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Research Paper

Residual effects of herbicides on weed interference and productivity in wheat (*Triticum aestivum*) under a conservation agriculture-based onion (*Allium cepa*)–wheat cropping system

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) and winter (*rabi*) seasons of 2015–16 and 2016–17 at the ICAR-Indian Agricultural Research Institute, New Delhi, to evaluate the effects of conservation agriculture (CA) and carryover weed management on weed interference and crop productivity of wheat [*Triticum aestivum* (L.) emend Fiori & Poal] in an onion (*Allium cepa* L.)–wheat system. Three conventional and conservation tillage and 7 weed-management treatments were laid out in a split-plot design, with 3 replications. The CA-based zero-till raised-bed system with residue retention (ZTRB + R) resulted in significant reduction in total weed density and biomass compared to conventional till flat bed (CTFB), which led to higher weed control efficiency (11%), grain (4.02 t/ha) and straw yield (4.24 t/ha), and net returns 46000 ₹/ha in the year 2016–17. The zero-till flat bed with residue (ZTFB + R) and ZTRB + R led to an increase in wheat grain yield by 5.1 and 3.6%, and net returns by 28 and 18% than CTFB respectively. Among the herbicidal treatments, the pendimethalin followed by (*fb*) ethoxysulfuron resulted in the highest reduction in weed density (29 and 34%) and weed dry weight (55 and 56%) in both years, and the pendimethalin *fb* quizalofop was comparable with it in these regards. The pendimethalin *fb* quizalofop- or ethoxysulfuron- treated plots provided higher wheat grain yield (4.24 t/ha), net returns 49000 ₹/ha and net benefit: cost (B: C) in the year 2016–17. The pendimethalin *fb* ethoxysulfuron had higher residual effect on weeds in wheat but inflicted severe phytotoxicity to onion in previous season that reduced onion yield significantly. Therefore, the pendimethalin *fb* quizalofop application to onion is most preferred considering onion and wheat crops safety and may be adopted under zero-till raised-bed for higher productivity and profitability in onion–wheat cropping system.

Key words: Net returns, Pendimethalin *fb* ethoxysulfuron, Residual/carryover effect, Raised bed, Zero tillage

Conservation agriculture (CA) with 3 inter-linked principles (i.e. minimal soil disturbance, permanent retention of crop residue and diversified crop rotation involving a legume) can sustain crop productivity, improve resource/ input-use efficiency, maintain soil health and mitigate climate change effects (FAO, 2011; Das *et al*., 2013; Ladha *et al.,* 2016; Kassam *et al*., 2019). Malik *et al.* (2014) reported that, CA could reduce *Phalaris minor* in wheat (*Triticum aestivum* L.), enhance production and productivity by 4–10% and reduce cost of production by ₹2,000 to 3,000/ha. Residue retention and its gradual decomposition under CA are keys to improvement in soil structure, carbon and N sequestration, and recycling and availability of plant nutrients (Jat *et al*., 2011).

Wheat is the second most important cereal crop and immensely contributes to India's food security. It can successfully be grown after onion under CA. The CA-based onion–wheat cropping system having less water use and higher irrigation water-use efficiency and negligible/ less emission of greenhouse gases may be a potential alternative to conventional rice–wheat system. Yet weeds remain

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a major constraint for the success of CA in most locations/ cropping systems. The absence of tillage in CA makes weed management a greater challenge than conventional agriculture. Weeds are ubiquitous, having a wide range of ecological amplitude that determines their adaptability (Das, 2008). Certain weed species germinate and grow more profusely than others under continuous zero till (ZT) system. As a result, weed shift occurs (Nichols *et al*., 2015) with the change from conventional till (CT) to ZT system, which can affect weed dynamics including weed seed redistribution and abundance in soil seed bank (Nath *et al*., 2016). Thus, the present study was undertaken to quantify the effects of tillage, residue and residual weed management on weed interference, crop productivity and profitability of wheat in an onion–wheat cropping system.

