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AGRONOMY

Impact of Tillage and Herbicides on the Dynamics of Broad Leaf Weeds in Wheat (*Triticum aestivum* L.)

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ABSTRACT

The investigation was carried out to evaluate the influence of tillage and herbicides on broad leaf weeds (BLW) at Varanasi. The treatments consisting of four tillage practices *viz.* conventional tillage no-residue, conventional tillage with residue, zero tillage no residue, zero tillage with residue in main plot and six herbicidal treatments *viz.* weedy check, weed free, mesosulfuron (12 g *ai* ha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS, metsulfuron (4 g *ai* ha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS, clodinafop + metsulfuron (60+4 g *ai* ha^{-1} at 30 DAS) and mesosulfuron + iodosulfuron (12+2.4 g *ai* ha^{-1} at 30 DAS) were allocated to sub plots with three replications. In the present study, zero tillage with residue recorded the lowest density of BLW *viz. Rumex dentatus*, *Chenopodium album*, *Anagallis arvensis*, *Melilotus indica* and *Vicia sativa*, total weed density; and the highest WCE as compared to the conventional tillage no-residue, zero tillage no residue and conventional tillage with residue, respectively. However, conventional tillage with residue recorded significantly the highest grain yield of wheat. Among herbicidal treatments, mix application of mesosulfuron + iodosulfuron recorded significantly the lowest density of all the BLW and total weed density, highest WCE and grain yield over mesosulfuron followed byone hand weeding at 45 DAS and metsulfuron followed by one hand weeding at 45 DAS and it was statistically at par with clodinafop + metsulfuron.

Highlights

- Zero tillage with residue recorded lowest density of BLWs and the highest of WCE,however, conventional tillage with residue recorded the highest grain yield
- Mesosulfuron + iodosulfuron recorded lowest density of BLWs and the highest of WCE and grain yield

Keywords: Herbicides, broad leaf weed, WCE, wheat yield, tillage

Wheat (*Triticum aestivum* L.) is the first important strategic cereal crop for majority of the world's population. It is the most important staple food of the world. It exceeds in acreage and the production of every other grain crop (including rice and maize) and is therefore, the most important cereal grain of the world, which is cultivated over a wide range of climatic conditions. It has an area of 220.4 mha with a production of 748.8 mt and the average productivity 3307 kg ha^{-1} at the global level (FAO 2017 and FAO 2017a). In India, it is cultivated in almost all the parts with a majority in the Indo-Gangetic –Plains and has as area of 30.22 mha with 98.38 mt of production during 2016-17 (DACFW 2017 and DACFW 2017a). However, the world's population is increasing by over 74 million per year, which will accumulate approximately 2.4 billion additional people by 2050. Global demand for crop calories is expected to double between 2005 and 2050 (Tilman *et al*. 2011). It is projected that, at 2050, the world's annual demand for rice, wheat and maize will be around 3.3 billion tonnes (FAO, 2016). Whereas, in India the demand for food is expected to increase significantly in the coming decades, and the study estimates that India's overall demand for food grains will increase from 236.2 mt in 2010 to 272-277 mt in 2020 and 303-318 mt in 2030 (DACFW, 2017).

Thus, to fulfil that demand of food grains, we have to increase the production and the productivity of wheat. There are some biotic factors including weeds, insect-pest and disease reducing the production and productivity of wheat crop. Losses caused by weeds have been estimated to be much higher than those caused by insect-pests and diseases together (Fakkar and Amin 2012).

Wheat is infested with diverse weed flora, as it is grown in diverse agro-climatic conditions, under different cropping sequence, tillage and irrigation regimes (Rao *et al*. 2014). The crop rotations, tillage and herbicides have pronounced an effect on the type of weed flora. Reduced tillage or no-till (NT) wheat with higher moisture in rice-wheat system favours the infestation of *Rumex dentatus* and *Malva parviflora* (Chhokar *et al.* 2012), *Chenopodium album*, *Anagalli sarvensis*, *Melilotus indica* and *Vicia sativa* (Singh *et al*. 2017). Some parts of eastern India have severe problem of *Solanum nigrum* and *Physalis minima* (Chhokar *et al.* 2012), where growers mostly depend on 2, 4-D, which is not effective against these weeds. Broad-leaf weeds are becoming a problem in areas where grassy herbicides (clodinafop, fenoxaprop and pinoxaden) without supplementing with broad-leaf weed herbicides are used continuously. For the control of broad-leaf weeds in wheat, the major herbicides used in India are metsulfuron, 2, 4-D and carfentrazone (Singh *et al*. 2012). Generally, a herbicide is more effective against some of the target weeds and less or not effective against others. Also, some of the post-emergence contact herbicides are less effective on weeds having an advanced stage, and they are unable to control the subsequent weeds emerging after application due to its lack of residual activity in the soil. As the wheat fields are infested with diverse weed flora and for their effective management, combination of herbicides either as ready mixture, if compatible or tank mixture or as sequential, if not compatible are required.

