Indian Journal of Weed Science **48**(4): 404–409, 2016
DOI: 10.5958/0974-8164.2016.00105.2

Use of herbicides against *Orobanche* in tomato and their residual effect on succeeding crop

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Received: 24 October 2016; Revised: 1 December 2016

ABSTRACT

Egyptian broomrape (*Orobanche aegyptiaca*) is the most troublesome root holoparasitic weed cause severe damage to tomatoes grown in Mewat and Bhiwani areas of Haryana. In the present study, efficacy and selectivity of two sulfonylurea herbicides, *viz*. sulfosulfuron and ethoxysulfuron, neem cake, pendimethalin/metribuzin in conjunction with metalaxyl were tested in controlling on tomatoes grown under field conditions. Sulfosulfuron and ethoxysulfuron applied as post-emergence at 30, 60 and 90 DAT were more selective to tomato and controlled the parasite more effectively. Neem cake or metalaxyl were not found to inhibit growth of *Orobanche aegyptiaca*. No herbicide residues were observed in tomato fruits and soil at harvest. No residual carry over effect of these herbicides was observed on succeeding sorghum crop planted 2 months after harvest of tomato crop. It was concluded that post-emergence application of ethoxysulfuron at 25 g/ha at 30 DAT followed by at 50 g/ha or sulfosulfuron at 50 g/ha at 30 and 60 DAT, provided 85-90% control of *Orobanche* in tomato without any adverse effect on crop with yield increase of 46-58% as compared to untreated check.

Key words: Egyptian broomrape, *Orobanche aegyptiaca,* Sulfosulfuron, Ethoxysulfuron, Tomato

Egyptian broomrape (*Orobanche aegyptiaca* Pers.) locally known as "Margoja/Rukhri/Khumbhi/ Gulli" is an achlorophyllous, phanerogamic troublesome root parasite that depend completely on host to complete its life cycle. This parasitic plant caused economic damage in field crops and vegetable production worldwide (Parker and riches 1993, Eizenberg *et al.* 2004). Tomato is highly vulnerable to three broomrape species, *viz. O. aegyptiaca, O. ramosa and O. cernua* that are known to cause damage and reduce yields of tomato (Joel *et al.* 2007). Egyptian broomrape is the main limiting factor in tomato production in Israel, Egypt, Sudan, Syria, Tunisia, Turkey and Lebanon.

During survey of weed flora in tomato fields in Haryana, in Nuh, Ferozepur Jhirka, Nagina, Taoru areas of Mewat, Charkhi Dadri and Loharu of district Bhiwani was found badly infested with *Orobanche aegyptiaca* threatening the cultivation of this crop in the regions. Farmers reported 40-75% loss in fruit yield due to its infestation in tomato crop depending on intensity of infestation (Anonymous 2014). A continuous increase in *Orobanche* infestation in these ares has forced farmers to abandon tomato cultivation and switch over to other profitable crops cultivation.

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Orobanche exert their greatest damage prior to emergence of flowering shoot. Therefore, most of the field losses may occur before diagnosis of infection. In such situation, chemical control measures and host resistance appear to be the most appropriate measures when available and affordable. Potiental herbicides must be selective for the host plant but phytotoxic to the parasite. The most effective chemical method is soil fumigation with highly volatile compounds such as methyl bromide, metham sodium and dazomet (Foy *et al.* 1989), but cost of treatment is very high and moreover due to environmental concerns, methyl bromide has been phased out. Soil fumigation with metham-sodium provides only partial and inadequate control of Egyptian broom rape in tomato (Goldwasser *et al.* 1995)

Studies conducted earlier by Eizenberg *et al.* (2003a, 2004), Hershenhorn *et al.* (2009) in Israel demonstrated effectiveness and selectivity of sulfosulfuron and other ALS inhibiting herbicides to control broomrape in tomato by killing preconditioned seeds or young attachments. Mode of resistance of specific solancaeous species to sulfosulfuron has not been studied but it probably involves alteration of acetolactate synthatase (ALS) binding site or metabolism of the herbicide to non phytotoxic products. Sulfosulfuron applied in wheat caused residual toxicity to sorghum and maize crops grown in quick succession after wheat harvest (Chhokar *et al.* 2006).

