Research Article

Evaluating the Efficacy of Thifensulfuron- Methyl Herbicide in Soybean for Weeds Control

Masoumeh Younesabadi[1]*, Parviz Sharifi Ziveh[2] and Sepideh Hatami[3]

[1]Plant Protection Research Department, Golestan Agricultural and Natural Resources Research and Education Center, AREEO, Gorgan, Iran; [2]Plant Protection Research Department, Ardabil Agricultural and Natural Resources Research and Education Center, AREEO, Moghan, Iran; [3]Plant Protection Research Department, West Azarbaijan Agricultural and Natural Resources Research and Education Center, AREEO, Urmia, Iran.

Abstract | In order to evaluate the effectiveness of thifensulfuron-methyl herbicide on broad-leaved weeds in soybean, an experiment was conducted in RCBD with three replications in Golestan, Ardabil and West Azarbaijan provinces in Iran in 2020. The treatments were: trifluralin (Treflan 2.5 L ha^{-1}) as pre plant, bentazon (Basagran 1.5 L ha^{-1}) as post-emergence, thifensulfuron-methyl (15, 30, 45 and 60 g ha^{-1}) and imazethapyr (Pursuit 0.8 L ha^{-1}) as pre-emergence, and weed free treatment. Weed density was measured at 30 days after treatment and weed dry weight was measured before soybean harvesting. Data were analysed with SAS 9.2 and means comparison was done by LSD at p=0.05. Based on the results, the highest weed control efficiency (WCE) and weed control index (WCI), after hand weeding treatment (weed free), was observed in 45 and 60 g ha^{-1} of thifensulfuron-methyl in Golestan and Ardabil. In West Azarbaijan, similar results were observed for all weeds except *Xanthium struamarium,* which was controlled by bentazon better than the other treatments. The highest seed yield was obtained by thifensulfuron-methyl 45 g ha^{-1}, being at par with hand weeding (weed free) and thifensulfuron-methyl 60 g ha^{-1}. The highest number of pods/ plant and seeds/pod were obtained by 60 g ha^{-1} of thifensulfuron-methyl. Visual observation showed no herbicide-burning effects on soybean crop by thifensulfuron-methyl in Ardabil, but 5-10 % phytotoxicity was caused by 60 g ha^{-1} of thifensulfuron-methyl in Golestan and and West Azarbaijan province, which recovered back after about 2 weeks. Based on the results of this experiment, application of 45-60 g ha^{-1} of thifensulfuron-methyl can be recommended for the control of broad-leaved weeds in soybean crop.

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***Correspondence** | Masoumeh Younesabadi, Plant Protection Research Department, Golestan Agricultural and Natural Resources Research and Education Center, AREEO, Gorgan, Iran; **Email:** myounesabadi@yahoo.com, myounesabadi8@gmail.com, m.younesabadi@areeo.ac.ir
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Introduction