However, the sole dependence on herbicide of single mode of action is also not advisable as it has contributed to shift towards difficult-to-control weeds and the rapid evolution of multiple herbicide resistance, which is a threat to wheat production (Singh *et al.* 2011 and Malik *et al*. 2013).

Tillage influences weed life cycle process by directly destroying the seedlings, redistributing seeds vertically in the soil profile, and by altering the soil properties that influence seed persistence, dormancy, germination, and seedling survival. Therefore, shifts in weed community population dynamics frequently occur when any type of conservation tillage is adopted, including zero tillage (ZT). Understanding the tillage effects on weed community dynamics can be challenging because the effects are variable and they depend on interactions with other management tactics, environmental conditions, and weed biology (Verma *et al*. 2015). Residue retention acts as mulches which can influence weed seedling emergence and weed biomass. Globally there is mounting evidence that the retention of crop residues from one season to the next suppresses the germination and the development of weeds (Mashingaidze *et al*. 2009), thus enhancing system productivity. Residue retention has significantly influenced weed emergence, although several interacting factors may determine the extent of this influence including residue nature, height, type and quantity, prevailing weed flora, soil type and weather conditions (Bahadur *et al*. 2015). Residue mulching is a practical method for early season weed control in minimum tillage systems for smallholder farmers (Chauhan and Abugho 2013). This is because of the surface application of residue of 5 to 7 tha^{-1} which significantly suppress weed growth and the development when compared to the incorporation and no-residue retention (Brar and Walia 2010).

For sustaining food grain production to feed burgeoning population and for ensuring food security, effective weed management is very essential. Therefore, tillage with residue retention and the use of chemical for weed control is the preferred option. Farmers of the region generally used herbicides for weed control in wheat which have monotonous mode of action. This type of herbicide patterns has caused a shift in weed flora in favour of the broad-leaf weeds. It has also led to the development of resistance against the widely used herbicide in weed species (Lemerle 2016). To broaden the spectrum of weed kill and to provide the long term residual weed control, the use of herbicide mixture with other possible methods is advisable. Herbicide mixture besides providing control of complex weed flora will also help in managing and delaying the herbicide resistance problem (Chokkar *et al*. 2015). Diversifying herbicide-based weed management by using rotation, tank mixtures, and sequential application in integration with tillage will help in controlling difficult-to-control weed species (Peerzadaa and Ali 2016). The practice of zero tillage along with residue has enough bearing towards weed suppression in both cropped and non-cropped situations in addition to the conservation of soil moisture by reducing evaporation (Nagrea and Chanderb 2016). Keeping all these facts in view, the present investigation was carried out to find out the effective crop establishment method and herbicides for effective control of broad leaf weeds in wheat crop.