Information on chemical control of *Orobanche* in tomato under Indian conditions is meager or not available and results reported above are mostly from green house studies in Israel. So, to validate these results under field conditions and generate data under Indian context, present investigation was planned to assess the efficacy of various sulfonylurea herbicides against *Orobanche aegyptiaca* in tomato under Indian conditions.

MATERIALS AND METHODS

Tomato hybrid '*Himsona*' was planted for two consecutive years on November 15, 2013 and December 5, 2016 at Farm of Arsad s/o Nurdin, tehsil Nuh Distt. Mewat (Haryana). Crop was grown as per university recommended package of practices for tomato except herbicide treatments. All pre-emergence herbicides were sprayed by knapsack sprayer fitted with flat fan nozzle using 750 litres of water/ha. Quantity of water applied in post-emergence treatments was 375 litres/ha. Post-emergence herbicides were applied at various stages as per treatment using 375 litres of water/ha. Observations on number of broomrape spikes/m^2 and broomrape visual control (0-100 scale) by different treatments was recorded at 60, 90, 120 DAT and at harvest. Data on plant height, length of broom rape spike were recorded at 120 DAT. Number of fruits/ plant was recorded from five tagged plants at 90,120 DAT and harvest which were averaged to compute values/plant. Tomato fruits picked in four flushes were weighed and thus total yield/plot was computed. WCE was recorded on the basis of fresh biomass of broomrape spikes. These observations were subjected to ANOVA and means were compared with appropriate Fisher's protected LSD test at 5% level of probability. Crop phyto-toxicity due to different treatments was assessed at 80, 120 DAP and harvest on a scale of 0-100, where 0 means no injury and 100 means complete mortality of tomato plant. Foliar necrosis, yellowing, stunting, necrosis and wilting were the main symptoms considered while making visual estimate of visual injury on tomato plants. Injury data were arc sin transformed prior to ANOVA.

To study residual carryover effect on succeeding sorghum crop, variety '*Hara chara*' of sorghum was planted during June, 2015 and 2016 on the same plots without disturbing the original layout.

For herbicides residues estimation, tomato and soil samples from the experimental field were collected in triplicate at crop maturity. A standard stock solution of sulfosulfuron and ethoxysulfuron were prepared in acetonitrile (HPLC grade) and that of pendimethalin and metribuzin was prepared in n-hexane. The standard solutions required for constructing a calibration curve (1.00, 0.5, 0.25, 0.1, 0.05, 0.01, 0.005 and 0.001 µg/ml) were prepared from stock solution by serial dilutions in respective solvents as mentioned above. All standard solutions were stored at -4°C before use. Sulfosulfuron and ethoxysulfuron were extracted by methods developed by Anjana *et al.* (2006) with slight modifications. For extraction of these herbicides fifty gram of the finely grinded, sieved soil and 25 gm crushed tomato samples were taken in separate conical flasks and about 50 ml of acetonitrile and ammonium carbonate mixture in ration 9:1v/v was added to the flask. The flask was shacked for half hour on shaker and the content was poured in another flask by filtering it. The residues were again extracted with another 50 ml of acetonitrile and ammonium carbonate with same procedure. The content was again filtered in the same flask containing the first fraction. The combined content was concentrated on Heidolph rotavapour to 20 ml at 40 °C and was partitioned thrice with dichloromethane (50, 30 and 20 ml) after dissolving 20 ml of saturated brine solution. The combined dichloromethane extract was collected and passed through anhydrous sodium sulphate packed in a funnel so as to remove the moisture. Filtrate was collected, pooled and dried at 40 °C on flash evaporator to near dryness. The residues were finally dissolved in 2 ml of HPLC grade acetonitrile and filtered through 0.45µm syringe filter before injection into HPLC. For extraction and clean-up of pendimethalin and metribuzin 20 g of air dried, finely grounded and sieved (through a 2 mm sieve) soil samples and 25 g finely crushed tomato fruit was taken in separate 250 ml conical flasks and added with 50 ml of acetone. The samples were shaked over rotary shaker for one hour. The contents were decanted in separate conical flask by passing over a bed of anhydrous Na_2SO_4. The contents were concentrated to about 10 ml over rotary evaporator at 35 °C. The samples were partitioned with hexane-ethyl acetate (9:1) thrice by taking 50, 30 and 20 ml after adding 50 ml saturated brine solution. The organic phases were collected by passing over $Na_2 SO_4$ in separate bottles and concentrated over rotary evaporator to 10 ml at 35 °C. No further clean-up was required for soil samples as the samples were clear and containing no color.