Due to its slow growth rate, soybean has little competitive ability against weeds in the early growing season. Critical period of weed control has been reported from 26 to 63 days after sowing (Keramati *et al*., 2008). Hrusti´c *et al*. (1998) showed that soybean yield decreased by about 25 to 30% if weeds were removed late in the season. At the highest weed density levels, this economic loss may reach as high as 80% (Aghaalikhani and Kariminejad, 2005). It is anticipated that manual weeding (weed free) increased the production cost about 40-60% (Nasrin *et al.*, 2016). Despite some environmental concerns related to the use of herbicides, farmers are more inclined to opt chemical weed control chiefly due to the shortages of labour and high manpower costs. Although a number of herbicides are available to control weeds in soybean world over, but in Iran only a limited number of herbicides, such as trifluralin, ethalfluralin, dinitramine, metribuzin, bentazon and Storm^R (bentazon 29.2% + acifluorfen 13.4%) have been registered for this purpose. Trifluralin inhibits most weed seeds germination, but this herbicide is unable to control the weeds of the solanaceae family. Abbasi *et al.* (2005) reported that trifluralin + bentazon and trifluralin + cultivation + a reduced dose of bentazon were the best treatments for weed control in soybean. Younesabadi (2013) showed that the lowest weeds density in soybean was observed in pendimethalin + imazethapyr. For many years, bentazon was the only effective herbicide used to control broadleaf weeds in soybean fields in Iran. Thifensulfuron-methyl with the chemical formula ($C_{12}H_{13}N_5O_6S_2$) is a herbicide from the group of sulfonylureas that differs in mechanism of action from many common herbicides and can be used in management of resistant weeds in soybean fields. Thifensulfuron-methyl (50% SG) was registered by DuPont in 2003 for controlling broad-leaved weeds in wheat, barley, corn and soybean field (Anonymous 2003). This product may be applied to soybean any time after the first trifoliate has expanded fully (Anonymous 2003). Its recommended rate for soybean is 4.3 g of a.i. or 17.2 g of Pinacell commercial product (25% DF) (Anonymous 2003). This herbicide can control some weeds such as *Amaranthus* sp., *A. theophrasti*, *Chenopodium album*, *Convolvulus arvensis*, *Xanthium strumarium* (Brown *et al.*, 1993). Since this herbicide is rapidly degraded by soil microorganisms, it has a short half life, so the treated soil can be replanted 45 days after herbicide application (Brown *et al.*, 1993). The mechanism of its selectivity is the rapid metabolic inactivation of the herbicide in soybean foliage (Brown *et al.*, 1993). Hart and Roskamp (1998) showed that the use of bentazon in combination with the thifensulfuron-methyl herbicide would reduce phytotoxicity effects of thifensulfuron-methyl on soybean. Green (1991) showed that *Amaranthus* sp. is well controlled with 2 g ha^{-1} of thifensulfuron-methyl, but the full dose of this herbicide (5 g ha^{-1}) is needed to control *A. theophrasti*. His studies also showed that 4 g of thifensulfuron-methyl can be used to control *C. album*, but 14 g is needed for *X. strumarium*. The required dose of thifensulfuron-methyl in controlling *X. strumarium* and *C.album* can be reduced by combining it with the chlorimurone. Meseldzija *et al.* (2020) showed that the greatest reduction in the number of weeds was observed when a combination of metribuzin + S-metolachlor + imazamox + oxasulfuron + thifensulfuron-methyl was used in soybean fields. Soybean yield increased 1.91 times compared to the control by using this treatment. Application of a split dosage of imazamax + oxasulfuron + thifensulfuron-methyl had good efficiency for weed control in soybean. Thifensulfuron-methyl (68.2%) + metsulfuron-methyl (6.8%) is a new POST herbicide used to control broad-leaved weeds in wheat, barley, oats and triticale in Australia (Arends and Peg, 1990). Thifensulfuron-methyl (3.27 g ha^{-1}) combined with metsulfuron-methyl (7.2 g ha^{-1}) could be used to control *Polygonum convolvulus* (Arends and Peg, 1990). Pre-planting application of S-metolachlor in combination with metribuzin followed by thifensulfuron-methyl controlled atrazine-resistant *C. album* weed more than 90% in tomatoes (Robinson *et al.*, 2006). In this study, the efficiency of the thifensulfuron-methyl (Harmony product 75% WG) of China's Anhui Fengle Agrochemical Company in controlling broad-leaved weeds of soybean fields was investigated. Based on company suggestion this product should be applied after planting and before crop emergence. It is forbidden to use during soy season (Anhui Fenhle Agrochemical Co., Ltd., 2019). This product is not recommended for use on sand, windy sand, low-lying land and high alkalin soil (Anhui Fenhle Agrochemical Co., Ltd., 2019).

This herbicide can control some weeds such as *Salvia* sp., *Phacelia* sp., *Sorghum* sp., *Solanum nigrum*, *Xanthium* sp., *Chloracantha* sp., *Bidense* sp., *Fructus sinensis*, *Kochia scoparia*, *Salsola* sp., *Boehmeria* sp., *Symphytum* sp. (Anhui Fenhle Agrochemical Co., Ltd., 2019). The aim of this study was to achieve herbicides with a wider weed control spectrum and different mechanism of action from the common herbicides in soybean fields.

Materials and Methods

In order to evaluate the thifensulfuron-methyl

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Table 1: *Characteristics of the experimental locations.*

Province	City	Agricultural research station	Longitude (E)	Latitude (N)	Height above mean sea level (m)	soil texture	Soil organic matter (%)	pH	previous crop
Golestan	Gorgan	Gorgan	47° 25'	39° 23'	72.8	clay	0.9	7.8	wheat
Ardabil	Moghan	Parsabad	54° 25'	36° 54'	5.5	Silty-clay	1.1	7.7	wheat
West-Azarbaijan	Urmia	Saatloo	45° 03'	33° 37'	1320	Clay-sand	0.8	7.7	wheat

(Harmony 75% WG) herbicide for soybean weed control, an experiment was conducted in a Randomized Complete Block Design with 8 treatments and 4 replications at 3 locations in Iran (Tables 1 and 2) during 2020. The experimental treatments (8) comprised of trifluralin herbicide (Treflan 48% EC) @ 2.5 L ha^{-1} (incorporated with soil, immediately before planting), thifensulfuron-methyl herbicide (Harmony 75% WG) @ 15, 30, 45 and 60 g ha^{-1} (applied after planting and before crop emergence), imazethapyr herbicide (Pursuit 10% SL) @ 0.8 L ha^{-1} (used after planting and before crop emergence), bentazon herbicide (Basagran 48% SL) @ 2.5 L ha^{-1} (used at 4-6 leaf stage of weeds) and weed-free check. The herbicides were applied by a back sprayer with a blowing nozzle at 250 kPa pressure. Each plot size was 2 m × 6 m. The first four meters of each experimental plot was considered as treatment and the upper part (last two meters) as the control of the same plot and was not subjected to weeding or chemical control in any way. A quadrate of 50 cm × 50 cm was fixed in both parts of each experimental plot and weed species counted 30 days after sowing in each quadrate. Before soybean harvesting, all weed species of these fixed plots were identified, counted and finally foamed and then placed in the oven and their dry weight measured after 72 hours at 75 °C. Weed control efficiency (WCE) and weed control index (WCI) were calculated by Equations 1 and 2 (Das, 2008).