MATERIALS AND METHODS

The field experiment was conducted during rainy (*kharif*) and winter (*rabi*) seasons of 2015–16 and 2016–17 at the ICAR-Indian Agricultural Research Institute, New Delhi. Three tillage treatments in main plot and 7 weed managements in subplot were laid out in a split-plot design with 3 replications in onion-wheat cropping system. Tillage [conventional till flat bed (CTFB), zero till flat bed with residue (ZTFB + R), and zero till raised bed with residue (ZTRB + R)] were common practices for both onion and wheat crops. These tillage practices had 7 weed management/ herbicides treatments [unweeded control (UWC), weed-free control (WFC), 2 hand-weedings–at 20 and 40 days after planting of onion (DAP) (2HW), pendimethalin [1 kg/ha pre-emergence (PE) followed by (*fb*) quizalofop-ethyl (0.05 kg/ha) at 30 DAP, (Pendi *fb* quizalo)], pendimethalin (1 kg/ha PE) *fb* ethoxysulfuron (0.02 kg/ha) at 30 DAP (Pendi *fb* ethoxy), quizalofop-ethyl (0.05 kg/ha) + metsulfuron (0.006 kg/ha) at 20 DAP tank-mix (Quizalo + metsulf), and quizalofop-ethyl (0.05 kg/ha) + ethoxysulfuron (0.02 kg/ha) at 20 DAP tank-mix (Quizalo + ethoxy)]. Weed-management treatments were applied to the rainy season onion only and their carry-over effect was investigated in wheat in both years. Only weed-free treatment was freshly imposed in wheat during the winter season. The CT plots were prepared using tractor-drawn disc plough and harrow followed by planking. In CA-based treatments (ZTFB + R and ZTRB + R), no ploughing was done. The ZTRB + R plots had the dimension of 40 cm bed and 30 cm furrow. Permanent raised bed were made with the help of bed planter initially and maintained throughout the experiment with the help of same implement before sowing of each crop. In CA-based residue-retention plots, residues of wheat (2.5 t/ha) grown in previous season were applied to onion and no residues were applied to CT plots.

Soil of the experimental site was sandy loam, *p*H 7.6, organic carbon (C) 0.46%, low in available N (220 kg/ha) and medium in available P (15.4 kg/ha) and available K (260 kg/ha). Wheat variety 'HD 3117' was sown with 100 kg seed/ha at 22.5-cm-row-spacing. In CT, wheat was sown using a tractor-drawn seed-cum-fertilizer drill. In CA-based ZTFB + R plots sowing of wheat was done using a happy turbo seeder. In ZTRB + R plots, the sowing was done using bed planter. A dose of 120 kg N, 60 kg P_2O_5, 40 kg K_2O/ha was applied, of which half of N and full doses of P and K were applied basal. Rest of N was given in 3 split doses–20 kg N in each dose under moist field conditions. Total weed population and weed dry weight were recorded at 40 days after sowing (DAS). An area of 0.25 m^2 surrounding 2 wheat crop rows was selected randomly at 3 spots by a quadrate 0.5 m × 0.5 m/plot and weed species were counted. Weed and wheat plant samples were sun-dried for 3 days and kept in an oven at 70°C till constant weight obtained. The total weed density and dry weight constituted of grassy, broad-leaf and sedge weeds and these values were transformed through square-root [$\sqrt{x + 0.5}$] method before analysis of variance (Das, 1999). Weed control efficiency (WCE) was calculated by the formula given below (Das, 2008):

$$\text{WCE} = \frac{(\text{WDc} - \text{WDt})}{\text{WDc}} \times 100$$

where, WDc, weed density in unweeded control; WDt, weed density in treated plots.

