SCREENING OF HERBICIDES FOR EFFECTIVE CONTROL OF WEEDS IN SOYBEAN (*Glycine max* L.)

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ABSTRACT

A two-year field study was accomplished at College of Agriculture experimental site, Sargodha in spring seasons of 2018 and 2019 to evaluate the performance of various herbicides to combat weeds in soybean. The study consisted of 8 herbicide treatments including two pre-emergence herbicides (pendimethalin at 489.1 g a.i. ha^{-1}, pendimethalin + S-metolachlor at 731.1 g a.i. ha^{-1}) which were applied immediately after sowing and six post-emergence herbicides (oxyfluorfen at 237.1 g a.i. ha^{-1}, metribuzin at 518.7 g a.i. ha^{-1}, quizalofop-p-ethyl at 148.2 g a.i. ha^{-1}, acetochlor at 741 g a.i. ha^{-1}, halosulfuron at 37 g a.i. ha^{-1}and topramezone at 21.5 g a.i. ha^{-1}) which were used 25 days after sowing. In contrast to control, all herbicides have shown significant decline in weed density (up to 94%) and dry weight (up to 88%); and caused significant increases in plant height (up to 85%), pod bearing branches (up to 77%), number of pods per plant (up to 83%), 100-seed weight (up to 37%) and seed yield (up to 160%) of soybean. Among herbicides, topramezone at 21.5 g a.i ha^{-1} gave significantly the highest (1234 and 1272 kg ha^{-1} in years 2018 and 2019) seed yield of soybean and HEIs (1.28 and 1.03 in year 2018 and 2019, respectively). However, oxyfluorfen at 237.1 g a.i. ha^{-1}, pendimethalin + S-metolachlor at 731.1 g a.i. ha^{-1}, pendimethalin at 489.1 g a.i. ha^{-1}, quizalofop-p-ethyl at 148.2 g a.i. ha^{-1} followed it. The regression analysis depicted a significant negative moderate relationship of soybean seed yield with weed dry weight (R^2 = 0.7074). However, pods per plant was proved to be the main yield component responsible for higher yield of soybean as it had significant positive relationship (R^2 = 0.7012) with seed yield.

Key words: Oxyfluorfen, pre-emergence, post-emergence, seed yield, topramezone, weed density, weed dry weight

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INTRODUCTION

Soybean (*Glycine max* L.) is an essential legume of Fabaceae family, mainly grown for its edible seed. Soybean seed contains about 20-26% carbohydrates, good quantity of Ca, 20-22% oil, 40-45% protein, vitamins and P (Rahman *et al.*, 2011). Soybean products such as flour, oil, soya milk, soya beverages, snacks and chunks have a more shelf life and soybean milk is important for babies with lactose intolerance (Karuga and Gachanja, 2004). In 2019, soybean was cultivated on worldwide scale over an area of 122.68 m ha with 337.41 million metric tons (MMT) production. In soybean production, Brazil is ranked first with 126 MMT production, USA is ranked second with 96 MMT while Argentina is ranked third with 50 MMT (USDA, 2019). In Pakistan, the soybean production was 260 tons and area under soybean crop was 309 hectares in 2017 (USDA, 2017). Pakistan is ranked 16th in soybean oil production and 85% of soybean is produced by Sindh province. However, Pakistan imports approximately 1.0 MMT of soy meal (150 million US$) for livestock and poultry feed (USDA, 2017).

Soybean belongs to Fabaceae family and has a potential to enhance soil nutrient capability and production of upcoming crop (Foyer *et al.*, 2019). Most of the soybean produced in the world is used in soybean meal and oil. Pakistan had greater ability to encounter the native need of soybean by making it a commercial crop. In country, the oil production of soybean during 2017 was raised up to 260 tons in contrast with 240 tons in 2016. The average soybean yield (1.18 tons per hectare) is lower than other soybean producing countries. The reasons of low yield are improper planting time, lack of high yielding varieties, absence of site-specific production technology, lack of local marketing and processing facilities, and higher weed infestation (Anonymous, 2015).

Integrated weed control methods are recommended with pre emergence and post emergence use of herbicide at suitable time (Knezevic, 2014). The soybean production at national level is less than its demand. There are certain problems to obtain maximum yield of soybean in Pakistan. Heavy weed infestation and its poor management is a major problem in soybean as well as other crops of Pakistan. A high yield loss occurs if appropriate weed management is not done. In addition to different biotic and a-biotic factors, weeds also put a negative impact on the average yield of crop. It has been reported that uncontrolled weed infestation caused up to 43% crop yield losses on a worldwide scale (Oerke, 2006). In Pakistan, average production losses due to weeds in many crops are much higher (11.5%) than global average which is 9.5%. Hence, it is extremely important to control weeds for better crop production.

