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RESEARCH ARTICLE

Enhancing herbicide efficacy with improved spray technology adoption in rice-wheat cropping system

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ABSTRACT

The spraying herbicides with unrecommended spray technology using gun sprayers/knapsack sprayers equipped with single hollow-cone or flat-fan nozzle and lower water volume, has been one of the important factors responsible for the lower efficacy of herbicides in rice-wheat cropping system in Punjab, India. The improved spray technology, involving spraying with tractor operated multi-boom sprayer fitted with flat-fan nozzles, was compared with farmer's practice in rice-wheat system adopting farmers' field in Amritsar County during 2015-16 and 2016-17. In dry-seeded rice, pre-emergence application (PE) of pendimethalin alone and its tank-mix with pyrazosulfuron were used, and in wheat, pendimethalin alone and pre-mix of sulfosulfuron plus metsulfuron-methyl were used for weed management. The major weed flora in dry-seeded rice included: *Dactyloctenium aegyptium, Echinochloa colona, Echinochloa crus-galli, Leptochloa chinensis* and *Digitaria ciliaris* and in wheat, *Phalaris minor* was the dominant weed. The improved spray technology enhanced weed control by 93% in dry-seeded rice and by 95 % in wheat, compared to farmer's practice. The study indicated good scope for enhancing herbicides efficacy by the use of appropriate recommended spray technology

Keywords: Direct-seeded rice, Herbicides efficacy, Rice-wheat cropping system, Spray technology

INTRODUCTION

Rice-wheat cropping system is the most important cereal based cropping system in India. In Indo-Gangetic Plains adoption of rice wheat system is faced with severe competition from several grassy and broad-leaved weeds during crops growth period depending upon the adopted agronomic practices, weed control techniques, soil types and underground water quality. The herbicides use resulted in improved crops yield but the inappropriate use of herbicides is causing herbicide resistance evolution in addition to increasing financial burden on farmers. Due to the use of unrecommended sprayers and spraying methods *i.e.*, gun sprayers equipped with single hollow-cone or flat-fan nozzle and using lower water volume, the adequate volume of herbicides never reaches target weeds resulting in spray loss due to drift of sprayed herbicides (Mohammed *et al.* 2021). This has been one of the important factors responsible for the lower efficacy of herbicides in rice-wheat cropping system in Indian Punjab. The herbicides *viz.* clodinafop, sulfosulfuron and fenoxaprop were recommended to control isoproturon resistant population of *Phalaris minor* which provided effective control of it up to 2007 and improved the productivity of wheat crop. But due to the continuous use of these herbicides resulted to the development of resistance to alternate herbicides too, in *P. minor* (Dhawan *et al.* 2012).

In Punjab, having more than 90 per cent irrigated areas, weed problem is becoming sever due to increased cropping intensity. The yield losses vary from 5% to 100% have been reported in different crops of different areas depending upon the weed density, frequency, type and intensity of competition for growth / yield components (Khaliq *et al.* 2012). The weed management using hoeing, harrowing and cultivation practices has become difficult in Punjab and farmers are opting for herbicides for weed management as proper weed management at the time of seeding or immediately afterwards, crop plants can make the best use of soil and environmental resources leading to enhanced crop productivity. However, the use of unrecommended spray technology, spraying herbicides with gun sprayers/knapsack sprayers equipped with single hollow-cone or flat fan nozzle and using lower water volume, has been one of the important factors responsible for the lower efficacy of herbicides in rice-wheat cropping system in Punjab, India.