Weed index (WI) is an expression of loss in crop yield due to presence of weeds in comparison with weed-free control (Das, 2008) and was calculated as:

$$\text{WI} = \frac{(\text{Ywf} - \text{Yt})}{\text{Ywf}} \times 100$$

where, Ywf, crop yield in weed-free control; Yt, crop yield in treated plot.

In tillage levels maximum yield giving treatment was considered as weed-free treatment.

The ear-bearing tillers were counted from 2 rows of 50 cm length randomly and expressed as number of ear-bearing tillers/m^2. Wheat was harvested manually from a net plot of 2.0 m × 2.0 m area from the central portion of each plot, sun-dried for 5 days, threshed, and grain and straw yields were recorded. The cost of cultivation under various treatments was estimated on the basis of prevailing market prices of various inputs used in the treatments. For gross returns, minimum support price of wheat declared by the Government of India during 2015 (1,450 ₹/q or 100 kg) and 2016 (1,525 ₹/q), and the market price of wheat straw were considered. The net benefit: cost (Net B: C) of various treatments was estimated from the net returns divided by the cost of cultivation. The two-year mean data on weed density, weed dry weight, crop growth, yield attributes and productivity, net returns, and net B: C were subjected to analysis of variance (ANOVA) in a split-plot design using PROC GLM procedure of SAS (SAS Institute, 2003), to determine the significance of treatments at 5% probability.

RESULTS AND DISCUSSION

Weed interference in wheat

Weed species dominant in wheat were: common lambsquarters (*Chenopodium album* L.), Indian sweetclover (*Melilotus indica* (L.) All.], field bind weed (*Convolvulus arvensis* L.), and scarlet pimpernel (*Anagallis arvensis* L.) among the broad leaf weeds; littleseed canarygrass (*Phalaris minor* Retz.) and wild oat [*Avena sterilis* sp. *ludoviciana* (Dur.) Nym.] among the monocot grassy weeds; and monocot sedge purple nutsedge (*Cyperus rotundus* L.). Result showed that, CA-based practices resulted in significant reduction in total weed density and dry weight in both years (Figs. 1 and 2). The ZTFB + R and ZTRB + R treatments led to comparable reduction in weed interference in wheat and were superior to CT. These CA-based practices, i.e. ZTFB + R, ZTRB + R, resulted in 14–19% and 10–11% lower weed density, respectively, compared with CTFB over the years. Herbicides application in the previous onion crop showed some residual/ carry-over effects on winter weeds due to which weed density and dry weight were significantly reduced in the succeeding wheat crop. In wheat, no hand-weeding was done in 2 hand-weeding (2 HW) treatment. As a result, unweeded control and 2 HW treatments were comparable and caused the maximum weed interference against wheat. This indicated negligible or no residual effect of hand weeding on winter weeds. Among the herbicide treatments, the pendimethalin *fb* ethoxysulfuron led to the highest reduction in weed density (29% and 34%) and dry weight (55% and 56.2%), but the pendimethalin fb

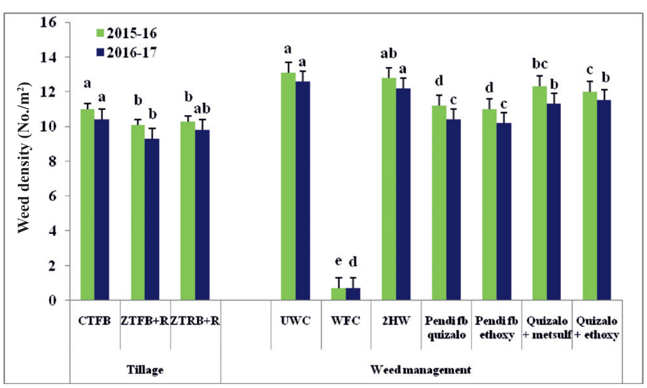

Fig. 1. Square-root transformed [$\sqrt{(x + 0.5)}$] total weed density (no./m^2) in wheat during 2015–16 and 2016–17 at 40 days after sowing; Vertical bars indicate the LSD values at ($P \leq 0.05$)