MATERIALS AND METHODS

The experiment was conducted during the winter (*rabi*) season of 2014-15 and 2015-16 at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (25° 18′- N latitude, 83° 03′- E longitude and altitude of 129 m above mean sea level). It is characterized by the low land sub-tropical climate which is often subjected to extreme weather conditions *i.e*. heat of summer and cold of winter with an average annual rainfall of 1080.4 mm and potential evapotranspiration (PET) account of 1500 mm annually. The experiment was laid out in a split plot design and was replicated three times. Twenty four treatment combinations of four crop establishment methods *viz*. conventional tillage no-residue, conventional tillage with residue (6 tha^{-1}), zero tillage no-residue and zero tillage with residue (6 tha^{-1}) were assigned to the main plots and the weed management practices *viz*. weeded check, weed free (weeds were removed with the help of hand hoe during entire crop period), mesosulfuron 12 g $aiha^{-1}$ at 30 days after sowing (DAS) followed by one hand weeding at 45 DAS, metsulfuron (4 g *ai* ha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS, clodinafop + metsulfuron (60+4 g *ai* ha^{-1} at 30 DAS) and mesosulfuron + iodosulfuron (12+2.4 g *ai* ha^{-1} at 30 DAS) were allocated to the sub plots. Conventional tillage plots were ploughed by a tractor- drawn disc plough followed by planking and the zero tillage plots were left undisturbed. Each replication was separated by one meter path-way and 50 cm space was left between the plots. Each plot measured 5 m × 4 m^2 area. The treatment combinations were allocated completely at random in each of the three replications. Wheat variety ′HUW 234′ was sown (23 November 2014 and 27 November 2015, respectively in the cropping season) under different tillage practices at a row distance of 22.5 cm by opening slits with zero-till-drill machine in the conventionally tilled as well as undisturbed plots. After complete crop germination, the previous season's rice straw was applied as residue mulch in the respective treatment. All the herbicides were applied as post emergence (30 DAS) with the help of foot sprayer fitted with a flat fan nozzle. The spray volume was 400 litres water/ha. The fertilizers used were 120 kg ha^{-1}nitrogen (N), 60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O.N was supplied by urea (46% N), while phosphorus (P) and potassium (K) were supplied by single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O) respectively. N was applied in splits. The first half was applied at the planting (basal), while the second dose (1/4 part) was top dressed after the first irrigation and the remaining ¼ (third dose) part of nitrogen was top dressed at the spike initiation stage. P and K were applied during the planting. Broadcasting method of application was adopted for the top dressing of N while the basal dressing of N as well as P and K was done by a seeding machine. Three irrigations were given to crop at the critical growth (CRI- 21 DAS, before spike initiation-75 DAS and grain filling 90 DAS) stages. Weed sampling was done at 40, 80DAS and at harvest by randomly throwing quadrant of 0.5×0.5 m, at three spots in each net plot. The weeds inside the quadrant was uprooted, weed species were counted and the density was expressed in numbers m^{-2}. As a wide variation existed in data, the number of weeds was transformed through squire-root $\sqrt{(x+0.5)}$ methods before the analysis of variance.

Weed control efficiency (%) was computed using the following formula:

$$\text{WCE} = \frac{\text{Dry wt. of weeds in control plot-Dry wt. of weeds in treatment plot}}{\text{Dry wt. of weeds in control plot}} \times 100$$

Harvesting was done manually using a sickle at few centimetres from the ground level and the harvested wheat was left on the field for two days for field drying before threshing. The harvested wheat from eachnet plot was threshed by power operated thresher and then winnowed and the grain was weighed using a weighing balance and was converted to tonnes per hectare and bagged separately. All the data collected were statistically analysed to draw a valid conclusion.

RESULTS AND DISCUSSION

Relative frequency of weed flora

The important broad leaved weed and their relative composition was recorded at 80 DAS in the weedy check plot which revealed the weed flora of the experimental field in order of dominance (Table 1). Experimental field was dominated by *Rumex dentatus* (27.9%), *Chenopodium album* (24.5%), *Anagallis arvensis* (18.6%), *Melilotus indica* (15.5%) and *Vicia sativa* (13.6%), respectively. Similar weeds flora distribution in wheat has been reported by Singh *et al.* (2017).

Table 1: Relative composition of weeds in weedy plot at 80 DAS (Pooled data of two years)

Weed species	Weed (No. m^{-2})	Relative composition of weeds (%)
Rumex dentataus	45.6	27.9
Chenopodium album	40.1	24.5
Anagallis arvensis	30.5	18.6
Melilotus indica	25.3	15.5
Vicia sativa	22.2	13.6
Sub-total	**163.7**	**100.0**