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Direct-seeded rice (DSR) in *Kharif* season become very popular among the farmers (Kumar and Ladha 2011; Rao *et al.* 2007; 2017) as it has several advantages such as requirement of 35-57% less water and 67% less labour over transplanting rice and have lesser methane emissions (Chauhan *et al.* 2012 and Singh *et al.* 2016). As the impounding of water is absent in DSR, weeds emerging along with crop compete and severely affect the rice productivity (Rao *et al.* 2007). Manual weeding is considered as the best method to control, but it is not economical. In this situation, herbicides play an important role. It is suggested to use sequential application of pre-emergence herbicides followed by post-emergence herbicides in DSR to effectively manage weeds. However, the efficacy of pre-emergence herbicides can vary with herbicides used and the prevailing climatic conditions (Mahajan and Chauhan 2013). Since, area under DSR is rapidly increasing and weeds are the major constraints, efforts to improve herbicides efficacy under DSR system is essential. Thus, the present study was under taken to identify weed control options, improved spray technologies for enhancing weed control efficacy of herbicides in rice-wheat cropping system to enhance DSR productivity and profitability.

MATERIALS AND METHODS

The present study was carried out by Krishi Vigyan Kendra, Amritsar with collaboration of Department of Agronomy, PAU, Ludhiana. The recommended improved spray technology, spraying with tractor operated multi-boom sprayer fitted with flat-fan nozzles, was compared with farmer's practice (**Table 1**) at farmers' field in Amritsar County in rice-wheat system during 2015-16 and 2016-17. Twenty-five farmers from five different villages were selected in each season in both years. During these two seasons of study, an area of 10 ha was covered with plot size of 0.4 ha. The most popular paddy variety PR121 and wheat variety HD2967 were used in these demonstrations. In dry-direct seeded rice, the standard recommendation of pre-emergence application (PE) of pendimethalin 0.75 kg/ha alone is compared with and its tank-mix with pyrazosulfuron 0.015 kg/ha and farmer's practice (only post-emergence herbicides) (**Tables 2** to **5**). In wheat, treatments *i.e.,* pendimethalin PE and pendimethalin PE followed by (*fb*) post-emergence application (PoE) of pre-mix of sulfosulfuron plus metsulfuron-methyl were compared with farmer's practices for controlling weeds. The major weed flora in dry-direct seeded rice included: *Dactyloctenium aegyptium, Echinochloa colona, Echinochloa crus-galli, Leptochloa chinensis* and *Digitaria ciliaris;* while in wheat, *Phalaris minor* was the dominant weed along with *Chenopodium album, Medicago polymorpha, Melilotus indica* and *Rumex dentatus*.

Before conducting the trial, a survey was conducted to understand the basic problems of weed control with respect to herbicide resistance in rice-wheat cropping system (**Table 1**). 50 farmers were interviewed using a structured questionnaire on different aspects of weed control in DSR and wheat. Later, farmers were selected for conducting demonstrations. Training was imparted to the selected farmers prior to conducting the demonstration. The package of practices used in DSR (**Table 2**) and wheat (**Table 3**) demonstrations and cultural practices currently used by farmers in DSR differed (**Table 2** and **3**). In all the demonstrations, DSR sowing was done with DSR machine and weedicides were sprayed with tractor

Table 1. Herbicides and herbicide spray techniques used, as reported by farmers, in direct-seeded rice and wheat

Parameter	Details	Rice farmers (%) N= 50	Wheat farmers (%) N=50
Herbicides	Only pre-emergence herbicides used	15	12
	Only post-emergence herbicides used	20	75
	Both pre- and post-emergence herbicides used	25	13
	Herbicide use plus hand weeding	40	-
Post- emergence application time	20 days after sowing	51	-
	20-30 days after sowing	40	-
	30-40 days after sowing	09	55
	40-50 days after sowing	-	45
Type of nozzle used	Flood jet/ cone type	61	47
	Flat-fan/cut type	39	63
Volume of spray (l/ha)	225	22	25
	300	34	35
	375	44	40
Type of spray pump	Power operated gun sprayer	73	81
	Power operated knapsack sprayer	27	29

mounted spray pumps fitted with flat fan nozzles. Also, application of recommended dose of fertilizers at right time and in right method as well as need-based plant protection measures were emphasized and comparison has been made with the existing farmers' practice (**Table 2**). The data on weed density were recorded by randomly placing 1 m^2 quadrat at two places per plot at sampling time of 30 days after seeding (DAS) in rice and 50 DAS in wheat. The weed density data was subjected to square root transformation before statistical analysis. The original values were given in parentheses. Weed control efficiency was calculated based on weed dry weight (biomass) recorded using standard procedures. The data were analysed by using standard statistical procedures and comparisons were made at 5% level of significance.

