments, highest N (32.22 kg/ha), P (9.02 kg/ha) and K (55.57 kg/ha) removal by weeds was in unweeded control during the first year (**Table 2**). However, following one cycle of the DSR-yellow mustard sequence, weeds under ready-mix penoxsulam + cyhalofop-butyl alone removed more nitrogen (60.72 vs. 38.56 kg/ha), phosphorus (12.18 vs. 6.50 kg/ha) and potassium (79.90 vs. 78.91 kg/ha) than the unweeded control due to the highest total weed biomass associated with it, followed by unweeded control and fexoxaprop-p-ethyl + ethoxysulfuron during second year (**Table 2**). When the weed biomass decreased, nutrient removal by weeds also decreased (Sangeetha *et al.* 2011). Within a very short period of life cycle, *Cyperus iria* removed 5.52 kg/ha of N, 0.68 kg/ha of P and 12.56 kg/ha of K in the unweeded control at 30 DAS (**Figure 2**). Poor control of *C. iria* with fenoxaprop-p-ethyl + ethoxysulfuron resulted in 4.03, 0.50 and 9.17 kg/ha N, P and K removal, respectively. Considerable removal of N (7.06 kg/ha), P (2.33 kg/ha), and K (12.17 kg/ha) by *Digitaria sanguinalis* was observed in unweeded control at 60 DAS (**Figure 3**). Penoxsulam + cyhalofop-butyl (ready-mix) applied alone, caused 3.07, 1.00 and 5.29 kg/ha of N, P and K removal , respectively by *D. sanguinalis*. In the second year penoxsulam + cyhalofop-butyl treated plot had the highest removal of N, P and K by *L. parviflora* at 90 DAS (**Figure 4**). *Ludwigia parviflora* removed 84.61, 86.12 and

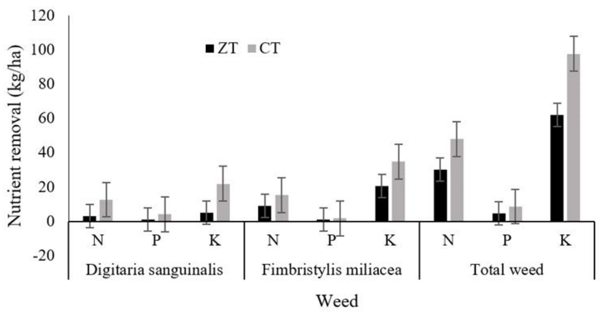
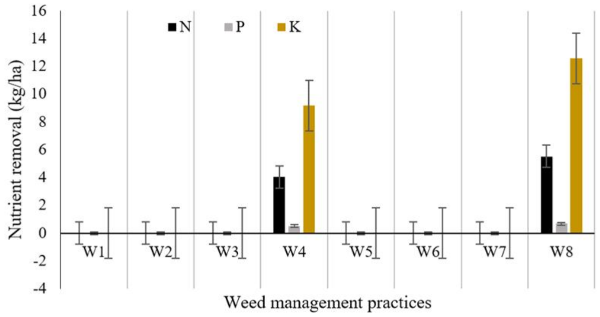
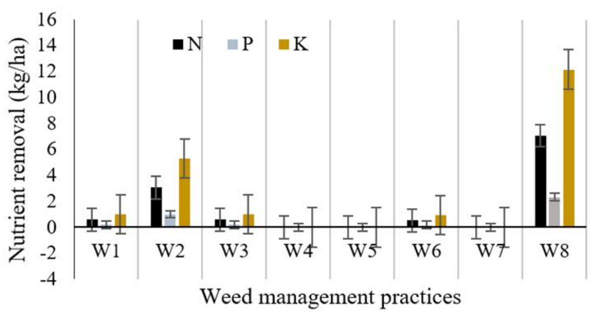


Figure 1. Removal of N, P and K by weeds in unweeded control under different tillage during 2020