Rumex dentatus

Among the crop establishments, zero tillage with residue resulted significantly with the lowest density and dry weight of *Rumex dentatus* over the conventional tillage with residue, zero tillage no-residue and conventional tillage no-residue, respectively (Table 2). Among the weed management treatments, weed free recorded the lowest density and dry weight of *Rumex dentatus* when compared to the herbicidal treatments. Chhokar *et al*. (2007) reported that wheat sown with zero tillage recorded significantly a lower density of *Rumex dentatus* when compared to the conventional till-sown crop. Singh *et al.* (2015) reported the application of 6 tha^{-1} rice residues as mulch reduces the emergence of *Rumex dentatus* by 88-90% compared to without residue application. All the herbicidal treatments were superior to the unweeded check in controlling *Rumex dentatus* at all the stages of observation. An application of mesosulfuron + iodosulfuron (12+2.4 g *ai*ha^{-1} at 30 DAS) recorded that the lowest density and dry weight of *Rumex dentatus* was at par with the mixed application of clodinafop + metsulfuron (60+4 g *ai* ha^{-1} at 30 DAS) and significantly superior over mesosulfuron 12 g *ai* ha^{-1} at 30 days after sowing (DAS) followed by one hand weeding at 45 DAS and metsulfuron (4 g *ai* ha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS at all the stages of observation. Singh*et al*. (2011) reported better control of *Rumex spinosus* (92%) with metsulfuron + carfentrazone applied as tank mixture when compared to the sole application of either metsulfuron (85%) or carfentrazone (78%).

Chenopodium album

Crop establishment and weed management practices significantly reduced the density of *Chenopodium album* than weedy check at all the stages of observation (Table 2). Significantly the lowest density of *Chenopodium album* was recorded under zero tillage with residue when compared to the conventional tillage with residue, zero tillage no-residue and conventional tillage no-residue. Shyam *et al*. (2014) reported that wheat sown with zero tillage recorded significantly a lower density of *Chenopodium album* when compared to the conventional till sown crop. When rice residues (6 tha^{-1}) are kept on soil surface as mulch, emergence of *Chenopodium album* was inhibited by 83-90% compared to without residue mulch, Singh *et al.* (2015). Among the weed management treatments, mix application of mesosulfuron + iodosulfuron (12+2.4 g *ai* ha^{-1} at 30 DAS) recorded significantly the lowest density of *Chenopodium album* when compared to mesosulfuron 12 g *ai* ha^{-1} at 30 days after sowing (DAS) followed by one hand weeding at 45 DAS and metsulfuron (4 g *ai* ha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS and it was at par with the mixed application of clodinafop + metsulfuron (60+4 g *ai* ha^{-1} at 30 DAS). Mesosulfuron + iodosulfuron and clodinafop + metsulfuronare almost equally effective against *Chenopodium album* (Kumari *et al.* 2013).

Table 2: Effect of crop establishment and weed management practices on weed density (No.m^{-2}, pooled data of two years)