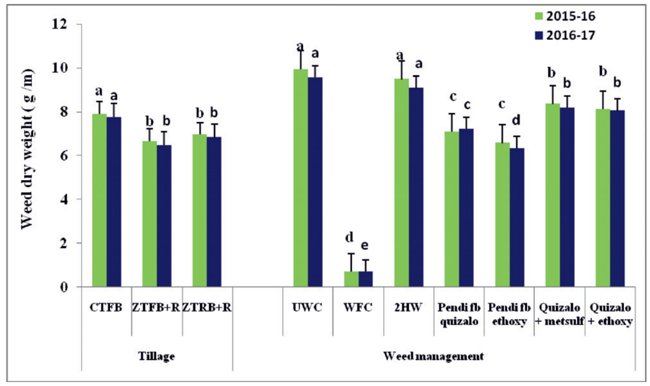

Fig. 2. Square-root transformed [$\sqrt{(x + 0.5)}$] total weed dry weight (g/m^2) in wheat during 2015–16 and 2016–17 at 40 days after sowing; Vertical bars indicate the LSD values at ($P \leq 0.05$)

quizalofop treatment was comparable with it (Figs. 1 and 2). Our results indicating ZT with residue resulted in greater weed suppression than CT. Baghel *et al*., (2020) reported similar results. Zero tillage under a fixed lay-out/ plot prevented weed-seed recruitment from lower layers of soil and led to rapid exhaustion of surface-layer weed seeds. Besides, residue retention could have smothering effect and acted as physical barrier to weed emergence. It might have induced some allelopathic effects, although not studied here. On the contrary, CT had frequent inversion, better soil aeration, frequent irrigation, which facilitated higher weed emergence. Susha *et al.* (2014) observed residual effects of herbicides applied to rainy season maize crop to the succeeding wheat crop during winter. Depletion of seed bank of certain winter season weeds in the rainy season itself due to herbicide application might be a reason.

Wheat growth and yield attributes

Tillage and weed management significantly influenced crop growth and yield attributes of wheat (Table 1). Wheat

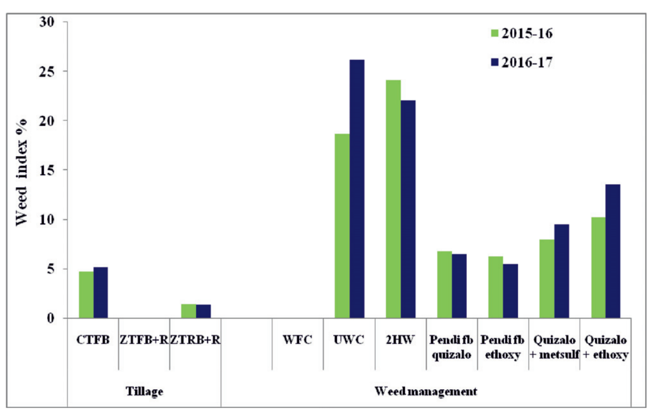

Fig. 3. Tillage and residual/ carryover effects on weed index in wheat during 2015–16 and 2016–17

sown under flat bed showed similar level of dry-matter accumulation and number of ear-bearing tillers irrespective of tillage and residue-retention practices. Zero-till-raised-bed with residue (ZTRB + R) resulted in significantly higher wheat plant dry weight (910.5 and 917.0 g/m^2) and number of ear-bearing tillers (341.0 and 347.7/m^2) than CTFB and ZTFB + R in both the years. This ZTRB + R also led to highest 1,000-grain weight (38.4 and 38.1 g) of wheat, which was significantly different from that in CTFB (Table 1).