$$\text{Weed control efficiency } (WCE) = ((WDc-WDt) * 100)/WDc \quad ....(1)$$

$$\text{Weed control index } (WCI) = ((WDMc-WDMt) * 100)/WDMc \quad ....(2)$$

Whereas WDc is the weed density (number/m^2) in control plot; WDt is the weed density (numbers/m^2) in treated plot. WDMc is weed dry weight in control plot (g/m^2); WDMt is the weed dry weight (g/m^2) in treated plot (Das, 2008).

At harvest, 5 plants per plot were randomly selected and yield components measured. For yield, two 0.5 square meter quadrate per plot were harvested and seed and biomass yield determined. Soybean phytotoxicity evaluation was performed with the standard method proposed by European Weed Research Council (EWRC) (Dear *et al*., 2003). The percentage of changes compared to the control treatments were calculated and ANOVA performed using PROC GLM procedure of SAS, after normalizing the data. Dependent variable means were compared using LSD test at 5% probability.

Table 2: *Physical and chemical characteristics of experimental soil at 0-30 cm depth at each location.*

Soil characteristic	Golestan province	Ardabil province	West Azarbaijan province
pH	7.3	7.7	7.63
CEC (dS m^{-1})	1.27	2.4	1.78
Organic carbon (%)	1.1	1.2	1.1
Total nitrogen (%)	0.11	0.21	0.19
Available phosphorus (ppm)	4.8	14.8	4.2
Available potassium (ppm)	220	420	280
Bulk density (g cm^{-3})	1.41	1.40	1.41
Soil texture			
Clay %	30	40.7	30
Silt %	52	30.9	26
Sand %	18	28.4	44
Water content			
Saturation point (%) (θm)	52.2	43	50
Field capacity (%)(θm)	27	24	27
Wilting point (%)(θm)	12.3	17	11.2

Results and Discussion

WCE and WCI in Golestan province

Portulacca oleracea, *C. arvensis*, *Cyperus rotundus*, *Echinochloa colonum* and *Sorghum halepense* were the most important weeds in Gorgan agricultural research station. The weed density and dry weight and their changes compared to the control treatment (WCE and WCI) were affected by the treatments

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significantly. The lowest weed density or the highest dry weight reduction compared to the corresponding control in *C. arvensis* and *C. rotundus* density after weeding (weed free) treatment was observed at 60 g ha-1 of thifensulfuron-methyl herbicide, which was not different from 45 and 30 g ha-1 thifensulfuron-methyl treatments statistically (Table 3). The highest density of these weeds was observed in the imazethapyr treatment, which showed a decrease of 15 % compared to the corresponding control. Regarding *P. oleracea,* the highest dry matter reduction percentage was observed at all the three doses thifensulfuron-methyl of (60, 40 and 30 g ha-1). The lowest percentage of weed control was observed in trifluralin and bentazon treatments (Table 3).

Soybean yield components and yield in Golestan province

Seed and biomass yield and the number of pods per plant were affected significantly by the herbicide treatments, but 100-seed weight and the number of seeds per plant were not affected by the treatments. The highest yield was obtained at 45 gha-1 of thifensulfuron-methyl, which was not statistically significant with weeding (weed free) and 60 g ha-1 thifensulfuron-methyl herbicide (Table 4). The lowest yield was obtained in bentazon, which was not significantly different from trifluralin and thifensulfuron-methyl at 15 and 30 g ha-1. The highest number of pods per plant was observed at 45 g ha-1 thifensulfuron-methyl. Similarly, thifensulfuron-methyl treatment at 45 gha-1 caused the highest increase in seed and biological yield (Table 4).

In general, the results of Gorgan city experimnt showed that thifensulfuron-methyl was reduced the *C. arvensis* density by about 60-85% and 89-96% at low and high doses, respectively. This herbicide reduced the density of C.rotundus by about 49-83% and 86-88% at low and high doses respevtively. The density of *P. oleracea* reduced by about 51-96% at low doses and 99% at high doses of this herbicide too (Table 5).