Treatments	*Rumex dentatus*			*Chenopodium album*			*Anagallis arvensis*			*Melilotus indica*			*Vicia sativa*		
	40DAS	80DAS	At harvest	40DAS	80DAS	At harvest	40DAS	80DAS	At harvest	40DAS	80DAS	At harvest	40 DAS	80DAS	At harvest
Tillage practices															
Conventional tillage-no residue	5.67 (31.6)	5.05 (24.6)	4.27 (17.7)	6.17 (37.5)	5.45 (29.2)	3.61 (12.6)	4.88 (23.4)	4.34 (18.4)	3.72 (13.3)	4.07 (16.1)	3.62 (12.6)	3.11 (9.2)	3.87 (14.5)	3.35 (10.7)	2.65 (6.5)
Conventional tillage-with residue	5.33 (28.1)	4.72 (22.0)	4.00 (15.5)	4.60 (21.1)	4.08 (16.6)	2.74 (7.5)	4.25 (17.5)	3.78 (13.8)	3.24 (10.0)	3.64 (12.7)	3.24 (10.0)	2.50 (7.3)	2.71 (7.1)	2.34 (5.2)	1.90 (3.3)
Zero tillage-no residue	5.59 (30.7)	4.98 (24.3)	4.21 (17.2)	6.03 (35.9)	5.33 (27.9)	3.54 (12.0)	4.73 (21.8)	4.21 (17.2)	3.60 (12.5)	3.95 (15.1)	3.52 (11.8)	3.02 (8.6)	3.41 (13.3)	3.21 (9.8)	2.54 (6.0)
Zero tillage-with residue	5.02 (25.2)	4.50 (20.2)	3.80 (14.4)	4.21 (17.7)	3.69 (13.5)	2.36 (5.5)	3.99 (15.7)	3.54 (12.5)	3.02 (9.1)	3.37 (11.0)	3.00 (8.7)	2.54 (6.3)	2.24 (5.6)	2.12 (4.2)	1.63 (2.4)
CD (P=0.05)	0.29	0.21	0.19	0.37	0.39	0.38	0.24	0.23	0.21	0.27	0.23	0.24	0.16	0.20	0.27
Herbicides															
Weedy check	7.63 (57.6)	6.79 (45.6)	5.73 (32.3)	7.48 (55.4)	6.60 (40.1)	4.36 (18.5)	6.27 (38.8)	5.57 (30.5)	4.76 (22.2)	5.71 (32.2)	5.08 (25.3)	4.34 (15.4)	5.51 (29.9)	4.77 (22.2)	3.74 (13.2)
Weed free	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)
Mesosulfuron @ 12 g *ai* ha^{-1} at 30 DAS*fb*one HW at 45 DAS	5.69 (31.8)	5.07 (25.2)	4.28 (17.9)	6.15 (37.3)	5.43 (29.0)	3.60 (12.5)	4.74 (21.9)	4.22 (17.3)	3.61 (12.5)	3.97 (15.2)	3.53 (12.0)	3.04 (8.7)	3.38 (10.9)	3.21 (8.1)	2.33 (4.9)
Metsulfuron @ 4 g *ai* ha^{-1} at 30 DAS*fb*one HW at 45 DAS	5.62 (31.0)	5.00 (24.5)	4.23 (17.4)	5.98 (35.3)	5.29 (27.4)	3.51 (11.8)	4.63 (20.9)	4.12 (16.4)	3.52 (11.9)	3.81 (14.0)	3.40 (11.0)	2.91 (8.0)	3.20 (9.7)	3.03 (7.2)	2.21 (4.4)
Clodinafop+metsulfuron @ 60 + 4 g *ai* ha^{-1} at 30 DAS	5.28 (27.4)	4.71 (21.7)	3.99 (15.4)	4.63 (21.0)	4.10 (16.1)	2.74 (7.2)	4.40 (19.1)	3.88 (15.0)	3.34 (10.9)	3.39 (11.4)	3.01 (9.0)	2.61 (6.5)	2.44 (5.4)	2.31 (4.0)	1.72 (2.4)
Mesosulfuron+iodosulfuron @ 12+2.4 g *ai* ha^{-1} at 30 DAS	5.09 (25.4)	4.54 (20.1)	3.84 (14.3)	4.44 (19.4)	3.95 (15.1)	2.64 (6.3)	4.25 (17.1)	3.74 (10.3)	3.21 (9.8)	3.17 (9.9)	2.83 (7.5)	2.44 (5.4)	2.28 (4.7)	2.18 (3.5)	1.62 (2.1)
CD (P = 0.05)	0.21	0.18	0.16	0.24	0.20	0.21	0.22	0.17	0.15	0.23	0.18	0.19	0.36	0.28	0.31

DAS- Days after sowing. Original data are subjected to square root transformation

Anagallis arvensis

Significantly the lowest density and dry weight of *Anagallis arvensis* was recorded under zero tillage with residue when compared to conventional tillage with residue, zero tillage no-residue and conventional tillage no-residue, respectively (Table 2). Singh (2014) reported the lower density of *Anagallis arvensis* under zero tillage system. Among the herbicidal treatments, mixed application of mesosulfuron + iodosulfuron (12+2.4 g *ai*ha^{-1} at 30 DAS) recorded significantly the lowest density and dry weight of *Anagallis arvensis* over mesosulfuron 12 g *ai*ha^{-1} at 30 days after sowing (DAS) followed by one hand weeding at 45 DAS and metsulfuron (4 g aiha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS and was statistically at par with the mixed application of clodinafop + metsulfuron (60+4 g *ai*ha^{-1} at 30 DAS).All the herbicidal treatments were superior to the weedy check in controlling *Anagallis arvensis* at all the stages of observation.Similar results were reported by Malik *et al*. (2013).

