INTEGRATION OF ALLELOCHEMICALS WITH VARYING RATES OF HERBICIDES FOR ECONOMICAL WEED MANAGEMENT IN RAINFED WHEAT

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https://doi.org/10.28941/25-4(2019)-7

ABSTRACT

Allelopathic extracts can be used for weed management but are not preferred by the farmers due to low phytotoxicity. Phytotoxicity of allelopathic aqueous extracts may be synergized by the appropriate mixing with compatible herbicides at their economically lower and effective rates. The impact of aqueous extracts of sunflower and sorghum alone and in integration with the reduced doses of mesosulfuron plus iodosulfuron were examined to manage weeds in wheat under rainfed conditions. A field study was carried out during 2009-11 in a randomized complete block design. The treatments were hand weeding, mesosulfuron plus iodosulfuron at 14.4 g a.i. ha^{-1}, sorghum extract at 20 L ha^{-1}, sunflower extract at 20 L ha^{-1}, sorghum plus sunflower extracts each at 10 L ha^{-1}, mixtures of sorghum plus sunflower extracts with 3.6, 7.2 and 10.8 g a.i. ha^{-1} of mesosulfuron plus iodosulfuron, and a control. The data exhibited greater than 80% suppression of weeds with hand weeding. Allelopathic extracts reduced weed density, fresh and dry weight of total weeds in the range of 25-58% while mesosulfuron plus iodosulfuron at 14.4 g a.i. ha^{-1} controlled weeds by 58-65%. The mixture of extracts with 75% of the recommended rates of mesosulfuron plus iodosulfuron was comparable with its full rate. Regression analysis showed that 1 kg of weed biomass reduced 7.67 kg ha^{-1} of wheat grain yield. Hand weeding exhibited the highest number of tillers per unit area and grains per spike. Allelopathic extracts integrated with mesosulfuron plus iodosulfuron at 10.8 g a.i. ha^{-1} produced similar grain yield as obtained from the hand weeding and mesosulfuron plus iodosulfuron at 14.4 g a.i. ha^{-1}. Extracts mixed with mesosulfuron plus iodosulfuron at 7.2-10.8 g a.i. ha^{-1} provided more net benefits as compared to the other treatments. It is inferred that sorghum and sunflower aqueous extracts integrated with 7.2-10.8 g a.i. ha^{-1} of mesosulfuron plus iodosulfuron may be used to manage weeds in rainfed wheat for environmental safety.

Keywords: Allelopathy, crop extracts, environmental pollution, herbicide, integration, weed management.

Citation: Hussain, S., Fayyaz-ul Hassan, M. E. Safdar, M. A. Nadeem, M. Asif, A. Rehman and T. H. Awan. 2019. Integration of allelochemicals with varying rates of herbicides for economical weed management in rainfed wheat. Pak. J. Weed Sci. Res., 25 (4):321-335

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INTRODUCTION

Wheat is a primary diet of almost 50 percent people of the world and is ranked as second among the cereal crops after rice in the developing world. It is cultivated in a variety of ecosystems. Although a major area of wheat lies under irrigated system and yet a one-third of the total production is met through rainfed areas. Average rainfed wheat yield in Pakistan is 1.2 t ha^{-1} which is very low as compared to advanced wheat producing nations (PARC, 2019). Numerous factors limit wheat yield especially in rainfed conditions, which include depleted soil moisture, unavailability of improved seed, improper sowing time, imbalanced fertilization and weed competition. Uncontrolled weeds can cause 20-50% yield loss in wheat crop (Hussain *et al*., 2012). A number of weed control techniques may be applied but chemical weed control method is widely adopted by the farming community because of its efficacy, economy, time and labour saving characteristics (Awan *et al*., 2015). Besides multiple benefits of herbicides their usage evokes many concerns related to environment and health issues thereby questioning the produce quality (Nazarko *et al*., 2003; Richard *et al*., 2005). It is need of the hour to employ alternative applicable methods for controlling weeds and reduce herbicide applications to minimize environmental and health risks. Certain chemicals called 'allelochemicals' are produced or released by some plants which affect the growth of neighboring plants (Minorsky, 2002). Allelochemicals exist in many plant tissues in conjugated forms (Weston and Duke, 2003). These can be obtained from decomposed and fresh plant materials through aqueous dissolution (Narwal, 2004). Use of these chemicals to manage weeds offers a safe and natural alternative strategy named allelopathy (Duke *et al*., 2001).