There are different methods of controlling weeds that are being used in Pakistan and in many other countries such as mechanical, biological, cultural and chemical methods (Marwat *et al.*, 2008). Gianessi (2013) reported that herbicide use is the most suitable for managing weeds and is mostly practiced throughout the world. Herbicides are more readily available and cheaper as compared to labor for hand weeding. Due to higher labor cost, the developed nations including the Germany, USA, South Korea and Japan have been moved to herbicide use as this is the only option left. Manual removal of weed is not economically feasible method to control weeds and it is time consuming also. Akter *et al.* (2016) observed statistically similar yield of soybean with chemical weed control in comparison with manual weeding. There is a long list of herbicides that are recommended for weed control in soybean. Some of those are available in markets of Pakistan. Pendimethalin is a pre-emergence herbicide which is a cell division inhibitor (Mallory *et al.*, 2003). It inhibits the tubulin formation and stops the organization of microtubules which results in cell division failure (Chu *et al.*, 2018). Metribuzin was firstly introduced in 1972 with 2, 4-triazin-5(4H) chemical identity (Mallory *et al.*, 2003). It disturbs the electron flow in non-cyclic photophosphorylation. Oxyfluorfen is also photosynthetic inhibitor which inhibits the non-cyclic electron transfer and phosphorylation through photosystem (Pritchard *et al.*, 1980). Acetochlor is a cell division inhibitor whose biochemical name is N-(ethoxymethyl)-2-chloro-6-methylacetanilide; it prevents the protein production (Mamun *et al.*, 2011). Halosulfuron is an amino acid inhibitor herbicide which inhibits the acetolactate synthase, an enzyme which is convoluted in biosynthesis of branched chain amino acid (Schloss, 1990). The S-metolachlor is a cell division inhibitor (Hudetz *et al.*, 1999). Metolachlor is achloroacetamide that contains half-life of 23 days (O'Connell *et al.*, 1998). Quizalofop-*p*-ethyl is inhibitor of acetyl CoA carboxylase belonging to chemical family aryloxyphenoxy (Mallory *et al.*, 2003). Topramezone is a latest herbicide with pyrazole arrangement that is recommended for the eradication of grasses and broadleaf weeds. It blocks the structure of homogentisate, probably throughout inhibition of 4-hydroxyphenylpyruvate dioxygenase (4-HPPD) (Grossmann and Ehrhardt, 2007). It also triggers oxidative stress, disrupted the photosynthetic system and cell membrane permeability (Zhao *et al.*, 2017). To our knowledge, little is known about the best option for chemical weed control in soybean under agro-ecological conditions of Sargodha-Punjab. Thus it has become imperative to suggest the most appropriate herbicide for better management of weeds in soybean with little crop injury. In the light of above mentioned facts, an experiment was proposed to screen herbicides for best weed control in soybean for getting its higher seed yield.

MATERIALS AND METHODS

The field experiment was laid out at experimental area, College of Agriculture, University of Sargodha during spring seasons of years 2018 and 2019 for screening different herbicides for efficient weed management in soybean. Meteorological data about temperature (°C) and rainfall (cm) for growing season (Feb-July, 2018 and 2019) of soybean crop are presented in Figure 1. The seed bed was prepared by running cultivator and rotavator. Soybean variety NARC-2 was sown on 2nd of February 2018 and 16th of February 2019 on flat seed bed at a distance of 30 cm between rows by using hand drill. The seed rate was 100 kg per ha. After emergence, space of 5 cm was maintained by lessening out extra plants. Nitrogen and P_2O_5 were used basally at 25 and 60 kg per ha, correspondingly from diammonium phosphate source. Four irrigations were applied, 1st after three weeks of crop emergence, 2nd at flower initiation, 3rd at pods formation and 4th one was applied at seed formation. The herbicide treatments were pendimethalin at 489.1 g a.i. ha^{-1}, pendimethalin + S-metolachlor at 731.1 g a.i. ha^{-1}, oxyfluorfen at 237.1 g a.i.ha^{-1}, metribuzin at 518.7 g a.i. ha^{-1}, acetochlor at 741 g a.i. ha^{-1}, quizalofop-*p*-ethyl at 148.2 g a.i.ha^{-1}, halosulfuron at 37 g a.i. ha^{-1} and topramezone at 21.5 g a.i. ha^{-1}. Manually kept weed free and weedy treatments were kept as controls. The herbicides were applied with the help of knap sack sprayer by using T-jet nozzle. The calibration of the knap sack sprayer was done by spraying on non-experimental area. The volume of water used for spray was 300 L per ha. Pre-emergence herbicides were sprayed instantly after crop sowing while after-emergence herbicides were sprayed 25 days after sowing. All other agronomic procedures were kept uniform. Both the broadleaf and narrow leaf weeds were present in experiment. The dominant broad leaf weeds were *Parthenium hysterophorus* and *Trianthema portulacastrum* while narrow leaf weeds were *Cynodon dactylon*, *Avena fatua* and *Cyperus rotundus*.

Data collection:

Data related to weeds were recorded near crop harvest (10th July, 2018 and 14th July, 2019) by taking weed sample from 1 m^2 area at two random sites in a single plot. Total weed biomass was measured through harvesting the above ground material of weeds, initially sun dried for two days and then was oven dried at 70^{o}C for 48 hours.

Weed density (m^{-2}): All type of weeds (narrow leaf and broadleaf) were counted from samples and their average was calculated.

Dry weight of weeds (gm^{-2}): The above-ground portion of weeds was harvested and shade dried. Then further drying was carried out in electric oven for 48 hours set at 70°C. The weed dry weight was noted by means of electric balance.

Weed control efficiency (WCE) (%): It was obtained by using equation described by Gupta (1998):

$$WCE = \frac{W1 - W2}{W1} \times 100$$

Where, W_1 = weed dry biomass in weedy check treatment and W_2 = weed dry biomass in herbicide treatment.

Pod bearing branches per plant: At crop ripeness, pod -containing branches were scored from 10 haphazardly selected plants per plot. Then averages were calculated.

Pods per plant: At harvesting, data about pods per plant was obtained from 10 haphazardly chosen plants in each plot. Then averages were recorded.

Plant height (cm): Near crop maturity, data of plant height was recorded from 10 haphazardly chosen plants in single plot. Their heights were recorded by using meter rod and after that average plant height was calculated.