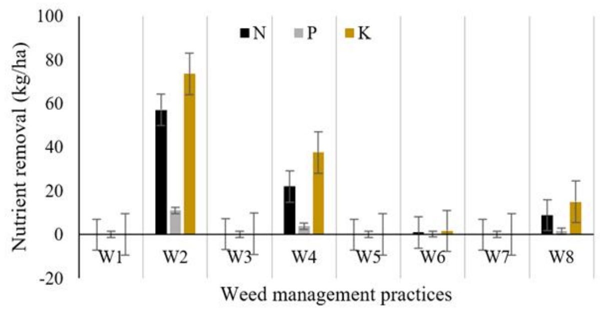
W1: Oxadiargyl *fb* bispyribac-sodium; W2: Penoxsulam + cyhalofop-butyl;W3: Oxadiargyl *fb* penoxsulam + cyhalofop-butyl;W4: Fenoxaprop-p-ethyl + ethoxysulfuron; W5: Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron; W6: Pendimethalin *fb* bispyribac-sodium; W7: Weed free check; W8: Unweeded control

Figure 2. Effect of weed management practices on removal of N, P and K by *C. iria* during 2020



W1: Oxadiargyl *fb* bispyribac-sodium; W2: Penoxsulam + cyhalofop-butyl;W3: Oxadiargyl *fb* penoxsulam + cyhalofop-butyl;W4: Fenoxaprop-p-ethyl + ethoxysulfuron; W5: Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron; W6: Pendimethalin *fb* bispyribac-sodium; W7: Weed free check; W8: Unweeded control

Figure 3. Effect of weed management practices on removal of N, P and K by *D. sanguinalis* during 2020



W1: Oxadiargyl *fb* bispyribac-sodium; W2: Penoxsulam + cyhalofop-butyl;W3: Oxadiargyl *fb* penoxsulam + cyhalofop-butyl;W4: Fenoxaprop-p-ethyl + ethoxysulfuron; W5: Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron; W6: Pendimethalin *fb* bispyribac-sodium; W7: Weed free check; W8: Unweeded control

Figure 4. Effect of weed management practices on removal of N, P and K by *L. parviflora* during 2020

Table 1. Nutrient content of weeds in direct seeded rice at their maturity

Weed species	Nutrient content of weeds (%)		
	N	P	K
Digitaria sanguinalis	1.29	0.42	2.23
Cyperus iria	0.98	0.12	3.20
Fimbristylis miliacea	1.13	0.13	2.58
Spilanthes calva	2.18	0.16	5.48
Ludwigia parviflora	1.72	0.30	2.94
Echinochloa colona	0.78	0.10	1.59
Eclipta alba	2.30	0.47	3.79
Alternanthera philoxeroides	0.95	0.10	2.61
Cyanotis axillaris	2.13	0.48	4.71

79.61% more N, P and K in penoxsulam + cyhalofop-butyl treated plot than the unweeded control. *Ludwigia parviflora* removed higher N (21.99 kg/ha), P (3.84 kg/ha) and K (37.58 kg/ha) in fenoxaprop-p-ethyl + ethoxysulfuron due to its greater dominance in that treatment than in unweeded control. Among the different herbicide combinations, the lowest removal of N, P and K by weeds in DSR was recorded with sequential use of oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron, oxadiargyl *fb* penoxsulam + cyhalofop-butyl, oxadiargyl *fb* bispyribac-sodium and with pendimethalin *fb* bispyribac-sodium (**Table 2**). Similar results were previously reported by Hemalatha *et al.* (2017).

Effect of tillage and herbicides on crop growth, yield and nutrient uptake and economics

The leaf area index (LAI) and soil plant analysis development (SPAD) values of rice leaf in the DSR were unaffected by tillage (**Table 3**). Unweeded control recorded the lowest value of LAI (2.64) and SPAD (24.1 and 33.2 at 30 and 60 DAS, respectively). The sequential application of oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron recorded the highest LAI (4.43) and was at par with oxadiargyl *fb* penoxsulam + cyhalofop-butyl (4.39) and with oxadiargyl *fb* bispyribac-sodium (4.12). These findings are in accordance with those of Soni *et al.* (2020) and Pavithra *et al.* (2021). The SPAD value of rice leaf remained statistically comparable among herbicide treated plots (**Table 3**). Herbicide reduced weed competition for growth resources and increased rice LAI and chlorophyll content in rice leaves (Sanodiya and Singh 2017).