Incorporation of sorghum straw and spray of sorghum extracts reduced weed biomass (fresh and dry weights) and enhanced wheat yield (Ashraf and Iqbal, 2006). Sorghum aqueous extracts suppressed weed density and dry weight by 38% and 48%, respectively, in wheat under irrigated conditions (Cheema *et al*., 2002). Extracts of sunflower herbage suppressed growth of broad and grassy weeds of wheat (Naseem *et al*., 2009). Ashraf and Naeem (2005) found stronger inhibition of weed population and biomass by combined extracts of sorghum and sunflower compared to that by their individual extracts. Awan *et al*. (2012) also observed compatibility of mixed crop extracts in decreasing weed dry weight. The use of allelopathic aqueous extracts, though suppress the weeds but usually don't result in satisfactory weed control. Allelochemicals can be utilized with herbicides for attaining effective weed management (Jamil *et al*., 2005). Jabran *et al*. (2010) and Mushtaq *et al*.(2010) demonstrated effective weed control by mixing the crop aqueous extracts with reduced application rates of herbicides in irrigated systems.

Availability of moisture for herbicide application under irrigated systems is not a limiting factor; however, it is a major issue for employing chemical weed control options under rainfed system. Considering moisture constraints in rainfed conditions, the current field study was planned for documenting the sole and integrated impact of allelopathic crop extracts with reduced rates of herbicides to obtain efficient weed management in wheat. The study is aimed at reducing expenditures incurred on weed control by decreasing herbicides use, harnessing on farm resources, and ultimately enhancing yield, lowering environmental pollution and health risks.

MATERIALS AND METHODS

Site description

The study was performed at University Research Farm, Chakwal Road, Koont, Pakistan during 2009-10 and 2010-11. Weather data of the site is given in Figures 1 and 2. The experimental site consisted of sandy loam soil with 0.67% organic matter and 7.5 pH. The total N content of the site was 0.033% while available P and K contents were 3.5 ppm and 80 ppm, respectively.

Preparation of aqueous extracts

Mature sorghum *Sorghum bicolor(* L.) Moench. and sunflower (*Helianthus annuus* L.) plants were harvested from the University Research Farm, Koont Chakwal located at 33° 6′ N, 73° 1′ E at an altitude of 502 m. Grains were separated and remaining material was chopped into 2.5 cm pieces. Chopped herbage was soaked in water at 1:10 (w/v) ratio for 24 hours at room temperature. Filtrate was obtained using sieves (mesh size 60 and 80) and it was boiled at 100°C to achieve 1/20th of the initial volume (Cheema and Khaliq, 2000). This concentrated aqueous extract of both crops was utilized in different treatments during the study.

Field Experiments

Experiments were conducted in a randomized complete block design (RCBD) with four replicates of 6 m × 5 m summer fallow plots. Two allelopathic crop extracts (sorghum and sunflower) and one post-emergence herbicide, mesosulfuron plus iodosulfuron available in a mixed formulation were evaluated for weed control and their economic viability in rainfed wheat. The schedule and rate of all allelochemicals, post-emergence herbicides and their combinations are shown in Table-1. Crop extracts and herbicides were applied with a knapsack sprayer calibrated to deliver 220 L ha^{-1} of spray solution through flat-fan nozzles at a spray pressure of 140 kPa. Crop extracts were applied at 40 and 60 days after sowing (DAS) while herbicide either alone or combined with allelopathic extracts was sprayed only at 40 DAS. Wheat cultivar Chakwal 50 was sown on November 14, 2009 and October 30, 2010 using a seed drill at 100 kg seed ha^{-1} in 25 cm apart rows. Fertilizers at 75, 60, and 60 NPK kg ha^{-1} were used as urea (46% N), di-ammonium phosphate (46% P_2O_5 and 18% N) and sulphate of potash (50%) at sowing.