100-seed weight (g): The hundred seeds of soybean from each plot were dried under sun to attain constant weight and then weighed by electric balance.

Seed yield (kg ha^{-1}): The seed was threshed manually from harvested crop. The collected seeds were weighed to get seed yield per plot. It was further transformed into kg per ha seed yield.

Herbicide efficiency index: It was computed by the equation described by Walia (2003):

$$HEI = \frac{YT - YC}{YC} \times 100 \Big/ \frac{DMT}{DMC} \times 100$$

Where

YT = pod yield of herbicide treated plot, YC = pod yield of control plot, DMT = weed dry biomass in herbicide treated plot and DMC = weed dry biomass in control plot.

Fischer's ANOVA procedure was employed to examine the recorded data and least significant difference test at 5% probability level was used to ascertain significantly different means (Steel *et al.*, 1997). Statistical analysis was carried out with the help of Statistix 8.1 computer software.

RESULTS AND DISCUSSION:

Weed density (plants m^{-2}): It is a vital parameter as greater the weed density in a crop, greater will be the yield loss. Data presented in Table1 suggested that weed density in soybean was noticeably affected by using different herbicides. In contrast with control, weed density was substantially reduced by herbicides. In the first year of study, plots where topramezone at 21.5 g a.i. ha^{-1} was applied, weed density was the lowest (38.0 plants m^{-2}). Still, this treatment remained statistically similar to pendimethalin at 489.1 g a.i. ha^{-1}, pendimethalin + S-metolachlor at 731.1 g a.i. ha^{-1} and oxyfluorfen at 237.1 g a.i. ha^{-1}. In 2nd year of experiment, in comparison to weedy check all herbicide have shown markedly reduced weed density (60-84%). Decline of weed density in soybean crop in response to action of different herbicides was probably as a result of toxic effect towards weeds. The outcomes of our research are comparable to that of Green *et al.* (1988) who concluded that the 73% of all weed species present in soybean were controlled by chlorimuron at 31 g ha^{-1}, and metribuzin at a.i. 250 g ha^{-1} controlled almost 85% broadleaf weeds besides morning glory species. Our outcomes are also similar with those of Fickett *et al.* (2013) who advocated that average weed population of up to 10 plants per m^2 reduced the crop yields up to 27% and weed infestation was greatly reduced by using herbicides.

Weed dry weight (g m^{-2}): It is the oven dried weight of weeds which is an indicator of biomass accumulation by weeds and have significant role in the reducing yield of crop. It can be observed from comparison of treatment means (Table 1) that there was significant decrease occurred by application of all herbicides. In both experimental years, among herbicides the lowest weed dry weights (28.7 and 21.4 g m^{-2}) were noted in treatment where topramezone at 21.5 g a.i. ha^{-1} was sprayed. Although, this treatment was found to be statistically similar with all herbicides except metribuzin and acetochlor in year 2018 while only pendimethalin+ S-metolachlor at 731.1 g a.i. ha^{-1} (pre-emergence) and oxyfluorfen at 237.1 g a.i. ha^{-1} were at par with topramezone at 21.5 g a.i. ha^{-1} during 2019. The loss of weed dry weight in response to various herbicide applications may be attributable to weed population decline because higher weed population results in higher dry weight and lower weed density results in lower dry weight. Our outcomes are similar with Hager *et al.* (2003) who determined that efficient reduction in dry biomass of common water hemp (*Amaranthus rudis*) was noted when acifluorfen, fomesafen and lactofen was applied as post-emergence in soybean. Our results also have resemblance with those of Askew *et al.* (1998) which proved that use of the recommended doses of trifluorfen, metolachlor and pendimethalin have shown decline in total dry weight of weeds by 87%, 62% and 67%, correspondingly and ultimately improved the soybean yield.

Weed control efficiency: This parameter indicates percent diminution in weed dry weight over control in response to application of a weed control treatment. In 1st and 2nd year of experiment, the highest weed control efficiency (WCE) (100%) was shown by manual weeding. Among herbicides, topramezone at 21.5 g a.i. ha^{-1} attained the maximum WCEs (88 and 84% in year 2018 and 2019, respectively) that did not vary considerably from all herbicides except acetochlor and metribuzin in year 2018 while it was at par with oxyfluorfen and pendimethalin + S-metolachlor in year 2019. The least WCEs (59 and 60%) were shown by metribuzin during years 2018 and 2019, respectively (Figure 2). The higher values of WCE in year 2018 in comparison to 2019 were probably due to prevalence of higher temperatures in cooler months (February-March) while moderate temperatures in warmer months (April-July) that favored the soybean growth on the expense of weed growth. Tuti and Das (2011) observed up to 83% WCE by metribuzin application in soybean.

Plant height (cm): It is a basic and major morphological trait that is controlled genetically, however it is also affected by water, nutrient and environmental stresses. Vegetative growth is indicated by plant height, higher the vegetative growth more will be plant height. Results concerning plant height of soybean are mentioned in Table 2. The results showed it was significantly increased by all herbicide treatments. Among herbicides, maximum heights of soybean plants (58.5 and 58.0 cm in years 2018 and 2019, respectively) were observed in treatment where topramezone at 21.5 g a.i. ha^{-1} was applied. Although, this treatment was statistically at par with other herbicide treatments regarding plant height of soybean, while minimum plant heights (31.5 and 35.5 cm in year 2018 and 2019, respectively) were noted in weedy check. The improvement in this parameter of soybean crop by the various herbicide applications was the outcome of the reduction in weed infestation. The reduction in weed competition with crop resulted in lower inter-specific competition stress that enhanced soybean growth. The similar results showing 16% increase in plant height of soybean by chemical control due to weed suppression had been presented by Eldabaa *et al.* (2012).