Table 3: *Effect of treatments on weed control efficiency (WCE %) and weed control index (WCI %) in soybean at Gorgan Agricultural Station.*

Treatment	*C. arvensis*		*C. rotundus*		*P. oleraceae*	
	WCE (%)	WCI (%)	WCE (%)	WCI (%)	WCE (%)	WCI (%)
Trifluralin 2.5 L ha-1	55.8ab	66.6a	45.6bc	57.0ab	18.3b	50.2ab
Thifensulfuron-methyl 15 g ha-1	59.7ab	57.8a	46.8c	58.8ab	50.0ab	50.0ab
Thifensulfuron-methyl 30 g ha-1	79.1a	90.4a	82.6ab	87.9a	96. 0a	99.4a
Thifensulfuron-methyl 45 g ha-1	83.3a	95.1a	85.7a	89.7a	100.0a	100.0a
Thifensulfuron-methyl 60 g ha-1	91.7a	97.2a	88.5a	98.3a	100.0a	100.0a
Imazethapyr 0.8 L ha-1	15.0b	15.2b	0. 0d	0.0c	50.0ab	50.0ab
Bentazon 2.5 L ha-1	43.7ab	71.5a	29.6c	40.1b	33.3b	30.2b
Manual weeding (weed free)	100a	100a	100a	100a	100a	100a

The treatments within each column having common letters are not statistically significant at the 5% level of significance.

Table 4: *Effect of treatments on seed yield components, and seed and biological yields of soybean at Gorgan Agricultural Station.*

Treatment	Pod number/ plant	Seed number/ pod	100-seed weight (g)	Yield		Biological yield	
				kg ha-1	Increase % over control	kg ha-1	Increase % over control
Trifluralin 2.5 L ha-1	15.0g	1.7bc	18.3a	1401e	19.9c	6274cd	1.3e
Thifensulfuron-methyl 15 g ha-1	18.1fg	1.5c	18.76a	1565de	43.9abc	7843a	10.6c
Thifensulfuron-methyl 30 g ha-1	30.3cd	2.9a	18.9a	1819be	39.7bc	7092abc	17.7b
Thifensulfuron-methyl 45 g ha-1	50.1a	2.2abc	20.1a	2205a	64.3a	6768bcd	26.7a
Thifensulfuron-methyl 60 g ha-1	34.6c	2.7ab	18.2a	2031ab	49.8ab	5859d	7.8cd
Imazethapyr 0.8 L ha-1	25.0de	2.2abc	18.6a	1634cd	29.9bc	7369ab	3.9de
Bentazon 2.5 L ha-1	23.9ef	2.2abc	19.6a	1361e	28.2bc	4933e	0e
Manual weeding (weed free)	42.5b	2.5b	19.3a	2031ab	81.5a	7092abc	12.3bc

The treatments within each column having common letters are not statistically significant at the 5% level of significance.

Table 5: *Soybean and weeds phytotoxicity score based on European Weed Research Council (EWRC) standard method under different treatments at Gorgan Agricultural Station.*

Treatment	Soybean	*C. arvensis*	*C. rotundus*	*P. oleraceae*
Trifluralin 2.5 L ha^{-1}	10	58	48	20
Thifensulfuron-methyl 15 g ha^{-1}	0	60	49	51
Thifensulfuron-methyl 30 g ha^{-1}	0	85	83	96
Thifensulfuron-methyl 45 g ha^{-1}	0	89	86	99
Thifensulfuron-methyl 60 g ha^{-1}	6	96	88	99
Imazethapyr 0.8 L ha^{-1}	0	15	3	52
Bentazon 2.5 L ha^{-1}	9	58	36	38
Manual weeding (weed free)	0	100	100	100

Table 6: *Effect of treatments on weed control efficiency (WCE %) and weed control index (WCI %) in soybean at Parsabad Agricultural Station.*

Treatment	*A. retroflexuss*		*A. blitoides*		*A. theophrasti*		*X. strumarium*	
	WCE (%)	WCI (%)	WCE (%)	WCI (%)	WCE (%)	WCI (%)	WCE (%)	WCI (%)
Trifluralin 2.5 L ha^{-1}	37.8[c]	37.5[c]	35.3[d]	28.25[d]	14.8[e]	17.3[e]	61.0[ab]	65.3[a]
Thifensulfuron-methyl 15 g ha^{-1}	93.8[a]	91.3[a]	58.5[c]	56.75[c]	75.3[cd]	77.5[c]	42.0[c]	44.8[b]
Thifensulfuron-methyl 30 g ha^{-1}	97.5[a]	92.3[a]	63.0[c]	62.0[c]	82.8[bc]	84.0[bc]	52.5[bc]	48.5[b]
Thifensulfuron-methyl 45 g ha^{-1}	100[a]	93.8[a]	100[a]	98.0[a]	89.3[ab]	89.8[b]	70.5[a]	71.8[a]
Thifensulfuron-methyl 60 g ha^{-1}	100[a]	96.8[a]	100[a]	100[a]	100[a]	100[a]	76.75[a]	81.0[a]
Imazethapyr 0.8 L ha^{-1}	96.5[a]	95.0[a]	76.0[b]	75.5[b]	63.3[d]	64.5[d]	14.5[d]	42.0[b]
Bentazon 2.5 L ha^{-1}	73.3[b]	75.3[b]	97.8[a]	95.5[a]	62.0[d]	67.5[d]	74.0[a]	76.5[a]
Manual weeding (weed free)	100[a]	100[a]	100[a]	100[a]	100[a]	100[a]	100[a]	100[a]

The treatments within each column having common letters are not statistically significant at the 5% level of significance.