Data recorded

Weed density and weed biomass were recorded at 2 weeks after spray. The weeds were harvested at ground level from two randomly selected quadrates of 1 m^2 each per plot for recording density and weight of individual weeds. Ten plants were selected at random to record data regarding spike length, spikelets per spike, and number of grains per spike. Wheat yield was obtained from an area of 10 m^2 (4 m x 2.5 m) in each plot at crop maturity.

Economical and marginal analyses

Economic analysis was performed by employing prevailing market prices of variable production factors and the produce to reach at economical treatments. Marginal rate of return (MRR) was determined by adopting formula given by Byerlee (1988):

$$MRR\ (\%) = \frac{\text{Marginal returns}}{\text{Marginal cost}} \times 100$$

Statistical analyses

Analysis of variance (ANOVA) technique was employed to analyze the data. The ANOVA results indicated that interactions between treatments and year were non-significant; therefore, the pooled data were analyzed. To identify the significant difference among treatment means, the least significant difference (LSD) at 5% probability level was employed (Montgomery, 2001).

RESULTS

Total weed density

There was a natural occurrence of mixed weed flora mainly dominated by field bind weed (*Convolvulus arvensis* L.), lambsquarters (*Chenopodium album* L.), fumitory (*Fumaria indica* L.), wild oat (*Avena fatua* L.) and common vetch (*Vicia sativa* L.). *Convolvulus arvensis* was the major weed. All treatments reduced total weed density recorded at 75 DAS, compared to the non-treated control (Table-2). The highest weed density (48 plants m^{-2}) was found in the control plot while the lowest density (8.8 plants m^{-2}) was recorded in the hand weeded (HW) plots. Crop extracts reduced the total weed density and their decreasing potential increased by mixing them with herbicides at increasing concentrations (Table-2).

The maximum weed control (82%) was observed in the HW plots followed by the herbicide treated plots at its full rate (65%) and sunflower +

sorghum + mesosulfuron plus iodosulfuron at 10.8 g a.i. ha^{-1} (58%). Sole sorghum and sunflower extracts reduced total weed density by 27 and 29%, respectively. Their mutual combination reduced it by 30% while integration of the mixture with lower rates of mesosulfuron plus iodosulfuron controlled density of total weeds in the range of 47-58%.

Total weed fresh weight (g m^{-2})

All weed control treatments suppressed total weeds fresh weight (WFW). The lowest WFW (7.5 g m^{-2}) was achieved from the HW plots and the plots applied with (mesosulfuron + iodosulfuron) @ 14.4 g a.i. ha^{-1} (19.1 gm^{-2}) and sorghum + sunflower + (mesosulfuron + iodosulfuron) @ 10.8 g a.i. ha^{-1} (23.6g m^{-2}). Although crop extracts reduced FW of total weeds yet relatively higher fresh weight was recorded compared with other weed control treatments. Efficacy of crop extracts increased through their combinations with lower rates of (mesosulfuron + iodosulfuron). The maximum reduction (84.8%) of total FW was showed by HW while the lowest control (25.3%) was attained by sorghum water extract. Crop extracts reduced total FW by 25.3–28.8% and their effect improved by combining them with lower herbicide rates.