RESULTS AND DISCUSSION

Effect on weeds

In dry-direct seeded rice, pendimethalin and tank mix with pyrazosulfuron-ethyl PE sprayed with the improved spray technology resulted in higher weed control efficiency (71.4 and 73.5% in respective two years) as compared to farmer's practice (40.6 and 40.4%). Same trend was observed in wheat where the sequential spray of pendimethalin PE followed by (*fb*) sulfosulfuron plus metsulfuron-methyl with improved spray technology enhanced weed control efficiency as compared to farmer's practice (**Table 4**) indicating the vast scope for enhancing herbicides efficacy with the use of recommended spray technology. Pendimethalin PE usage with improved technology also achieved higher /equal weed control efficiency in both rice and wheat crop when compared to the farmer's practice of using gun sprayers.

Effect on Crop

All the herbicide applications resulted in significantly higher yield as compared to the non-treated plot. The application of pendimethalin PE alone with tractor mounted spray pump resulted in higher yield than farmer's practice in both rice and wheat crop (**Table 4**) confirming findings of Hundal and Dhillon (2018). The sequential application of pre- and post-emergence herbicide with tractor mounted spray pump resulted in highest yield of both rice and wheat. Thus, with the help of improved, recommended mechanized techniques, farmers realize higher profit with effective herbicides use which may lessen herbicide resistance.

Table 2. Comparison between cultural practices used in direct-seeded rice (DSR) in demonstrations and Farmers practice

Particulars/cultural practice	DSR (Demonstration)	DSR (Farmer's practice)
Farming situation	Irrigated	Irrigated
Soil type	Clay loam	Clay loam
Variety	PR 121	PR121
Time of sowing	10 to 12th, June	20thMay
Methods	DSR drill	Broadcast
Spacing	20 cm line to line	-
Seed treatment	Carbendazim 2g/kg seed	Carbendazim 2g/kg seed
Seed rate	20 kg/ ha	25 kg/ ha
Fertilizer dose	N= 150 kg/ha and 62.5 kg/ha Zinc sulphate heptahydrate (21%). No Phosphorus and Potash was required as per the soil test report	N= 200 kg/ha and 50 kg/ha Zinc sulphate heptahydrate (21%) No Phosphorus and Potash was required as per the soil test report
Fertilizer application time and methods	N fertilizer applied in three equal splits after 2,5 and 9 weeks after sowing and full Zn applied after 5 weeks	Urea applied in three splits *i.e.*, after 2,4, 6 weeks after sowing. Zinc applied 4 weeks after sowing.
Water management	First irrigation was given immediately after sowing and then irrigation given at 10 days interval according to the requirement.	First irrigation was given immediately after sowing and then irrigation given at 4-5 days interval
Weed management Pre-emergence	Tank mix application of pendimethalin 0.75 kg /ha with pyrazosulfuron-ethyl 0.015 kg/ha	Pendimethalin 0.75 kg/ha sprayed as pre-emergence
Weed management Post emergence	Bispyribac 0.025 kg /ha 25 days after sowing	Bispyribac 0.025 kg/ha 35days after seeding (DAS) and one hoeing
Type of spray pump used	Tractor operated multi-boom sprayer fitted with flat fan nozzles	Gun sprayer
Plant protection	Application of cartap hydrochloride 0.32 kg /ha to protect from stem borer at active tillering stage One application of propiconazole 0.075 kg /ha for controlling the sheath blight	Application of cartap hydrochloride 0.32 kg /ha to protect from stem borer at active tillering stage One application of propiconazole 0.075 kg /ha for controlling the sheath blight
Days taken to maturity	Second fortnight of October	Second fortnight of October