High pressure liquid chromatography Waters e2695 (e-alliance) was used for the analysis of sulfosulfuron and ethoxysulfuron residues in tomato fruits and soil samples using a reverse phase C-18 column (Sunfire) having dimension 250 x 4.6 (mm) with particle size of 5 μ. Photo dioade array detector (PDA) (model Waters 2998) was used for analysis at wavelength of 245 nm. Solvents used were acetonitril: water (7:3) in isocratic mode at flow rate of 1 ml/min. Injection volume was 10 μl. Under these conditions the retention time for sulfosulfuron and ethoxysulfuron was 1.8 and 1.6 minutes respectively.

Analysis of the pendimethalin and metribuzin was carried out using GCMS tandem mass spectrometry (Agilent 7890 A series with 7000 GCMS/MS detector). The instrument was tuned properly before injecting standards of herbicides. The operating parameters were: injection port temperature: 280 °C. Column: HP-5 (30 m x 0.32 mm i.d. x 0.25 μm film thickness). Oven temperature ramping was: 70 °C (2 min. hold), then increased at 25°C/min to 150 °C (0 min. hold), then increased at 15°C/min to 200 °C (0 min. hold), then increased at 8°C/min to 280 °C (2 min hold). Detector parameters were: source temperature, 230°C; emission current, 35 μA; energy, – 70 eV; repeller voltage, 11 V; ion body, 12 V; extractor, –7.2 V; ion focus, –7.4 V; quadrupole one (MS1) temperature, 150 °C; quadrupole two (MS2) temperature, 150 °C. Gas flow rates: helium (carrier gas), 1 ml/min though column and 2.25 ml/min as collision flow/quench flow, nitrogen (collision cell), 1.15 ml/min. Other parameters: split: pulsed splitless; vacuum (high pressure), 2.23 x 10–5 torr; rough vacuum, 1.51 x 102 torr; injection volume, 2 μl. Under these instrumental conditions, the retention time of pendimethalin and metribuzin was 19.6 and 12.9 minutes, respectively. A calibration curve was plotted for concentration of the standard injected versus area by injecting known concentration of working solutions of different herbicides in HPLC and GCMS/MS and the curve was found linear up to the lowest concentration range 0.01 μg/ml for sulfosulfuron, ethoxysulfuron and 0.001 μg/ml for pendimethalin and metribuzin, respectively.