Pod bearing branches plant^{-1}: Pod containing branches of soybean is pivotal yield component. This is because, more the branches a plant produces, more will be number of pods. The data about branches per plant of soybean are provided in Table 2. Results presented clearly indicated that the branches of each soybean plant were markedly increased by herbicide use. Among herbicides, the maximum branches per plant (2.67 and 2.87) were observed in plots where topramezone at 21.5 g a.i. ha^{-1} was applied. Still, this treatment was found to be statistically similar to all herbicide treatments in year 2018 and 2019 except metribuzin in year 2019. While, the minimum branches per plant (1.65 and 1.62 in year 2018 and 2019, respectively) were scored from weedy check. The substantial enhancement in soybean number of branches was probably caused by active handling of weeds by the use of different herbicides. As a result of efficient weed control, competition among plant and weed was decreased and ultimately the growth and number of branches of soybean crop were increased. Our finding are similar to those of Palmer *et al.* (2000) who suggested that when soybean was treated with chlorimuron and acifluorfen increased the number of branches due to decrease in weed competition with soybean crop. An experiment done by Soltani *et al.* (2013) publicized that by using different tank mixture of halosulfuron in white beans significantly increased branches of white bean plants.

Pods per plant: Number of pods produced by a leguminous crop is a vital yield parameter. More the pod number, higher will be its seed yield. Pod number of a plant is a genetically determined trait that is also greatly influence by the environmental stress like weed competition. Data showed in Table 2 unveiled the highest number of pods plant^{-1} (29.5 and 27.9 in year 2018 and 2019, respectively) were achieved in manually weeded plots. While the minimum pods per plant (15.3 in both years) of soybean were observed in control treatment. All the herbicides resulted in substantial enhancement in pods per plant of soybean. Among herbicides, topramezone at 21.5 g a.i. ha^{-1}, oxyfluorfen at 237.1 g a.i. ha^{-1} and pendimethalin + S-metolachlor at 731.1 g a.i. ha^{-1} achieved notably the higher number of pods (24.2-28.1 per plant). The enhancement in soybean pods per plant by use of herbicides was perhaps the response of reduced weed competition stress during flowering stage that increased number of flowers and pods. Our outcomes are similar with the outcomes of Kundu *et al.* (2009) who established that pods plant^{-1} of mung bean were more or highest in treatments where quizalofop-*p*-ethyl at 50 g a.i. ha^{-1} was applied. Singh *et al.* (1996) noted almost 40% reduction in pods per plant of mung bean crop in response to competitions of weeds with crop.

Hundred seed weight (g): The weight of soybean seeds is purely a genetically determined trait that is also somewhat influenced by environment and growing conditions. It affects greatly the final yield. Data concerning 100-seed weight of soybean as impacted by use of different herbicides is presented in Tables 2. The results indicated that as compared to control, use of all herbicides leads to considerable improvement in 100-seed weight of soybean. Among herbicides, maximum 100-seed weights of soybean (13.1 and 14.2 g) in years 2018 and 2019, respectively) were observed in treatment where topramezone at 21.5 g a.i. ha^{-1} was applied which was statistically similar to that observed with other herbicide treatments. The significant increase in this parameter due to herbicides use was probably on account of reduced weed competition stress during seed development phase. These outcomes are similar to previous results of Mitra and Bhattacharya (2005) who suggested that when butachlor is applied along with one hand-weeding, it gave maximum mung bean biomass, increased yield components and crop seed yield. Kulal *et al.* (2017) and Prachand *et al.* (2015) screened various herbicides for efficient weed control in soybean and found pendimethalin among pre-emergence and imazethapyr and quizalofop-*p*-ethyl among post-emergence herbicides to be superior in attaining better weed control and higher seed weight of soybean.

Seed yield (kg ha^{-1}): It is a vital parameter which relies on plant attributes such as pod bearing branches per plant, pods per plant and seed weight. Any reduction in seed yield shows the prevalence of environmental stress. Results about this parameter as impacted by herbicide use are mentioned in Table 2. It is clearly noted from the data that the seed yield was markedly enhanced by various herbicide treatments. The highest seed yield (1391 and 1389 kg ha^{-1} in the year 2018 and 2019, correspondingly) was obtained from manually treated plots. While, minimum (502 and 488 kg ha^{-1} in the year 2018 and 2019, correspondingly) seed yield was noted in control. Among herbicides, plots where topramezone at 21.5 g a.i. ha^{-1} was sprayed, soybean yield was maximum (1234 and 1272 kg ha^{-1} in the year 2018 and 2019, correspondingly) that was statistically dissimilar from all other herbicides. Among other herbicides, oxyfluorfen at 237.1 g a.i. ha^{-1}, pendimethalin + S-metolachlor at 731.1 g a.i. ha^{-1}, pendimethalin at 489.1 g a.i. ha^{-1}, quizalofop-*p*-ethyl at 148.2 g a.i. ha^{-1}, halosulfuron at 37 g a.i. ha^{-1}, acetochlor at 741 g a.i. ha^{-1} and metribuzin at 518.7 g a.i. ha^{-1} followed this treatment in this aspect.