However, ZTFB + R was comparable with it in this regard. Our results are in conformity with the findings of Ram *et al.,* (2017) and Ghosh *et al.,* (2021). As usual, weed-free control due to the highest weed control, resulted in the highest values of plant dry weight (980.0, 985.8 g/m^2), number of ear bearing tillers (359.0, 367.3/m^2) and 1,000-grain weight (42.8, 41.7 g). On the contrary, unweeded control having highest weed interference, was most inferior with respect to crop growth and yield attributes of wheat. Two hand-weeding treatment was so inferior as this (reasons mentioned above). Herbicides residual effects could not influence wheat plant dry weight and 1,000-grain weight significantly. Results also showed that, the sequential applications of pre- and post-emergence herbicides (pendimethalin *fb* quizalofop or ethoxysulfuron) were superior to the sole tank-mix application of post-emergence herbicides (Quizalofop + ethoxysulfuron) in the second year. Number of ear-bearing tillers obtained in the pendimethalin *fb* ethoxysulfuron (346.6 and 364.2) was comparable with that in weed-free control, and was significantly higher than in other herbicidal treatments. The interaction effect of tillage and herbicides were non-significant on crop growth and yield attributes except for the second year, when dry-matter accumulation was found significant (Table 1). This might be due to lower weed interference in second year (Figs. 1 and 2), favouring crop for better expression of growth and yield. Susha *et al.,* (2014) and Shaba *et al.,* (2015) also reported similar residual effect of herbicides in suppressing weeds.

Wheat yield and benefit: cost economics

In general, wheat grain and straw yields were higher in the second year and there was significant interaction between tillage and herbicides for grain yield in second year (Table 2). The ZTFB + R resulted in significantly higher grain yield than CTFB but ZTRB + R was comparable with it. In first year, ZTFB + R and ZTRB + R led to an increase in grain yield by 5.1 and 3.6% than CTFB respectively. Although straw yield was not affected significantly, zero-till-based practices gave higher values than CTFB. Similar trends were also observed in the second year with regard to grain and straw yield. The CA based treatments provided higher yield than CTFB, which could be attributed to better weed control, higher moisture supply and nutrients uptake. The findings of Chauhan *et al.,* (2003) and Das *et al.,* (2013) confirmed our results. Among the weed managements, weed-free control resulted in significantly higher grain yield (4.48 and 4.53 t/ha) than all the other treatments. All the herbicidal treatments were comparable with each other, although the sequential application proved more effective than sole tank-mix post-emergence

Table 1. Tillage and residual/carryover weed-management effects on growth and yield attributes of wheat

Treatment	Plant dry-matter (g/m^2)		Ear-bearing tillers (no./m^2)		1,000-grain weight (g)	
	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17
Tillage level (T)						
CTFB	892.4	904.8	315.1	322.4	34.0	34.2
ZTFB + R	894.1	901.7	322.7	329.4	36.2	36.1
ZTRB + R	910.5	917.0	341.0	347.7	38.4	38.1
CD (P=0.05)	8.8	11.6	16.2	5.8	3.2	3.3
Weed management (W)						
UWC	830.6	827.7	303.1	294.0	36.2	36.0
WFC	980.0	985.8	359.0	367.3	39.1	39.7
2HW	833.5	840.9	291.8	294.9	35.7	35.9
Pendi fb quizalo	914.3	931.9	330.6	339.0	36.9	36.6
Pendi fb ethoxy	915.1	928.6	346.6	364.2	35.4	35.7
Quizalo + metsulf	907.7	922.7	331.9	342.4	35.0	34.0
Quizalo + ethoxy	911.8	917.1	321.1	330.5	35.1	35.1
CD (P=0.05)	11.7	9.8	12.8	12.4	3.4	2.5
Interaction (T×W)	NS	S	NS	NS	NS	NS

Details of tillage levels and weed-management are given under Materials and Methods

Table 2. Tillage and residual/carryover weed management effects on productivity and profitability of wheat in an onion–wheat cropping system