RESULTS AND DISCUSSION

Weed studies

Broomrape panicles did not appear in any of the treatment up to 90 DAT during both the years of study (data not shown). Application of neem cake at sowing in combination with pendimethalin or metribuzin followed by soil drenching of metalaxyl MZ 0.2% at 20 DAT did not cause any inhibition in broomrape (*Orobanche*) emergence as evident from density of broomrape at 120 DAT and harvest (Table 1). *Orobanche* appeared only in weedy check and neem cake treatments up to 120 DAT. Excellent control of *Orobanche* was obtained with post- or pre-plus post-treatments of sulfosulfuron and ethoxysulfuron when compared with non treated controls. During 2014-15, ethoxysulfuron and sulfosulfuron treated plots remained free from *Orobanche* up to 120 DAT and gave 96.7 to 98.3% control of *Orobanche* up to harvest without any crop suppression. Only 1.7 spikes/m^2 of *Orobanche* were recorded with use of ethoxysuluron 25 g/ha at 60 and 90 DAT but during 2015-16, *Orobanche* stalks to the tune of 0.67-4.0 panicles/m^2 appeared in various herbicide treatments, which was significantly less than untreated control. Sulfosulfuron is registered for broomrape control in Israel in tomato, so was no damage reduction was expected in tomato yields. Weed control efficiency (WCE) in various herbicide treatments calculated on the basis of fresh weight of bromrape spikes varied from 96.2 - 97.7% in 2014-15 where as it was 85.2 - 89.2% during 2015-16. These results were in accordance with findings of Plakhine *et al.* (2001), Eizenberg *et al.* (2003) and Eizenberg *et al.* (2007) who reported effective control of broom rape in tomato with post-emergence use of sulfosulfuron at 37.5 and 75.0 g/ha. Length of broom rape spikes emerged at 120 DAT and harvest varied significantly among different treatments. Maximum spike length (13.9 - 15.2 cms) was recorded with use of neem cake 200 kg/ha either alone or in combination with pendimethalin 1.0 kg/ha at 3 DAP and soil drenching of metalaxyl MZ 0.2% at 20 DAT, which was significantly higher than ethoxysulfuron and sulfosulfuron treatments. Broom rape spikes which emerged at harvest or 120 DAT in ethoxysulfuron and sulfosulfuron treatments were very weak and small sized.

Crop studies

Treatments of ethoxysulfuron 25 g/ha (pre-emergence) were more phytotoxic than post-emergence and tomato exhibited severe growth reduction. Minor developmental delay in tomato was observed with ethoxysulfuron applied pre-emergence or 30 DAT at 25 g/ha. This delay was attributed to the herbicides and not to Egyptian broomrape (visual observation) but plants recovered upon maturity. No damage was observed to tomato plant with use of post-emergence application of either sulfosulfuron or ethoxysulfuron (Table 2). Ethoxysulfuron 25 g/ha (pre-emergence) and 50 g/ha at 45 DAT and ethoxysulfuron 25 g/ha (pre-emergence) *fb* 50 g/ha as 30 and 60 DAT treatments although proved very effective against *Orobanche* but caused 13.3-28.3% suppression in crop growth, which had reflection on plant height, number of fruits/plant and total fruit yield of tomato. During both the years, maximum fruit yield (18.7 and 20.6 t/ha) was recorded from use of sulfosulfuron 50 g/ha at 60 and 90 DAT, respectively, which was at par with ethoxysulfuron 25 g/ha at 60 and 90 DAT, ethoxysulfuron 25 g/ha at 30 and 60 DAT, ethoxysulfuron 25 g/ha at 45 DAT *fb* 50 g/ha 90 DAT and sulfosulfuron 25 g/ha at 60 and 90 DAT, which was 46 - 58% higher than untreated check (Table 2). Panicles which emerged with ethoxysulfuron and sulfosulfuron treatments were weak and length of these panicles was significantly less than neem cake, metalaxyl, pendimethalin and metribuzin treatments. Maximum B:C ratio (7.89 and 8.81) was obtained with post-emergence use of sulfosulfuron 25 g/ha at 60 and 90 DAT and minimum (4.15 and 3.82) with use of neem cake 200 kg/ha at sowing *fb* metribuzin *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT. These findings were in accordance with those of Dinesha *et al.* (2012) who reported excellent efficacy of sulfosulfuron 75 g/ha at 30 DAT in preventing the development of broomrape and reducing the seed inoculum potential in the soil by registering significantly lowest broomrape number, spike height, spike dry weight with higher broomrape control efficiency, which also accounted for higher tomato plant height, number of branches, leaf area/ plant at harvest, higher fruit weight/plant and fruit yield of tomato in Karnataka state of India.