Economics

The cost of cultivation under DSR was minimum compared to farmers practice (**Table 5)** in spite of usage of similar inputs. Due to higher weed competition the yield was lesser in farmer's practice. Net returns with pendimethalin and its tank mix with pyrazosulfuron-ethyl PE *fb* bispyribac-sodium PoE were higher due to direct-seeding of rice with seed drill which requires less labour. In this treatment, weeds were controlled effectively with the use of tractor mounted spray pumps. Net return was higher mainly due to lower cost of cultivation and higher return (**Table 5**) due to the spray technology which helped to reduce the cost of cultivation.

Across the locations, all the weed control treatments provided significantly higher returns and B:C over the weedy check. Sequential application of herbicides proved to be best over the sole application of pre-emergence herbicide and farmer's practice. In rice, the pendimethalin and its tank mix with pyrazosulfuron-ethyl PE recorded higher B:C than sole pendimethalin PE alone and farmer's practice confirming findings of Choudhary and Dixit (2018).

In case of wheat crop, pendimethalin PE alone proved better than farmer's practice in terms of net returns and B:C. In general, in rice-wheat cropping system, sequential application of pre- and post-emergence herbicide with tractor mounted spray

Table 3. Comparison between cultural practices used in wheat demonstrations and the wheat farmers fields

Particulars	Wheat demonstration	Wheat farmers fields practice
Farming situation	Irrigated	Irrigated
Soil type	Clay loam	Clay loam
Variety	HD 2967	HD 2967
Time of sowing	10 to 15th November	1-10th Nov
Methods	Drill	Drill
Spacing	20 cm line to line	20 cm line to line
Seed treatment	Tebuconazole 130 ml for 100 kg of seed	Tebuconazole 130 ml for 100 kg of seed
Seed rate	100 kg/ ha	100 kg/ ha
Fertilizer dose	125 kg/ha N and 62.5 kg/ha P and no K required.	125 kg/ha N and 62.5 kg/ha P and no K required.
Fertilizer application time and methods	Full dose of DAP applied at the time of sowing and the urea applied in two splits after 1st and 2nd irrigation	Full dose of DAP applied at the time of sowing and the urea applied in two splits after 1st and 2nd irrigation
Water management	Four irrigations were given as per the need	Four irrigations were given
Herbicide - pre-emergence	Pendimethalin 0.75 kg/ha	No pre-emergence spray
Herbicide - post emergence	Post-emergence spray at 35 DAS of sulfosulfuron plus metsulfuron-methyl 0.03 kg/ha	Tank mix application of clodinafop 0.06 kg/ha and sulfosulfuron 0.024 kg/ha
Type of spray pump used	Tractor operated multi-boom sprayer fitted with flat fan nozzles	Gun sprayer
Plant protection	Application of thiamethoxam 0.0075kg/ha to protect from aphids and jassid at boot stage. One application of propiconazole 0.075 kg/ha for controlling the yellow rust	Application thiamethoxam 0.0075kg/ha to protect from aphids and jassid at boot stage. One application of propiconazole 0.075 kg/ha for controlling the yellow rust
Days taken to maturity	2nd fortnight of April	2nd fortnight of April

Table 4. Comparative efficacy of herbicide treatments in direct-seeded rice and wheat