Herbicide efficiency index: Figure 3 depicted the comparative analysis of herbicide efficiency indices (HEIs) of herbicides tested. It is obvious from data that highest HEIs (1.28 and 1.03 in year 2018 and 2019, respectively) were attained by the topramezone at 21.5 g a.i. ha^{-1}. While the oxyfluorfen at 237.1 g a.i. ha^{-1}, pendimethalin + S-metolachlor at 731.1 g a.i. ha^{-1}, pendimethalin at 489.1 g a.i. ha^{-1}, quizalofop-*p*-ethyl at 148.2 g a.i. ha^{-1}, halosulfuron at 37 g a.i. ha^{-1}and acetochlor at 741 g a.i. ha^{-1} followed it in this regard. However, the lowest HEI (0.15 and 0.10 in the years 2018 and 2019, respectively) was given by the metribuzin at 518.7 g a.i. ha^{-1}.

The noteworthy boost-up in seed yield of soybean by herbicide application occurred due to improved growth and development of soybean plants under less weed competition that resulted in enhanced number of pod plant^{-1} and 100-seed weight. The significant moderate negative relationship of soybean seed yield with weed dry weight (R^2 = 0.7074) and positive relationship with pods per plant (R^2 = 0.7012) have been depicted by the regression analysis (Figure 4). The implication of this analysis is that on account of reduced weed infestation by herbicidal use; the pod number was increased that ultimately led to greater seed yield of soybean. Our conclusions are also similar with those of Kim *et al.* (2017) who observed pendimethalin among pre-emergence herbicides to be the most effective in controlling weeds and increasing seed yield of soybean. However, alachlor was found to be phytotoxic against soybean. Palmer *et al.* (2000) suggested that tank mixtures of CGA-277476 (oxasulfuron) at 79 g ha^{-1} with acifluorfen at 210 g a.i. ha^{-1}, fomesafen at 210 g a.i. ha^{-1} and imazaquin at 70 g a.i. ha^{-1} significantly improved the soybean yield over the untreated control. An experiment conducted by Borras *et al.* (2004) proved that reduction in weeds leads to increased assimilation of photosynthates and their translocation towards seed formation. An experiment conducted by Mitra and Bhattacharya (2005) suggested use of butachlor in combination with one manual weeding (35 days after sowing) leads to higher mung bean biomass, yield components and seed yield of crop. Kulal *et al.* (2017) and Prachand *et al.* (2015) screened various herbicides for efficient weed control in soybean and found pendimethalin among pre-emergence and imazethapyr and quizalofop-*p*-ethyl among post-emergence herbicides to be superior in attaining better weed control and higher seed yield of soybean.

CONCLUSION

Under agro-ecological conditions of Sargodha-Punjab, post-emergence use of topramezone at 21.5 g a.i. ha^{-1} is the best choice for chemical weed management as it gave significantly the highest WCE, HEI and seed yield of soybean. Among other post-emergence herbicides, oxyfluorfen at 237.1 g a.i. ha^{-1}, quizalofop-*p*-ethyl at 148.2 g a.i. ha^{-1} and halosulfuron at 37 g a.i. ha^{-1} followed it. However, among pre-emergence herbicides, pendimethalin + S-metolachlor at 731.1 g a.i. ha^{-1} gave the promising results.

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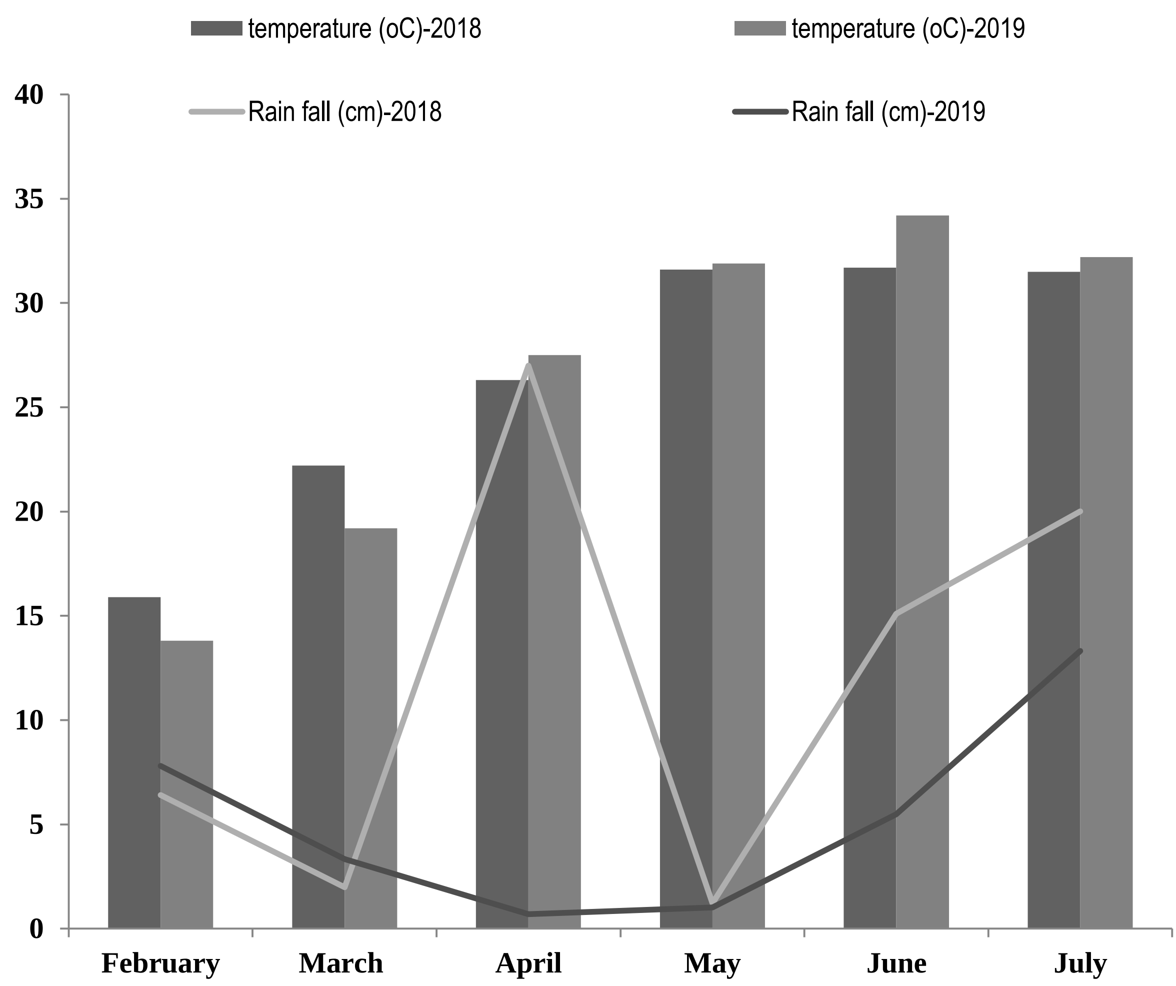