Total weed dry weight (g m^{-2})

Total weed dry weight (DW) was reduced significantly by all treatments. The maximum (9.8 g m^{-2}) and minimum (1.4 g m^{-2}) DW were recorded in the control and HW plots, respectively (Table-2). Crop extracts also reduced total DW when applied individually; however, their impact was enhanced by applying them mixed with herbicide at its reduced rates. Statistically similar total DW was recorded in the plots where mesosulfuron plus iodosulfuron was applied at full rate (14.4 g a.i. ha^{-1}) and sorghum + sunflower + mesosulfuron plus iodosulfuron at 10.8 g a.i. ha^{-1}. The maximum suppression (86%) of total weed DW was achieved in the HW plots and the plots applied with mesosulfuron plus iodosulfuron at 14.4 g a.i. ha^{-1} (58%). Weed suppression of 25-31% was obtained by using sole crop extracts but their combinations with lower rates of mesosulfuron plus iodosulfuron increased their effects thereby reducing total weeds dry weight by 39-56%. Regression analysis showed that one kg $ha^{-1}$of weed biomass reduced 7.67 kg ha^{-1} of wheat grain yield (Fig 3).

Yield and yield components of rainfed wheat

All treatments except individual allelopathic crop extracts increased the number of tillers per unit area significantly over control (Table-3). The maximum numbers of tillers (194 m^{-2}) were observed in the HW plots followed by sorghum + sunflower + mesosulfuron plus iodosulfuron at 10.8 g a.i. ha^{-1} (192 m^{-2}). The lowest number of tillers (164 m^{-2}) was observed in the control plots. Few treatments showed a significant impact on spike length of wheat (Table 3). The longest spikes (8.71 cm) were recorded in the HW plots and the plots applied with mesosulfuron plus iodosulfuron at 14.4 g a.i. ha^{-1} (8.66 cm) and sorghum + sunflower + mesosulfuron plus iodosulfuron at 10.8 g a.i. ha^{-1} (8.56 cm). Crop extracts and their mixtures except sorghum + sunflower + mesosulfuron plus iodosulfuron at 10.8 g a.i. ha^{-1} showed statistically similar spike lengths (Table-3).

Majority of the treatments increased the number of spikelets per spike in wheat (Table 3). The lowest numbers (15.5) of spikelets were recorded in the control plots which were at par with crop extracts (15.9). The maximum numbers of spikelets (16.7) were recorded in the plots treated with sorghum + sunflower + mesosulfuron plus iodosulfuron at 10.8 g a.i. ha^{-1} which were statistically similar with HW (16.5), sorghum + sunflower + mesosulfuron plus iodosulfuron at 7.2 g a.i. ha^{-1} (16.3) and mesosulfuron plus iodosulfuron at 14.4 g a.i. ha^{-1} (16.3). Number of grains per spike was enhanced by the treatments. The maximum (35.2) and minimum (31.6) numbers of grains $spike^{-1}$ were obtained from the HW and control plots, respectively. Crop extracts increased the number of grains $spike^{-1}$ (33) compared with the control (31). The increase was more obvious in combinations of extracts with lower rates of mesosulfuron plus iodosulfuron (34) which was at par with its recommended rates (35). All treatments except the sunflower water extract increased grain yield of wheat (Table-3). The maximum grain yield (2203 kg ha^{-1}) was achieved in the plots applied with sorghum + sunflower + mesosulfuron plus iodosulfuron at 10.8 g a.i. ha^{-1} and it was at par with HW (2197 kg ha^{-1}) and mesosulfuron plus iodosulfuron at 14.4 g a.i. ha^{-1} (2092 kg ha^{-1}). The sunflower aqueous extract could not enhance yield significantly; however, the sorghum water extract and the mixture of sorghum and sunflower extracts improved it significantly. Integration of extracts mixtures with herbicides increased wheat grain yields. One half to three-fourth rates of mesosulfuron plus iodosulfuron mixed with extracts produced similar yields as obtained from the plots applied with the recommended rate of mesosulfuron plus iodosulfuron.

Economical and marginal analyses

Economic analysis (Table-4) depicted the maximum net benefits ($ 615.5) from sorghum + sunflower + mesosulfuron plus iodosulfuron at 10.8 g a.i. ha^{-1} followed by sorghum + sunflower + mesosulfuron plus iodosulfuron at 7.2 g a.i. ha^{-1} ($ 586.9). Marginal analysis showed that crop extracts applied in mixture with lower rates of mesosulfuron + iodosulfuron were the only profitable treatments and these treatments showed 454-537% marginal rate of returns (Table-5).