Melilotus indica

The lowest density of *Melilotus indica* was recorded under zero tillage with residue and were found to be significantly the lowest than the conventional tillage with residue, zero tillage no-residue and conventional tillage no-residue at all the stages of observation (Table 2). Weed density reflected the growth potential of the *Melilotus indica* and its competitive ability with crop plants. Singh *et al*. (2015) revealed that there was less intensity of *Melilotus* spp. And *Polygonum* spp. in zero till sown wheat when compared to the wheat sown by conventional practice, resulting with less infestation and competition with the crop. Chhokar *et al*. (2009) observed that the application of 5.0- 7.5 tha^{-1} residue mulch under zero till sown wheat reduced weed biomass by 22-43% of *Melilotus indica* compared with zero tillage without residue. Among weed management treatments, weedy check recorded the highest density of *Melilotus indica* and it was the lowest under weed free (HW at 20 and 40 DAS). Mixed application of mesosulfuron + iodosulfuron (12+2.4 g *ai*ha^{-1} at 30 DAS) recorded significantly the lowest density of *Melilotus indica* followed by clodinafop + metsulfuron (60+4 g *ai*ha^{-1} at 30 DAS), mesosulfuron 12 g aiha^{-1} at 30 days after sowing (DAS) followed by one hand weeding at 45 DAS and metsulfuron (4 g *ai*ha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS, respectively.

Vicia sativa

All the crop establishment and weed management treatments where the residue was applied as mulch proved superior to no-mulching for reducing the density of *Vicia sativa* at all the stages of crop growth. Among crop establishment, the lowest density of *Vicia sativa* was recorded under zero tillage with residue followed by conventional tillage with residue, zero tillage no-residue and conventional tillage no-residue, respectively (Table 2). *Vicia sativa* density was substantially quite low in zero tillage system and was also reported by Singh (2014). Increase in *Vicia sativa* density might be due to the utilization ofapplied nutrients and available moisture ingreater quantity. All the herbicidal treatments reduced the density of *Vicia sativa* from the beginning to theharvest of crop compared with the weedy check. Mixed application of mesosulfuron + iodosulfuron (12+2.4 g aiha^{-1} at 30 DAS) was most effective in arresting the density of *Vicia sativa* followed byclodinafop + metsulfuron (60+4 g *ai*ha^{-1} at 30 DAS) and was significantly superior over mesosulfuron 12 g aiha^{-1} at 30 days after sowing (DAS) followed by one hand weeding at 45 DAS and metsulfuron (4 g aiha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS. None of the herbicidal treatments were comparable to weed free. Alone as well as the combined application of clodinafop 60 gha^{-1} with other herbicides recorded lower density of *Vicia sativa,* as reported by Kumar *et al*. (2013).

Total density of broad leaf weeds (BLW)

Heavy infestation of BLW was observedunder the weedy check (Table 3). Among the crop establishment methods, the lowest total density of BLW was recorded under zero tillage with residue followed by conventional tillage with residue, zero tillage no-residue and conventional tillage no-residue, respectively. The decrease in density of BLW under zero tillage with residue was due to the un-disturbance of upper soil layer that createun favourable environment for weed seedling germination and establishment. Similar results were reported by Mishra *et al*. (2010). Among the herbicidal treatments, mixed application of

Table 3: Effect of crop establishment and weed management practices on total weed density, weed control efficiency and grain yield of wheat (Pooled data of two years)

Treatments	Total weed density (No.m^{-2})			Weed control efficiency (%)			Grain yield (kgha^{-1})
	40DAS	80DAS	At harvest	40DAS	80DAS	At harvest	
Tillage practices							
Conventional tillage-no residue	11.1(123.0)	9.8(95.5)	7.7(59.3)	42.5	41.6	41.6	3446
Conventional tillage-with residue	9.3(86.5)	8.3(67.6)	6.6(43.5)	59.6	58.7	57.1	3667
Zero tillage-no residue	10.8(116.7)	9.6(91.0)	7.5(56.3)	45.4	44.4	44.6	3364
Zero tillage-with residue	8.7(75.2)	7.7(59.1)	6.2(37.7)	64.8	63.9	62.9	3542
CD (P=0.05)	1.36	1.33	1.34	—	—	—	78.5
Herbicides							
Weedy check	14.6(213.9)	12.8(163.7)	10.1(101.5)	0.0	0.0	0.0	2307
Weed free	0.71(0.0)	0.71(0.0)	0.71(0.0)	100.0	100.0	100.0	4162
Mesosulfuron @ 12 g ai ha^{-1} at 30 DAS*fb*one HW at 45 DAS	10.8(117.1)	9.6(91.5)	7.5(56.5)	45.2	44.1	44.4	3395
Metsulfuron @ 4 g *ai* ha^{-1} at 30 DAS*fb*one HW at 45 DAS	10.6(110.9)	9.3(86.6)	7.3(53.5)	48.2	47.1	47.3	3429
Clodinafop + metsulfuron @ 60+4 g *ai* ha^{-1} at 30 DAS	9.2(84.3)	8.1(65.8)	6.6(42.4)	60.6	59.8	58.2	3806
Mesosulfuron + iodosulfuron @ 12+2.4 g *ai* ha^{-1} at 30 DAS	8.8(76.6)	7.5(56.4)	6.2(37.9)	64.2	65.5	62.7	3854
CD (P=0.05)	1.32	1.24	1.23	—	—	—	58.5