Treatment	Wheat grain yield (t/ha)		Wheat straw yield (t/ha)		Net returns (₹×10³)		Net benefit: cost	
	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17	2015–16	2016–17
Tillage level (T)								
CTFB	3.89	3.87	5.45	5.93	32.1	38.6	0.85	0.98
ZTFB + R	4.09	4.08	5.88	6.90	39.3	49.4	1.14	1.38
ZTRB + R	4.03	4.02	5.85	6.23	38.3	45.5	1.11	1.27
CD (P=0.05)	0.13	0.16	NS	1.19	2.1	4.7	0.06	0.12
Weed management (W)								
UWC	3.64	3.35	5.19	5.90	31.3	38.5	0.91	1.08
WFC	4.48	4.53	6.72	6.69	38.2	44.7	0.88	0.99
2HW	3.40	3.53	5.07	5.59	27.5	37.2	0.80	1.05
Pendi fb quizalo	4.17	4.24	5.86	6.69	40.6	49.0	1.18	1.38
Pendi fb ethoxy	4.20	4.28	5.88	6.36	41.0	49.1	1.19	1.38
Quizalo + metsulf	4.12	4.10	5.67	6.49	39.4	47.1	1.15	1.32
Quizalo + ethoxy	4.02	3.91	5.70	6.74	37.9	45.9	1.11	1.29
CD (P=0.05)	0.29	0.19	0.64	0.75	3.9	5.6	0.11	0.15
Interaction (T×W)	NS	S	NS	NS	NS	NS	NS	NS

Details of tillage levels and weed-management are given under Materials and Methods

application (mentioned above). McMullen *et al.,* (2004) and Susha *et al.,* (2014) reported similar residual effect of herbicides on wheat. Among herbicidal treatments, the pendimethalin *fb* ethoxysulfuron, and pendimethalin *fb* quizalofop were comparable and resulted in significantly higher grain yield than unweeded control and HW treatments. The pendimethalin *fb* ethoxysulfuron resulted in 15.4 and 27.8% higher grain yield than unweeded control, and 4.5 and 4.4% higher grain yield than the tank-mix quizalofop + ethoxysulfuron in first and second year respectively. Straw yield of wheat was significantly higher in weed-free control in the first year, but was comparable with the other herbicidal treatments in the second year. Application of pendimethalin *fb* quizalofop led to 12.9 and 13.3% higher straw yield than unweeded control (Table 2). This might be due to depletion in weed seed bank/weed pressure provided better opportunity for crop growth at initial stage, which led to higher grain and straw yields.

Weed index indicated 19–26% wheat yield losses due to weed interference (Fig. 3). Wheat yield loss was reduced to 5.5–9.5% due to application of herbicides. Zero-till-based treatments resulted in significantly higher net returns (Table 2) and net benefit: cost (B: C). Net returns in ZTFB + R was comparable with ZTRB + R, but were 23 and 28% higher than in CTFB in first and second year, respectively. Pendimethalin *fb* ethoxysulfuron provided the highest net returns and net B: C, but other herbicidal treatments were found comparable. All herbicidal treatments led to significantly higher net B: C than weed-free control, indicating the superiority of previous season herbicide application to weed-free control. Nath *et al*., (2016) and Susha *et al.,* (2018) and reported similar residual effect of herbicides on succeeding crop.

The study indicates that, the conservation agriculture-based zero till raised bed with residue retention and residual/ carry-over effects of pendimethalin *fb* ethoxysulfuron and pendimethalin *fb* quizalofop resulted in considerable reduction in total weed density and dry weight in wheat. This led to a significant increase in wheat productivity, net returns and higher input-use efficiency. Application of pendimethalin *fb* ethoxysulfuron inflicted phytotoxicity to onion in previous rainy (*kharif*) season. Hence, ZTRB + R and sequential application of pendimethalin *fb* quizalofop for concurrent weed control in onion (data not shown) and residual weed control in wheat under onion-wheat system may be recommended for North-western Indo-Gangetic Plains of India.

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