Figure 1: Meteorological data of growing season during years 2018 and 2019

Table 1: Dynamics of weeds under various herbicides

Treatment	Weed density (m^{-2})		Weed dry weight (g)	
	2018	**2019**	**2018**	**2019**
Weedy check (No weed control)	701.0 a	619.7 a	252.4 a	136.9 a
Manual weeding	0.0 e	0.0 c	0.0 e	0.0 e
Pendimethalin (Pre-emergence)	58.3 bcd	52.6 b	51.2 cd	46.1 bc
Pendimethalin + S-metolachlor (Pre-emergence)	47.7 bcd	49.0 b	46.8 d	40.3 bcd
Metribuzin	68.3 b	61.2 b	103.4 b	54.3 b
Oxyfluorfen	45.0 cd	47.0 b	45.9 d	33.1 cd
Quizalofop-*p*-ethyl	63.3 bc	61.6 b	56.2 cd	45.4 bc
Acetochlor	64.3 bc	64.6 b	78.5 bc	48.3 bc
Halosulfuron	60.6 bc	61.0 b	54.2 cd	47.5 bc
Topramezone	38.0 d	43.0 b	28.7 de	21.4 d
LSD (at P < 0.05)	**21.96**	**31.63**	**31.01**	**21.11**

Table 2: Growth and growth attributes of soybean as affected by herbicides

Treatments	Plant height (cm)		Pod bearing branches per plant		Pods per plant		100-seed weight (g)		Seed Yield (kg ha^{-1})	
	2018	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**	**2018**	**2019**
Weedy check (No weed control)	31.5 c	35.5 b	1.65 b	1.62 d	15.3 d	15.3 e	9.5 b	10.3 b	502 e	488 f
Manual weeding	61.0 a	61.8 a	2.70 a	3.10 a	29.5 a	27.9 a	13.7 a	14.4 a	1391 a	1389 a
Pendimethalin (Pre-emergence)	53.0 b	56.3 a	2.60 a	2.70 abc	24.6 c	23.8 cd	12.5 a	13.5 a	937 cd	977 bc
Pendimethalin + S-metolachlor (Pre-emergence)	53.8 b	56.8 a	2.55 a	2.75 abc	25.1 bc	24.2 bcd	12.6 a	13.7 a	1015 c	1043 b
Metribuzin	52.5 b	51.3 a	2.22 ab	2.35 c	24.2 c	22.5 d	12.3 a	12.8 a	807 d	679 e
Oxyfluorfen	58.5 ab	55.3 a	2.65 a	2.90 ab	28.1 ab	26.2 abc	12.8 a	14.0 a	1032 c	1063 b
Quizalofop-*p*-ethyl	52.8 b	56.8 a	2.35 a	2.45 bc	23.1 c	22.8 d	12.4 a	13.1 a	920 cd	889 cd
Acetochlor	52.0 b	50.3 a	2.27 ab	2.52 bc	22.1 c	22.5 d	12.3 a	13.1 a	917 cd	830 d
Halosulfuron	53.3 b	54.3 a	2.42 a	2.60 abc	23.6 c	23.8 cd	12.6 a	13.3 a	920 cd	890 cd
Topramezone	58.5 ab	58.0 a	2.67 a	2.87 ab	28.1 ab	27.3 ab	13.1 a	14.2 a	1234 b	1272 a
LSD (at $P < 0.05$)	**26.53**	**9.25**	**0.6321**	**0.5013**	**3.326**	**3.309**	**2.559**	**2.351**	**142.7**	**129.2**