Residue studies

Table 1. Effect of different weed control measures on *Orobanche* population, WCE, visual control and spike length (2014-15 and 2015-16)

Treatment	Number of broomrape spikes/m^2				WCE (broomrape) (%)		Broom rape control (%)				Broomrape spike length (cms)	
	120 DAP		Harvest		120 DAP		120 DAP		Harvest			
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Neem cake 200 kg/ha at sowing *fb* pendimethalin 1.0 kg/ha at 3 DAT*fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	5.1 (25)	5.7 (32)	6.2 (38)	6.0 (36)	7.9	9.9	18 (10)	18 .4 (10)	12.9 (5.0)	12.9 (5.0)	15.2	14.7
Neem cake 200 kg/ha at sowing *fb* metribuzin 0.5 kg/ha pre-em, 3 DAT*fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	5.8 (32.7)	6.2 (38)	6.4 (40)	6.8 (46)	4.7	2.5	0 (0)	15.9 (8)	0 (0)	0 (0)	13.9	15.2
Neem cake 200 kg/ha at sowing *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	5.2 (26.3)	6.5 (41.2)	6.2 (37.3)	6.5 (41.9)	6.2	-4.9	0(0)	0(0)	15.6 (7.3)	0 (0)	14.8	14.8
Ethoxysulfuron 25 g/ha (PRE) and 50 g/ha at 45 DAT	1 (0)	2.6 (5.7)	2.2 (3.7)	2.9 (7.8)	95.2	88.5	90 (100)	63.5 (80)	79.5 (95)	53.7 (65)	5.8	6.3
Ethoxysulfuron 25 g/ha (PRE) *fb* 50 g/ha as 30 and 60 DAT	1 (0)	3.0 (8)	1.7 (2.3)	2.0 (3.2)	96.3	89.9	90 (100)	67.4 (85)	82.3 (97.3)	65.2 (82.3)	8.1	8.3
Ethoxysulfuron 25 g/ha at 30 and 60 DAT	1 (0)	2.3 (4.3)	2.2 (4)	3.0 (8.3)	96.0	85.2	90 (100)	59.6 (75)	81.4 (96.7)	56.8 (70)	7.0	7.6
Ethoxysulfuron 25 g/ha at 45 DAT *fb* 50 g/ha 90 DAT	1 (0)	1(0)	1.8 (2.7)	2.0 (3.0)	96.6	88.9	90 (100)	69.5 (88)	85.7 (98.3)	67.4 (85)	7.7	8.2
Ethoxysulfuron 25 g/ha at 60 and 90 DAT	1.6 (1.7)	2.2 (3.8)	1.9 (2.7)	2.4 (4.8)	97.0	89.2	81.4 (96.7)	74.8 (90)	83.8 (96.7)	59.8 (75)	7.4	8.0
Sulfosulfuron 50 g/ha at 60 and 90 DAT	1 (0)	1.5 (1.3)	1.3 (0.67)	1.8 (2.1)	97.7	88.3	90 (100)	75 (90)	85.7 (98.3)	71.9 (90)	7.2	7.8
Sulfosulfuron 25 g/ha at 60 and 90 DAT	1 (0)	1.6 (1.7)	1.7 (2.3)	1.5 (2.3)	96.8	87.6	90 (100)	65.4 (82.7)	82.3 (97.3)	60.1 (75)	8.5	6.8
Weedy check	6 (35)	6.1 (36.3)	6.4 (40)	6.8 (46)	0	0	0 (0)	0(0)	0(0)	0	14.1	15.9
LSD (P=0.05)	0.4	0.4	0.79	0.84			4.9	10.7	9.6	3.6	0.4	1.
CV(%)	8.9	8.9	12.7	11.3			5.1	13.4	10.7	5.1	2.3	

*Original figures in parentheses related to *Orobanche* density were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis. Values on *Orobanche* control were subjected to arc sine transformation before statistical analysis. Broom rape did not emerge above ground up to 90 DAP so no data was generated; PRE-Pre-emergence

Residues of sulfosulfuron, ethoxysulfuron or any of the herbicide at any dose and time of application did not cause any adverse on succeeding sorghum crop as is evident from number of plants/ meter row length, plant height and sorghum yield at 45 DAT (Table 3). Deep ploughing of field after harvest of tomato and 2 months interval between tomato harvest and sorghum sowing might be responsible for dissipation of sulfosulfuron from soil. These observations are in accordance with findings of Sondhia (2008) where even sulfosulfuron residues were not observed after wheat harvest.