Tillage did not influence the grain yield of DSR (**Table 3**). Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron recorded the highest grain yield of DSR (3.90-4.77 t/ha) and were closely followed by oxadiargyl *fb* penoxsulam + cyhalofop-butyl (3.93-4.37t/ha). Among herbicide treated plots, fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) and penoxsulam + cyhalofop-butyl (ready-mix) recorded the lowest grain yield (2.72-4.52 and 1.91-2.25 t/ha, respectively). Unweeded control recorded the lowest grain yield of DSR (0.37-0.78 t/ha) because of uncontrolled weed growth. Under weed free condition the growing environment provided favorable conditions for greater growth, which may have resulted in higher yield as also stated by Narolia *et al.* (2014).

Among tillage practices, no significant variation was recorded in N, P and K uptake by rice in DSR (**Table 4**). All the herbicide treated plots distinctly increased the N, P and K uptake by rice over unweeded control. As reported previously, there was higher uptake of nutrients in weed free conditions (Chakraborti *et al.* 2017).

Table 2. Nitrogen, phosphorus and potassium removal by weeds in DSR under different tillage and weed management practices

Treatment	Total weed biomass (g/m^2)		Nutrient removal (kg/ha) N		P		K	
	2019	2020	2019	2020	2019	2020	2019	2020
Tillage practice								
Zero tillage	4.65(21.1)	8.25(67.5)	2.02(3.60)	3.41(11.10)	1.21(0.97)	1.66(2.24)	2.49(5.71)	4.33(18.28)
Conventional tillage	5.68(31.8)	8.16(66.1)	2.34(4.98)	3.33(10.59)	1.38(1.40)	1.64(2.21)	2.94(8.17)	4.28(17.78)
LSD (p=0.05)	0.76	NS	NS	NS	0.15	NS	0.40	NS
Weed management practice								
Oxadiargyl *fb* bispyribac-sodium	3.94(15.0)	2.77(7.2)	1.61(2.10)	1.30(1.20)	1.07(0.65)	0.91(0.32)	2.02(3.58)	1.59(2.01)
Penoxsulam + cyhalofop-butyl	6.29(39.0)	19.89(394.9)	2.40(5.25)	7.82(60.72)	1.46(1.64)	3.56(12.18)	3.05(8.80)	8.97(79.90)
Oxadiargyl *fb* penoxsulam + cyhalofop-butyl	2.74(7.0)	3.64(12.7)	1.19(0.92)	1.70(2.40)	0.90(0.31)	1.03(0.56)	1.44(1.58)	2.12(4.01)
Fenoxaprop-p-ethyl + ethoxysulfuron	5.14(26.0)	13.68(186.6)	2.55(5.99)	5.51(29.84)	1.07(0.64)	2.28(4.68)	3.00(8.47)	7.51(55.91)
Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron	1.67(2.29)	3.31(10.5)	1.01(0.53)	1.70(2.39)	0.77(0.10)	0.97(0.45)	1.19(0.93)	2.18(4.23)
Pendimethalin *fb* bispyribac-sodium	5.26(27.2)	4.27(17.7)	2.27(4.68)	1.95(3.31)	1.29(1.16)	1.10(0.72)	2.85(7.60)	2.46(5.55)
Weed free check	0.71(0.0)	0.71(0.0)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)
Unweeded control	15.58	17.37(301.4)	5.72(32.2)	6.25(38.56)	3.08(9.02)	2.64(6.50)	7.49(55.57)	8.91(78.91)
LSD (p=0.05)	0.80	0.67	0.29	0.27	0.14	0.11	0.37	0.32

*Figures within parentheses indicate original values and the data were transformed to $\sqrt{x+0.5}$ before analysis; NS: Nonsignificant

Table 3. Leaf area index (LAI), SPAD value, grain yield and economics of DSR under different tillage and weed management practices