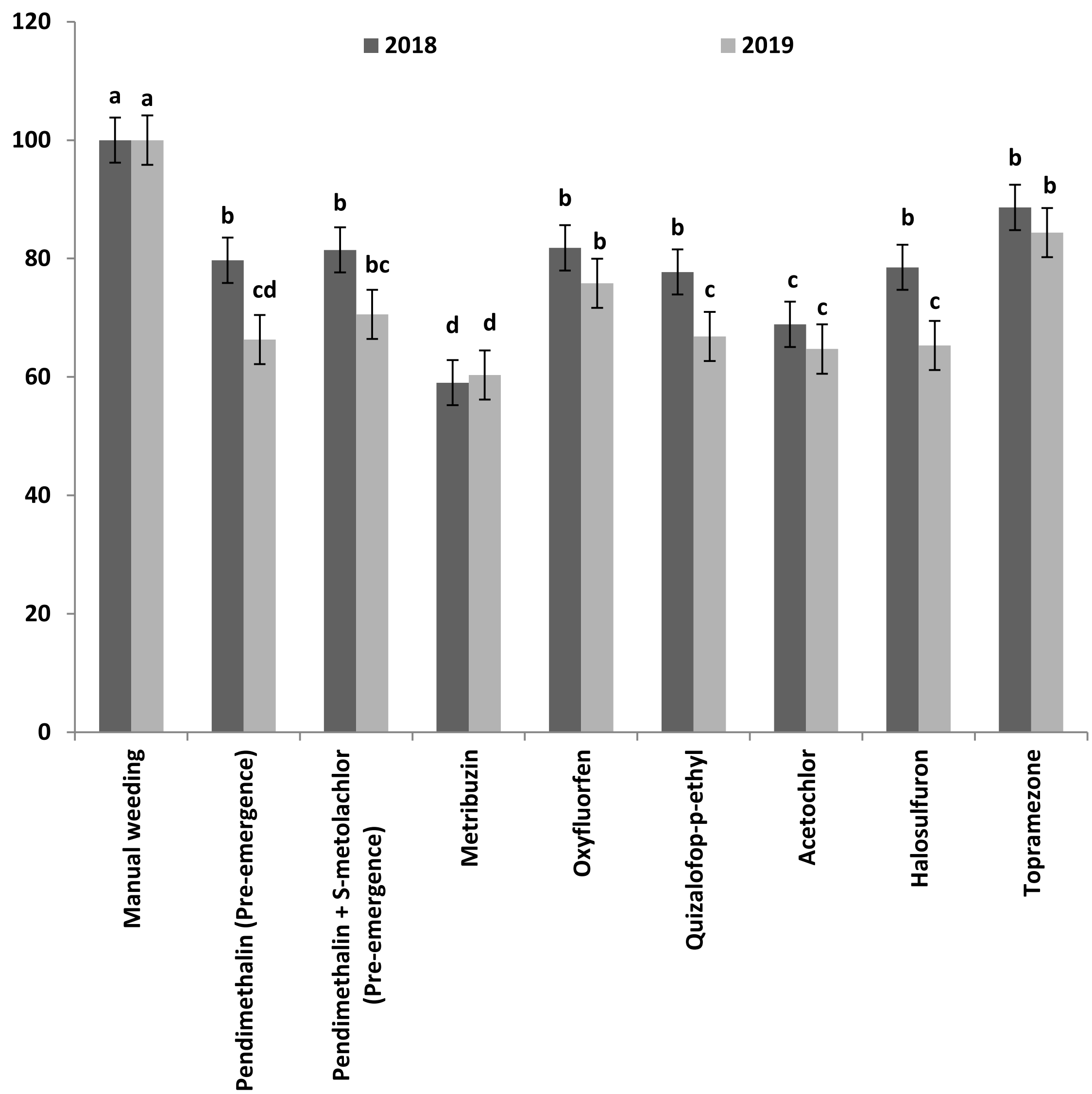

Figure 2: Weed control efficiencies (WCEs) of various weed control treatments in soybean