DISCUSSION

Sorghum and sunflower allelopathic extracts suppressed total weed density by affecting various physiological processes. Cheema *et al*. (2002) reported 21-38% suppression in weed density in wheat by applying water extract of sorghum. Application of allelopathic aqueous extracts in mixture with reduced rates of mesosulfuron plus iodosulfuron improved weed control efficiency. Integration of 75% of the recommended herbicide dose provided the same weed control efficiency as achieved in the plots applied with full rate of the herbicide. These findings supported previous results of Mushtaq *et al*. (2010) who attained equivalent reductions of weed density from the full doses of herbicides viz. isoproturon, metribuzin, meso + iodosulfuron, and fenoxaprop and their lower rates integrated with allelopathic extracts in irrigated wheat. Suppression of total weeds FW by sorghum and sunflower extracts may be due to their inhibitory impact on weeds.

Allelopathic extracts in integration with lower rates of (mesosulfuron + iodosulfuron) improved phytotoxic potential of the mixture which reduced total weeds FW to a greater extent compared with sole extracts. Ashraf and Naeem (2005) found stronger inhibition from mixture of sorghum and sunflower extracts for controlling weeds in wheat. Allelopathic extracts and their mixture diminished total weed DW but less than the recommended rate of mesosulfuron plus iodosulfuron. The phytotoxic ability of the extracts mixture towards weeds was elevated with the addition of lower herbicides rates. Jabran *et al.* (2010) attained a similar suppression level of weed biomass from allelopathic crops extracts + low rates of pendimethalin and its full dose. Sorghum and sunflower extracts reduced weeds biomass in wheat under rainfed conditions (Awan *et al*., 2012). Furthermore, Khaliq *et al*. (2011) demonstrated decrease in dry weight of weeds with the application of mesosulfuron plus iodosulfuron compared with the check.

The higher number of wheat tillers m^{-2} from weed management treatments may be attributed to lower weed density and biomass in comparison with control. Hand weeding enhanced fertile tillers of wheat per unit area over control (Rajpar *et al*., 2010). Herbicide (mesosulfuron @ 6.25 g ha^{-1}) application (Sharif *et al*., 2005), sorghum extract alone (Mahmood *et al*., 2009), sorghum + sunflower extracts (Iqbal *et al*., 2010), and allelopathic extracts mixed with reduced rates of herbicides (Razzaq *et al*., 2012) increased tillers of wheat crop under irrigated conditions.

Weed control measures increased spike length and number of spikelets $spike^{-1}$ in the present study. Khan *et al*. (2013) also obtained improvement in these parameters by herbicide applications in wheat. Riaz *et al*. (2006) also obtained longer spikes with more number of spikelets by managing weeds in wheat crop.

An increase in grain numbers per spike by applying different weed control treatments may be attributed to declining competition for growth factors. The results of the present work confirmed previous findings of Sharif *et al*. (2005) and Iqbal *et al*. (2010) who obtained more grains spike^{-1} in response to sunflower and sorghum extracts application mixed with reduced herbicides (Bromoxynil + MCPA and metribuzin + phenoxaprop-p-ethyl) doses in wheat under irrigated conditions.

Higher wheat grain yields obtained from weed management treatments may be attributed to better weed suppression, greater numbers of tillers m^{-2} and more number of grains spike^{-1}. Ashraf and Akhlaq (2007) obtained higher wheat grain yields in the herbicide applied and HW plots. Allelopathic crop (sorghum and sunflower) extracts combined with 25-50% rates of herbicides (Iodo+mesosulfuron) resulted in similar wheat grain yield as has been achieved from the plots applied with the recommended rate of herbicides under irrigated conditions (Khaliq *et al*., 2012). Allelopathic aqueous extracts integrated with 50-75% rates of mesosulfuron plus iodosulfuron acquired more net benefits compared with other treatments. Razzaq *et al*. (2012) achieved higher levels of net benefits from mixed applications of allelopathic crop (sorghum and sunflower) extracts with reduced herbicide (metribuzin + phenoxaprop-p-ethyl) rates.