WCE and WCI in Ardabil province

Amaranthus retroflexus, *Amaranthus blitoides*, *Abutilon theophrasti* and *X. strumarium* were the most important weeds in Parsabad agricultural station. The density and dry weight of these weeds was affected by the treatments. The highest reduction percentage in density and dry weight of *A. retroflexus* was observed in weeding (weed free) treatment followed by thifensulfuron-methyl at 45 and 60 g ha^{-1}, respectively (Table 6). The reduction percentage in density and dry weight of *A. retroflexus* in trifluralin and bentazon was significantly lower than other treatments. Brown *et al*. (1993) also showed that this herbicide can control *A. retroflexus*, *A. theophrasti*, *C. album*, *C. arvensis* and *X. strumarium*. In case of *A. blitoides*, 45 and 60 g ha^{-1} thifensulfuron-methyl followed by bentazon, with no significant difference with weeding treatment (weed free) caused the highest reduction percentage in weed density and dry weight. Regarding *A. theophrasti*, 60 g ha^{-1} of thifensulfuron-methyl showed the highest reduction percentage in density and dry weight (Table 6). 30 and 45 g ha^{-1} of thifensulfuron-methyl with 75-89% reduction in density and 78-90% reduction in dry weight were in the next group. Green (1991) showed that Amaranthus weeds were well controlled with 2 g ha^{-1} of thifensulfuron, but the full dose of this herbicide (5 g ha^{-1}) was needed to control *A. theophrasti*. Thifensulfuron-methyl at 60 g ha-1 with no significant difference with bentazon and thifensulfuron-methyl at 45 g ha^{-1} caused the highest reduction percentage of *X. strumarium* dry weight compared to the control, respectively (Table 6). Green (1991) showed that 4 g of thifensulfuron controlled *C. album*, but 14 g of this herbicide was needed to control *X.strumarium*.

Soybean yield components and yield in Ardabil province

In Parsabad, the highest soybean yield was observed in the thifensulfuron-methyl at 60, 45, 30 and 15 g ha^{-1}, respectively (Table 7). There was no significant difference between the treatments in terms of 100-seed weight. All treatments caused 18-40 % increase in yield compared to control. 60 g ha^{-1} of thifensulfuron-methyl had the highest number of pods per plant and number of seeds per pod.

Table 7: *Effect of treatments on seed yield components and seed yield of soybean at Parsabad Agricultural Station.*

Treatment	Pod number/ plant	Seed number/ pod	100- Seed weight (g)	Seed yield	
				kg ha^{-1}	Increase % over control
Trifluralin 2.5 L ha^{-1}	29.2^{c}	1.2^{d}	27.4^{b}	1465^{b}	19.00^{b}
Thifensulfuron-methyl 15 g ha^{-1}	49.0^{b}	1.7^{b}	46.4^{a}	2542^{a}	39.3^{a}
Thifensulfuron-methyl 30 g ha^{-1}	48.9^{b}	1.8^{b}	46.4^{a}	2545^{a}	39.5^{a}
Thifensulfuron-methyl 45 g ha^{-1}	55.1^{a}	2.2^{a}	46.6^{a}	2730^{a}	40.0^{a}
Thifensulfuron-methyl 60 g ha^{-1}	55.1^{a}	2.2^{a}	46.6^{a}	2744^{a}	39.6^{a}
Imazethapyr 0.8 L ha^{-1}	48.1^{b}	1.5^{bc}	45.4^{a}	2425^{a}	33.8^{a}
Bentazon 2.5 L ha^{-1}	47.9^{b}	1.3^{cd}	45.1^{a}	2409^{a}	31.3^{a}
Manual weeding (weed free)	56.6^{a}	2.4^{a}	49.4^{a}	2748^{a}	39.2^{a}

The treatments within each column having common letters are not statistically significant at the 5% level of significance.