Table 2. Effect of different weed control measures on plant height, crop toxicity and fruit yield of tomato (2014-15 and 2015-16)

Treatment	Plant height (cm)		Crop phytotoxicity (%) 20 DAT		80 DAT		Harvest		No. of fruits/ plant		Fruit yield (t/ha)		B:C	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Neem cake 200 kg/ha at sowing *fb* pendimethalin 1.0 kg/ha at 3 DAT *fb* soil drenching of metalaxyl MZ 0.2 % at 20 DAT	37.2	40.5	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	18.0	16.7	10.49	11.20	4.43	4.66
Neem cake 200 kg/ha at sowing *fb* metribuzin 0.5 kg/ha pre-em, 3 DAT *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	36.6	39.8	28.8 (23.3)	31.5 (27.7)	0 (0)	0(0)	0(0)	0(0)	15.3	16.0	9.73	9.10	4.15	3.82
Neem cake 200 kg/ha at sowing *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	35.3	38.0	0(0)	0(0)	0 (0)	0(0)	0(0)	0(0)	15.7	16.3	9.51	10.31	4.17	4.46
Ethoxysulfuron 25 g/ha (PRE) and 50 g/ha at 45 DAT	34.7	35.9	32.1 (28.3)	29.9 (25)	27.7 (21.7)	25.6 (18.7)	21.3 (13.3)	23.6 (15.7)	19.7	20.6	13.13	13.50	5.35	5.43
Ethoxysulfuron 25 g/ha (PRE) *fb* 50 g/ha as 30 and 60 DAT	36.6	36.2	34.2 (31.7)	36.2 (35.3)	32.1 (28.3)	33.1 (30.3)	32.1 (28.3)	30.6 (25.7)	17.7	19.0	12.52	13.85	4.76	5.20
Ethoxysulfuron 25 g/ha at 30 and 60 DAT	41.0	42.8	10.4 (5)	12.9 (5)	0 (0)	0(0)	0(0)	0(0)	24.0	26.4	17.13	16.84	7.22	7.00
Ethoxysulfuron 25 g/ha at 45 DAT *fb* 50 g/ha 90 DAT	40.8	41.9	10.4 (5)	12.9 (5)	0 (0)	0(0)	0(0)	0(0)	25.0	27.9	17.77	19.20	7.49	7.98
Ethoxysulfuron 25 g/ha at 60 and 90 DAT	39.7	41.7	0(0)	0(0)	12.9 (5.0)	0(0)	0(0)	0(0)	26.3	29.2	18.19	19.95	7.67	8.29
Sulfosulfuron 50 g/ha at 60 and 90 DAT	40.5	42.9	0 (0)	0(0)	0 (0)	0(0)	0(0)	0(0)	27.0	28.7	18.74	20.56	7.89	8.81
Sulfosulfuron 25 g/ha at 60 and 90 DAT	40.7	42.5	0 (0)	0(0)	0 (0)	0(0)	0(0)	0(0)	25.7	27.0	18.12	19.7	7.75	8.25
Weedy check	37.0	37.5	0 (0)	0(0)	0 (0)	0(0)	0(0)	0(0)	14.0	13.3	9.68	8.64	4.40	3.87
LSD(P=0.05)	0.8	1.2	6.7	2.6	1.6	1.7	1.8	2.0	2.7	2.1	0.77	2.1	-	-
CV(%)	3.5	2.6	30.2	13.3	12.4	18.7	18.9	23.9	7.7	10.2	3.32	5.6	-	-