Sorghum and sunflower aqueous extracts reduced weeds dynamics. Crop extracts integrated with the 75% rate of mesosulfuron plus iodosulfuron showed weeds suppression, improved wheat yield and attained higher net benefits compared with HW and recommended rates of mesosulfuron plus iodosulfuron, hence the treatment may be employed under rainfed conditions to control wheat weeds economically.

CONCLUSION

It can be inferred from our data that sorghum and sunflower aqueous extracts integrated with 7.2 - 10.8 g a.i. ha^{-1} of mesosulfuron plus iodosulfuron enhanced yield and decreased rates of herbicide by their combination with farm produce, hence, it may be used to manage weeds in rainfed wheat.

ACKNOWLEDGEMENTS

The authors are grateful to the support staff of PMAS Arid Agriculture University, Rawalpindi, Pakistan.

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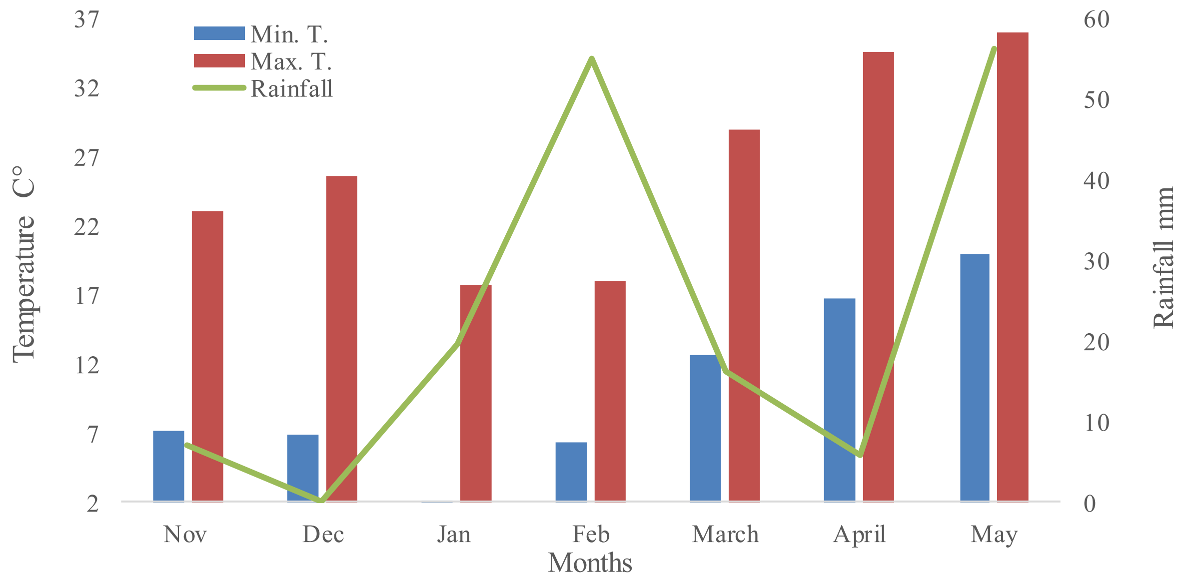

Figure 1. Mean monthly minimum and maximum temperatures and monthly rainfall for 2009-10