Table 8: *Soybean and weeds phytotoxicity score based on European Weed Research Council (EWRC) standard method under different treatments at Parsabad Agricultural Station.*

Treatment	Soybean	*A. retroflexus*	*A. blitoides*	*A. theophrasti*	*X. strumarium*
Trifluralin 2.5 L ha^{-1}	0	35	43	20	58
Thifensulfuron-methyl 15 g ha^{-1}	0	98	68	76	8
Thifensulfuron-methyl 30 g ha^{-1}	0	99	78	84	14
Thifensulfuron-methyl 45 g ha^{-1}	0	100	96	89	29
Thifensulfuron-methyl 60 g ha^{-1}	0	100	99	100	35
Imazethapyr 0.8 L ha^{-1}	0	93	79	70	16
Bentazon 2.5 L ha^{-1}	0	74	95	65	79
Manual weeding (weed free)	0	100	100	100	100

Table 9: *Effect of treatments on weed control efficiency (WCE %) at Saatloo Agricultural Station.*

Treatment	*A. retroflexus*	*A. theophrasti*	*X. strumarium*	*H. trionum*	*C. album*	*S. arvensis*
Trifluralin 2.5 L ha^{-1}	56.8^{e}	52.2^{e}	50.1^{c}	46.9^{d}	66.5^{c}	35.2^{d}
Thifensulfuron-methyl 15 g ha^{-1}	60.5^{de}	60.0^{d}	59.9^{b}	49.9^{c}	53.2^{e}	65.5^{c}
Thifensulfuron-methyl 30 g ha^{-1}	62.4^{d}	71.4^{c}	61.0^{b}	52.4^{c}	62.5^{d}	65.1^{c}
Thifensulfuron-methyl 45 g ha^{-1}	90.2^{a}	89.9^{a}	64.00^{b}	62.6^{b}	85.8^{a}	89.1^{a}
Thifensulfuron-methyl 60 g ha^{-1}	90.1^{a}	89.7^{a}	61.8^{b}	60.5^{b}	87.1	89.5^{a}
Imazethapyr 0.8 L ha^{-1}	69.7^{c}	61.5^{d}	61.9^{b}	61.5^{b}	67.0^{c}	64.5^{c}
Bentazon 2.5 L ha^{-1}	74.6^{b}	81.6^{b}	84.5^{a}	79.7^{a}	75.3^{b}	72.1^{b}
Manual weeding (weed free)	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}	100^{a}

The treatments within each column having common letters are not statistically significant at the 5% level of significance.

In Parsabad, thifensulfuron-methyl at low and high doses showed 98-99% and 100% reduction in the weed density of *A. retroflexus*, and 68-78% and 96-99% reduction in the weed density of *A. blitoides*, respectively. The density of *A. theophrasti* was reduced by 76-84% and 89-100% at low and high doses of thifensulfuron-methyl. Thifensulfuron-methyl herbicides reduced *X. strumarium* density by 8-14%, and 29-35% at low and high doses, respectively (Table 8).

WCE and WCI in West Azarbaijan province

X. strumarium, *A. theophrasti*, *Hibiscus trionum*, *Sinapis arvensis*, *A. retroflexus* and *C. album* were the most important weeds in Saatloo agricultural station. There was a significant difference between the treatments in terms of density and dry weight of mentioned weeds. The highest reduction percentage in *X. strumarium* density was caused by bentazon. Other treatments reduced the weed density by 50-63% compared to the control. *H. trionum* was also controlled more successfully by bentazon than other herbicides (Tables 9 and 10). In the case of *A. theophrasti*, *S. arvensis*, *A. retroflexus* and *C. album*, the thifensulfuron-methyl herbicide treatment at 45 and 60 g ha^{-1} caused the highest reduction percentage in

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Table 10: *Effect of treatments on weed control index (WCI %) in soybean at Saatloo Agricultural Station.*

Treatment	*A. retroflexus*	*A.theophrasti*	*X.strumarium*	*H.trionum*	*C. album*	*S.arvensis*
Trifluralin 2.5 L ha^{-1}	61.2[e]	50.6[f]	44.9[e]	38.4[e]	64.1[d]	36.6[f]
Thifensulfuron-methyl 15 g ha^{-1}	56.8[e]	58.9[d]	56.6[bc]	50.6[d]	51.0[e]	59.1[d]
Thifensulfuron-methyl 30 g ha^{-1}	59.1[de]	64.7[cd]	58.1[bc]	51.8[cd]	55.0[d]	59.3[d]
Thifensulfuron-methyl 45 g ha^{-1}	88.3[a]	86.2[a]	57.6[bc]	58.5[bc]	85.8[a]	88.6[a]
Thifensulfuron-methyl 60 g ha^{-1}	88.6[a]	86.3[a]	54.1[c]	59.9[b]	86.6[a]	89.1[a]
Imazethapyr 0.8 L ha^{-1}	66.7[c]	66.4[c]	64.2[b]	64.0[b]	74.6[b]	63.1[c]
Bentazon 2.5 L ha^{-1}	72.1[b]	78.6[b]	79.2[a]	71.4[a]	73.8[b]	82.8[b]
Manual weeding (weed free)	100[a]	100[a]	100[a]	100[a]	100[a]	100[a]

The treatments within each column having common letters are not statistically significant at the 5% level of significance.