Treatment	LAI (mean)	SPAD (mean)		Grain yield (t/ha)		Net return (× 1000 ₹/ha)	
	60 DAS	30 DAS	60 DAS	2019	2020	2019	2020
Tillage practice							
Zero tillage	4.03	33.3	40.3	3.32	2.92	27.76	26.37
Conventional tillage	3.92	33.0	39.0	3.57	3.06	29.84	26.67
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
Weed management practice							
Oxadiargyl *fb* bispyribac-sodium	4.12	33.5	40.1	3.15	3.25	25.31	34.53
Penoxsulam + cyhalofop-butyl	3.85	34.5	40.2	2.25	1.91	7.79	5.63
Oxadiargyl *fb* penoxsulam + cyhalofop-butyl	4.39	35.3	40.6	4.37	3.93	47.04	44.95
Fenoxaprop-p-ethyl + ethoxysulfuron	3.88	33.3	40.7	4.52	2.72	51.40	24.05
Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron	4.43	34.9	41.2	4.77	3.90	54.48	45.18
Pendimethalin *fb* bispyribac-sodium	4.04	34.4	40.4	3.35	3.46	28.11	37.57
Weed free check	4.45	35.2	41.1	4.81	3.98	41.57	32.58
Unweeded control	2.64	24.1	33.2	0.37	0.78	-25.28	-12.33
LSD (p=0.05)	0.37	2.1	1.6	0.55	0.47	10.15	8.62

DSR: Direct-seeded rice; NS: Nonsignificant; SPAD: Soil Plant Analysis Development

Table 4. Nitrogen, phosphorus and potassium uptake by rice under different tillage and weed management practices

Treatment	Nutrient uptake by DSR (kg/ha)					
	N		P		K	
	2019	2020	2019	2020	2019	2020
Tillage practice						
Zero tillage	75.0	73.1	22.9	21.1	107.3	104.2
Conventional tillage	78.5	75.2	24.4	22.0	110.4	106.1
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Weed management practice						
Oxadiargyl *fb* bispyribac-sodium	72.4	83.1	21.9	23.7	105.0	108.8
Penoxsulam + cyhalofop-butyl	56.1	49.9	16.3	14.1	85.0	75.8
Oxadiargyl *fb* penoxsulam + cyhalofop-butyl	97.0	91.5	29.9	27.5	137.2	129.5
Fenoxaprop-p-ethyl + ethoxysulfuron	97.4	72.6	30.6	20.3	135.1	111.4
Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron	101.0	91.8	32.0	27.4	138.4	114.9
Pendimethalin *fb* bispyribac-sodium	75.3	85.4	23.1	24.9	107.4	125.5
Weed free check	101.1	90.8	32.2	27.6	137.6	126.9
Unweeded control	13.9	27.9	3.3	6.8	24.9	48.6
LSD (p=0.05)	9.24	6.63	3.33	2.65	11.07	6.88

DSR: Direct-seeded rice; NS: Nonsignificant

No significant difference was observed in net return of DSR due to tillage practices (**Table 3**). There was net loss of 12,330-25,280 ₹/ha in unweeded control. In comparison to penoxsulam + cyhalofop-butyl (ready-mix) alone, oxadiargyl *fb* penoxsulam + cyhalofop-butyl fetched 6.03-7.98 times higher net return. Similarly, oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron fetched higher net return (by 5.99% in 2019 and 87.85% in 2020) as compared to fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) alone.

We observed that tillage had no effect on the total weed biomass and removal of N, P and K by weeds (at their maturity) after two cropping cycles of DSR-yellow mustard. *Digitaria sanguinalis* and *F. miliacea* together removed most of the applied N, P and K. Nutrient uptake by weeds was higher in CT than ZT under unweeded control. Herbicide application in sequence (pre-emergence *fb* post-emergence) not only reduced nutrient removal by weeds but also helped the crop absorbing more nutrients by providing almost a weed-free environment, resulting in a higher yield and return of DSR.

From the result, it can be stated that sequential application of pre-emergence oxadiargyl *fb* post-emergence fenoxaprop-p-ethyl + ethoxysulfuron or pre-emergence oxadiargyl *fb* post-emergence penoxsulam + cyhalofop-butyl will be an effective and economic approach for checking nutrient removal by weeds and managing complex weed flora both in zero and conventional tillage under DSR-yellow sarson sequence in lateritic soils of eastern India.

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