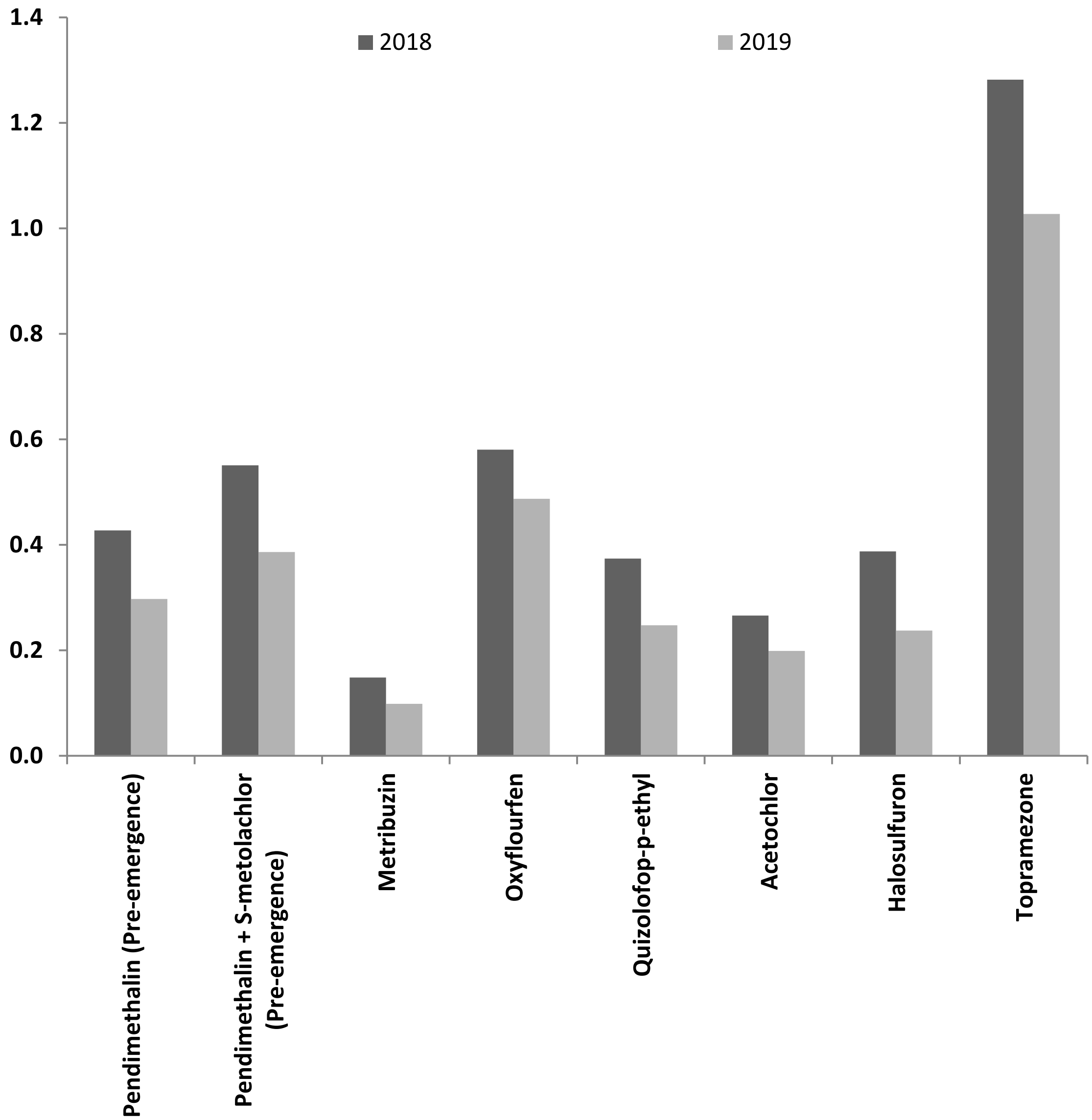

Figure 3: Herbicide efficiency indices (HEIs) of various herbicide treatments for controlling weeds in soybean

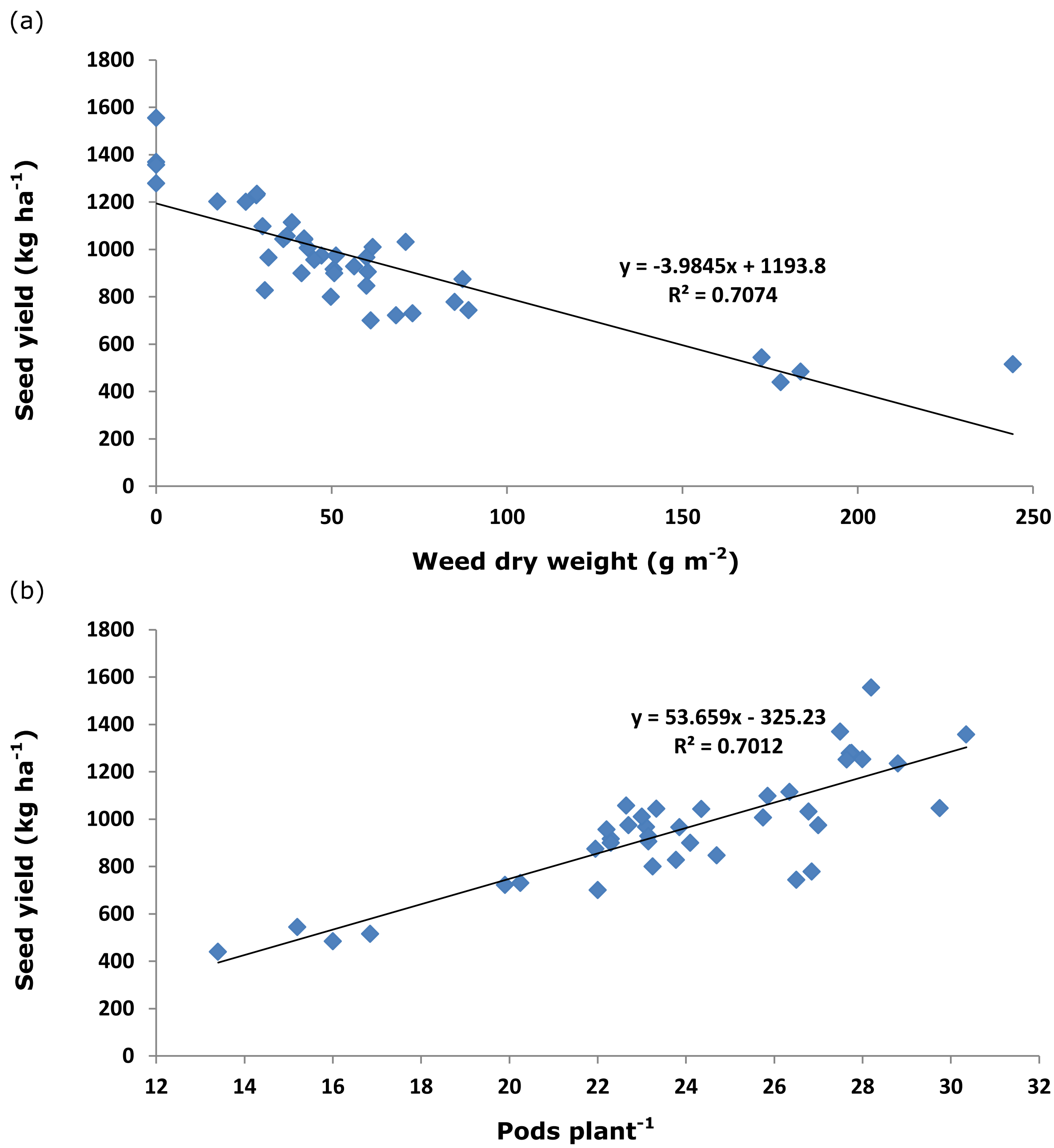

Figure 4: Relationship of seed yield of soybean with (a) weed dry weight and (b) pods per plant