Table 11: *Effect of treatments on seed yield components and seed and biological yields of soybean at Saatloo Agricultural Station.*

Treatment	Pod number/plant	Seed number/ pod	100-Seed weight (g)	Seed yield		Biological yield	
				kg ha^{-1}	Increase% over control	kg ha^{-1}	Increase % over control
Trifluralin 2.5 L ha^{-1}	25.2[d]	1.3[c]	12.6[d]	1374[c]	24.8[f]	1442[e]	25.0[e]
Thifensulfuron-methyl 15 g ha^{-1}	19.1[f]	1.2[c]	11.9[e]	1357[c]	18.1[g]	1334[f]	13.2[f]
Thifensulfuron-methyl 30 g ha^{-1}	24.3[e]	1.3[c]	12.7[d]	1359[c]	37.3[e]	1556[d]	31.5[d]
Thifensulfuron-methyl 45 g ha^{-1}	33.4[b]	1.5[a]	14.8[a]	1822[a]	94.2[b]	1772[a]	87.9[a]
Thifensulfuron-methyl 60 g ha^{-1}	34.7[a]	1.5[a]	15.0[a]	1818[a]	95.2[a]	1766[a]	89.8[a]
Imazethapyr 0.8 L ha^{-1}	2829.0[c]	1.4[bc]	13.2[c]	1760[b]	49.8[d]	1641[c]	45.2[c]
Bentazon 2.5 L ha^{-1}	29.4[c]	1.4[ab]	14.2[b]	1773[b]	70.7[c]	1684[b]	61.9[b]
Manual weeding (weed free)	40.2[a]	1.5[a]	16.6[a]	1811[a]	145.4[a]	1778[a]	135.00[a]

The treatments within each column having common letters are not statistically significant at the 5% level of significance.

weed density compared to the control and there was no statistically significant difference between these two treatments.

Soybean yield components and yield in West Azarbaijan province

Seed and biological yield, number of seeds per pod, number of pods per plant and 100-seed weight were affected by the treatments. The highest seed yield value (1822 kg ha^{-1}) was obtained by 45 g ha^{-1} of thifensulfuron-methyl, which was not statistically significant with weeding (weed free) and 60 g ha^{-1} of thifensulfuron-methyl but the highest increase percentage in yield was observed at 60 g ha^{-1}, which was in same statistical group with thifensulfuron-methyl at 45 g ha^{-1}. The lowest seed yield was obtained in 15 and 30 g ha^{-1} of thifensulfuron-methyl, which was not significantly different from trifluralin (Table 11). The highest number of pods per plant, seeds per pod and 100-seeds weight were obtained in 60 g ha^{-1} thifensulfuron-methyl, which was not significantly different from 45 g ha^{-1} thifensulfuron-methyl (Table 11). The lowest increase percentage in seed and biological yield compared to the control was obtained by the thifensulfuron-methyl at 15 g ha^{-1} (Table 11).

The results of Saatloo agricultural station showed that thifensulfuron-methyl herbicides at low and high doses caused 60% and 95% reduction in weed density of *A. retroflexus* and *C. album*, respectively. This herbicide reduced *H. trionum* density at low and high doses 60% and 75%, respectively. The density of *A. theophrasti* also decreased 83% at low doses of thifensulfuron-methyl and 95% at high doses of this herbicide (Table 12). The density of *X. strumarium* decreased 60% at low doses of thifensulfuron-methyl and 75-95% at high doses of this herbicide. S.arvensis decreased 75% and 95% at low and high doses of this herbicide.

The critical period of crop-weed competition in soybean is between 2–4 weeks after sowing, and weed control during this period is necessary to have an optimal yield. Pre-emergence herbicides, control

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or reduce the population of some problematic broad-leaved weeds, thus increase the control efficiency of post emergence treatments. One of the important advantages of using pre-emergence herbicides is that if the post-emergence treatment is delayed, serious problems are prevented. It seems necessary to introduce herbicides with different modes of action, such as acetolactate synthase (ALS) inhibitor herbicides to delay the occurrence of weed resistance in Iran. A pre-emergence herbicide, such as imazethapyr, is quite effective in controlling the broad-leaved weeds, but unfortunately it is not effective in controlling *C. rotundus* and other perennial weeds (Nasouti *et al*., 2015). Thifensulfuron-methyl is a ALS herbicide from the group of sulfonylureas that differs in mechanism of action from many common herbicides and can be used in management of resistant weeds in soybean fields (Brown, 2010, Brown *et al*., 1993). The effectiveness of herbicides mainly depends on their concentration, and in many cases this is a matter of course for their selectivity. A range of herbicide concentrations is generally recommended to their control in variable growth and environmental conditions and different densities (Mendes, 2024).