DAS- Days after sowing. Original data are subjected to square root transformation

mesosulfuron + iodosulfuron (12+2.4 g *ai* ha^{-1} at 30 DAS) exerted the maximum herbicidal effect and caused the highest reduction in the total density of BLW at all the stages of crop growth, which however, was statistically at par with clodinafop + metsulfuron (60+4 g *ai* ha^{-1} at 30 DAS) and significantly superior over mesosulfuron 12 g *ai* ha^{-1} at 30 days after sowing (DAS) followed by one hand weeding at 45 DAS and metsulfuron (4 g *ai* ha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS. This attributed to the inhibition of the germination of weeds due to the paralysis of vital metabolic process of germination, viz. cell-division, protein synthesis and secretion of hydrolytic enzymes, and subsequently drying of susceptible weeds species. This might be due to the fact that combined application of herbicides is known for controlling a broad spectrum of weeds to achieve high level of weed control. Further, the crop covers the soil surface and smothers the growth of weeds resulting in the least number of weeds at the later stage of crop growth. Among the weed management practices, weed free (HW at 20 and 40 DAS) provided excellent control of all the weed species than herbicides, due to the slow pace of growth of the first flush of weeds, 20 days after sowing thereafter the emergence of new flushes of weeds could not attain full growth under the shade of crop plants. The weedy check registered significantly the highest weed density, resulting from the luxuriant growth of the weeds in the absence of weed control treatments. The lower density of all the BLW in the later stage was a result of drying during the subsequent growing period of the crop. These results confirm the findings of Tiwari *et al*. (2015) and Pal *et al*. (2016).

Weed control efficiency

Among crop establishment, the highest weed control efficiency was recorded under zero tillage with residue than the conventional tillage with residue, zero tillage no-residue and conventional tillage no-residue (Table 3). Mixed application of mesosulfuron + iodosulfuron (12+2.4 g *ai* ha^{-1} at 30 DAS) recorded the highest weed control efficiency followed by clodinafop + metsulfuron (60+4 g *ai* ha^{-1} at 30 DAS), mesosulfuron 12 g *ai* ha^{-1}at 30 days after sowing (DAS) followed by one hand weeding at 45 DAS and metsulfuron (4 g *ai* ha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS, respectively. This might be due to the broad-spectrum activity and the persistence nature of both the mixture of herbicides in wheat (Singh *et al*. 2015).

Grain yield

Significantly the highest grain yield was recorded under conventional tillage with residue when compared to zero tillage with residue, zero tillage no-residue and conventional tillage no-residue (Table 3). Tillage affects the weeds by uprooting, dismembering and burying them deep enough to prevent emergence by changing soil environment and by inhibiting weeds germination and establishment, thereby creating favourable soil environment for plant growth, which would result in better yield attributes and yield (Jadhav 2014). Among the weed management treatments, mixed application of mesosulfuron + iodosulfuron (12+2.4 g*ai*ha^{-1} at 30 DAS) recorded significantly the highest grain yield of wheat over mesosulfuron 12 g *ai* ha^{-1} at 30 days after sowing (DAS) followed by one hand weeding at 45 DAS and metsulfuron (4 g *ai* ha^{-1} at 30 DAS) followed by one hand weeding at 45 DAS and it was statistically at par with the combined application of clodinafop + metsulfuron (60+4 g *ai* ha^{-1} at 30 DAS). Results are corroborated with the research findings of Bharat *et al*. (2012).

From the results of the field experiments, it is concluded that zero tillage with residue recorded lower density of BLWs whereas highest grain yield was recorded under conventional tillage with residue. Mixed application of mesosulfuron + iodosulfuron (12+2.4 g *ai* ha^{-1} at 30 DAS) recorded significantly lowest density of BLWs and the highest grain yield of wheat. The recommendation may be passed on to the farmers of wheat growing areas in eastern Uttar Pradesh.

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