Values on crop phytotoxicity were subjected to arc sine transformation before statistical analysis; PRE-Pre-emergence

Table 3. Residual effect of different herbicides applied in tomato on succeeding sorghum crop at 45 DAT

Treatment	No. of plants/m.r.l.		Plant height (cm)		Green fodder yield (t/ha)	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Neem cake 200 kg/ha at sowing *fb* pendimethalin 1.0 kg/ha at 3 DAT *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	20	24	144	134	38.9	36.8
Neem cake 200 kg/ha at sowing *fb* metribuzin 0.5 kg/ha pre-em, 3 DAT *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	18	24	142	132	38.4	36.5
Neem cake 200 kg/ha at sowing *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAT	19	26	144	134	38.0	36.8
Ethoxysulfuron 25 g/ha (PRE) and 50 g/ha at 45 DAT	18	28	145	135	37.4	37.8
Ethoxysulfuron 25 g/ha (PRE) *fb* 50 g/ha as 30 and 60 DAT	20	26	144	136	37.4	36.8
Ethoxysulfuron 25 g/ha at 30 and 60 DAT	19	24	142	132	38.0	37.0
Ethoxysulfuron 25 g/ha at 45 DAT *fb* 50 g/ha 90 DAT	18	27	145	134	37.8	36.2
Ethoxysulfuron 25 g/ha at 60 and 90 DAT	20	28	142	130	37.8	36.4
Sulfosulfuron 50 g/ha at 60 and 90 DAT	18	26	144	132	38.2	36.8
Sulfosulfuron 25 g/ha at 60 and 90 DAT	19	25	144	135	37.8	36.6
Weedy check	18	26	146	134	37.4	36.4
LSD (P=0.05)	NS	NS	NS	NS	NS	NS

m.r.l. - Meter row length

Table 4. Percent recovery of different herbicides in tomato and soil

Herbicides	Average* recovery (%)±SD			
	Tomato		Soil	
	Fortification level (0.01 mg/kg)	Fortification level (0.05 mg/kg)	Fortification level (0.01 mg/kg)	Fortification level (0.05 mg/kg)
Sulfosulfuron	81.92±2.65	88.95±1.15	91.30±2.95	92.27±1.25
Ethoxysulfuron	84.66±2.40	86.31±1.32	83.42±1.27	89.62±3.70
Pendimethalin	84.22±3.11	86.60±2.45	88.41±3.60	90.23±2.56
Metribuzin	81.16±2.41	85.40±2.01	85.70±2.45	87.62±2.10

*Average of three replicates

Herbicides residues in soil and tomato fruit: Recovery experiments were carried out to check the validity of the method in soil and tomato fruit samples by fortifying the control samples of each matrix at 0.01 mg/kg and 0.05 mg/kg level in triplicate. Per cent recoveries in all the samples of soil, and tomato fruit were greater than 80 (Table 4), therefore, no correction factor was needed for calculation of residues. It was observed that none of the samples of soil and tomato were having residues of any of the applied herbicides above detection limit of 0.01 µg/ml (in case of sulfosulfuron, ethoxysulufron) and 0.001 µg/ml (in case of pendimethalin and metribuzin). These results also corroborate with the finding of Singh and Kulshresthatha (2007) who studied the dissipation of sulfosulfuron and observed that the dissipation followed first-order rate kinetics and dissipated with a half-life of 5.4–6.3 days. After harvest, field soil was used for conducting a pot experiment with bottle gourd (*Lagenaria siceraria*) as test plants to study the carry over effect of sulfosulfuron. No phytotoxicity was observed to bottle gourd in pot experiment with harvest soil. This shows that the persistence of sulfonylurea residues at harvest is almost negligible. Sondhia (2008) also observed that sulfosulfuron degraded rapidly in soil and was not detected in soil, wheat grains and straw at harvest.

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