The results of the inferential evaluation of the effectiveness of the studied herbicides in the three provinces of Golestan, Ardabil and West Azarbaijan (Table 13) showed that with the application of thifensulfuron-methyl herbicides it is possible to control the broad-leaved weeds of soybean fields in a favorable way. The highest reduction percentage in total weed density and dry weight in the three provinces was observed in thifensulfuron-methyl at 45 and 60 g ha^{-1}. These treatments were significantly superior to other treatments so that the highest yield

Table 12: *Soybean and weeds phytotoxicity score based on European Weed Research Council (EWRC) standard method under different treatments at Saatloo Agricultural Station.*

Treatment	Soybean	*A. retroflexus*	*A. theophrasti*	*X. strumarium*	*H. trionum*	*C. album*	*S. arvensis*
Trifluralin 2.5 L ha^{-1}	0	75	60	60	60	75	60
Thifensulfuron-methyl 15 g ha^{-1}	0	60	83	60	60	60	75
Thifensulfuron-methyl 30 g ha^{-1}	0	60	83	60	60	60	75
Thifensulfuron-methyl 45 g ha^{-1}	0	95	95	75	75	95	95
Thifensulfuron-methyl 60 g ha^{-1}	9	95	95	95	75	95	95
Imazethapyr 0.8 L ha^{-1}	0	75	75	60	60	75	75
Bentazon 2.5 L ha^{-1}	0	95	95	95	95	95	95
Manual weeding (weed free)	0	100	100	100	100	100	100

Table 13: *Inferential evaluation report of the effectiveness of treatments on weed control at Gorgan, Parsabad and Saaltoo Agricultural Stations.*

	Gorgan			Parsabad				Saatloo					
Treatment	*C. arvensis*	*C. rotundus*	*P. oleraceae*	*A. retroflexuss*	*A. blitoides*	*A. theophrasti*	*X.strumarium*	*A. retroflexus*	*A.theophrasti*	*X.strumarium*	*H. trionum*	*C. album*	*S. arvensis*
Trifluralin 2.5 L ha^{-1}	**	*	-	*	*	-	**	***	**	****	**	***	**
Thifensulfuron-methyl 15 g ha^{-1}	**	*	**	****	***	***	-	**	****	**	**	**	***
Thifensulfuron-methyl 30 g ha^{-1}	***	***	****	****	**	***	-	**	****	**	**	**	***
Thifensulfuron-methyl 45 g ha^{-1}	****	****	****	****	****	****	-	****	****	***	***	****	****
Thifensulfuron-methyl 60 g ha^{-1}	****	****	****	****	****	****	*	****	****	****	***	****	****
Imazethapyr 0.8 L ha^{-1}	-	-	**	****	**	**	-	***	***	**	**	***	***
Bentazon 2.5 L ha^{-1}	**	*	*	***	****	**	****	****	****	****	****	****	****
Manual weeding (weed free)	****	**	****	****	****	****	****	****	****	****	****	****	****

(-): less than 30% Control, (*): 30 to 50% of control, (**): 50 to 70% of control, (***): 70 to 85% of control, (****): more than 85% of control.

was obtained in these treatments in all three provinces. In Ardabil, a visual assessment conducted in the middle of the growing season showed no phytotoxicity effects on soybean crop by thifensulfuron-methyl herbicide. In Golestan and west Azarbaijan, thifensulfuron-methyl herbicide at 60 g ha^{-1} caused 5-10% of plant burning in the form of chlorosis on soybean foliage, which was completely overcome after about 2-weeks. The efficacy of the herbicide increased as the herbicide dosage increased and there was a significant difference between the doses. The dose of 60 g per hectare had better control results than the other 3-doses but was at par with 45 g ha^{-1}. The evaluation of soybean yield components in 3-test locations showed that this herbicide in the examined doses, especially at 45 and 60 g ha^{-1} increased soybean yield compared to the uncontrolled treatment, however, 60 g ha^{-1} was in the same statistical group with the weeding treatment (weed free) in most cases.

Conclusions and Recommendations

Based on the results of this study, the application of thifensulfuron-methyl herbicides in the amount of 45-60 g ha^{-1} is recommended for the control of broad-leaved weeds and higher yield in soybean fields in the studied region.

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Novelty Statement

Bentazon and trifluralin herbicides have been used for many years to control weeds in soybean fields in IRAN. Undoubtedly, the repeated use of herbicides leads to problems such as increase in the frequency of resistant weeds populations. One of the most important methods in the management of weed resistance to herbicides is to minimize the continuous use of pesticides whose mechanism of action is similar. Diversification of the herbicide options available to farmers through the introduction of new herbicides with different modes of actions such as Thifensulfuron-methyl can not only delay the formation of resistance in weeds, but also can prevent the reduction of soybean yield and can reduce the production cost by optimally controlling weeds.

Author's Contribution

Masoumeh Younesabadi: Practical performance of experiment in it the field in Golestan province and collected data, data analysis and wrote the paper.
Parviz Sharifi Ziveh: Practical performance of experiment in it the field in Ardabil province and data collection.
Sepideh Hatami: Practical performance of experiment in it the field in West Azarbijan province and data collection.
All Authors contributed equally to the manuscript.

Conflict of interest

The authors have declared no conflicts of interest.

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