Treatment	Dose (kg/ha)	Weed density at 30 DAS (no./m^2)		Weed biomass at 30 DAS (g/m^2)		WCE at 30 DAS (%)	
		2016	2017	2016	2017	2016	2017
Direct-seeded rice							
Pendimethalin PE	0.75	4.4(19.0)	4.3(18.0)	7.3(53.0)	7.1(49.7)	59.5	58.6
Pendimethalin and tank mix with pyrazosulfuron-ethyl PE *fb* bispyribac-sodium PoE	0.75 + 0.015 +0.025	3.5(11.7)	3.8(13.7)	6.2(37.3)	5.7(31.7)	71.4	73.5
Farmer's practice (pendimethalin PE *fb* bispyribac- sodium PoE)	0.75 + 0.025	6.6(43.0)	6.4(40.0)	8.8(77.6)	8.5(72.0)	40.6	40.4
Weed free	-	1.9(2.7)	1.6(1.7)	2.6(6.0)	1.8(2.3)	95.3	98.1
Weedy	-	8.0(63.3)	7.8(60.6)	11.5(131.7)	11.0(121.3)	00	00
LSD (p=0.05)	-	1.1	1.0	0.8	0.7	7.7	6.59
Wheat							
Pendimethalin PE	0.75	5.5(29.0)	5.3(27.3)	8.7(74.7)	8.4(70.0)	41.5	38.1
Pendimethalin PE *fb* sulfosulfuron plus metsulfuron methyl PoE	0.75 + 0.03	4.6(20.3)	4.5(20.0)	5.7(32.0)	5.5(29.3)	74.9	74.3
Farmer's practice (tank mix clodinafop and sulfosulfuron -PoE)	0.06 + 0.024	6.8(45.0)	6.5(41.3)	8.5(72.3)	7.9(63.0)	43.2	44.1
Weed free	-	2.1(3.7)	1.8(2.33)	3.0(8.3)	2.7(6.3)	93.4	94.4
Weedy	-	8.6(73.7)	8.4(69.7)	11.3(127.7)	10.7(113.6)	00	00
LSD (p=0.05)	-	0.9	1.2	0.6	0.8	8.5	11.8

LSD-least significant difference at the 5% level of significance; DAS-Days after sowing; Figures in parenthesis are original values subjected of square root transformation; PE-Pre-emergence; PoE- Post emergence; *fb*- Followed by; WCE: Weed control efficiency

Table 5. Yield and economic returns of herbicide treatments in rice-wheat cropping system

Treatment	Dose (kg/ha)	Yield (t/ha)		Net returns (x10^3 `/ha)		B:C	
		2016	2017	2016	2017	2016	2017
Direct-seeded rice							
Pendimethalin PE	0.75	6.7	6.8	69.41	737.26	3.2	3.14
Pendimethalin and tank mix with pyrazosulfuron-ethyl PE *fb* bispyribac-sodium	0.75+0.015 +0.025	7.2	7.3	77.14	81.10	3.4	3.33
Farmer's practice - pendimethalin PE *fb* bispyribac-sodium - PoE	0.75 + 0.025	6.5	6.6	64.24	67.73	2.84	2.79
Weed free	-	7.4	7.5	78.78	84.02	3.43	3.38
Weedy	-	4.5	4.4	37.68	37.81	2.25	2.15
LSD (p=0.05)	-	0.6	0.7	-	-	-	-
Wheat							
Pendimethalin PE	0.75	4.7	4.8	63.78	77.09	3.74	4.24
Pendimethalin PE) *fb* sulfosulfuron plus metsulfuron-methyl PoE	0.75 + 0.03	5.1	5.0	70.85	81.35	3.85	4.27
Farmer's practice - tank mix of clodinafop and sulfosulfuron PoE	0.06 + 0.024	4.7	4.6	60.67	72.39	3.26	3.69
Weed free	-	5.4	5.3	75.08	88.85	4.02	4.57
Weedy	-	2.5	2.6	24.26	32.11	2.1	2.46
LSD (p=0.05)	-	0.4	0.6	-	-	-	-

LSD-least significant difference at the 5% level of significance; B:C- Benefit: cost ratio; DAS-Days after sowing; Figures in parenthesis are original values subjected of square root transformation; PE-Pre-emergence; PoE- Post-emergence; *fb*- Followed by

pump proved to be the best option for higher profit and lesser herbicide load.

Conclusions

It may be concluded that improved agronomic technologies with recommended method of herbicide spray helps farmers to attain higher crops productivity and net returns in rice-wheat cropping system.

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