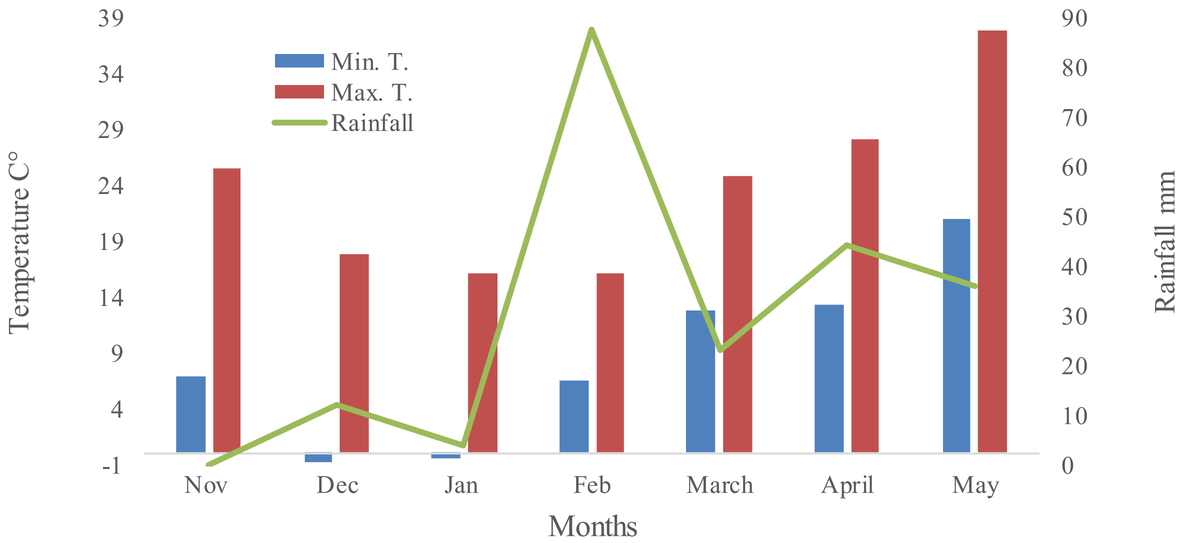

Figure 2. Mean monthly minimum and maximum temperatures and monthly rainfall for 2010-11

Table-1. Application rates and timing of different weed control treatments in rainfed wheat.

Weed control treatment	Application rates (ha^{-1})	Application timing (days after sowing)
Control	-	-
Hand weeding	-	40
Mesosulfuron + iodosulfuron (Atlantis 3.6 WG)	14.4 g a.i.	40
Sorghum water extract (WE)	20 L	40 and 60
Sunflower WE	20 L	40 and 60
Sorghum WE + sunflowerWE	10 L + 10 L	40 and 60
Sorghum + sunflower + mesosulfuron + iodosulfuron	10 L + 10 L + 3.6 g a.i.	40
Sorghum + sunflower +mesosulfuron + iodosulfuron	10 L + 10 L + 7.2 g a.i.	40
Sorghum + sunflower +mesosulfuron + iodosulfuron	10 L + 10 L + 10.8 g a.i.	40

Table-2. Total weeds density, fresh and dry weights as affected by weed control treatments.

Treatments	**Total weeds density**	**Weeds density reduction (%)**	**Total weeds dry weight (g m^{-2})**	**Weeds biomass reduction (%)**
Control	48.1 a	-	9.8 a	-
Hand weeding	8.8 f	81.8	1.4 g	86.1
Mesosulfuron + iodosulfuron at 14.4 g a.i. ha^{-1}	16.8 e	65.2	4.1 f	58.2
Sorghum water extract (WE) at 20 L ha^{-1}	35.0 b	27.3	7.4 b	24.8
Sunflower WE at 20 L ha^{-1}	34.4 b	28.6	7.3 b	26.2
Sorghum WE at 10 L ha^{-1}+ sunflower WE at 10 L ha^{-1}	33.6 b	30.1	6.8bc	30.9
Sorghum + sunflower +mesosulfuron + iodosulfuron at 3.6 g a.i. ha^{-1}	25.5 c	47.0	6.0 cd	38.6
Sorghum + sunflower +mesosulfuron + iodosulfuron at 7.2 g a.i. ha^{-1}	21.1 d	56.1	5.1 de	47.9
Sorghum + sunflower +mesosulfuron + iodosulfuron at 10.8 g a.i. ha^{-1}	20.0 de	58.4	4.3ef	55.9
$LSD_{0.05}$	**3.25**	**-**	**0.99**	**-**

Values in parenthesis are percent decrease compared with the control. Means sharing the same letter did not differ significantly at $p \leq 0.05$.

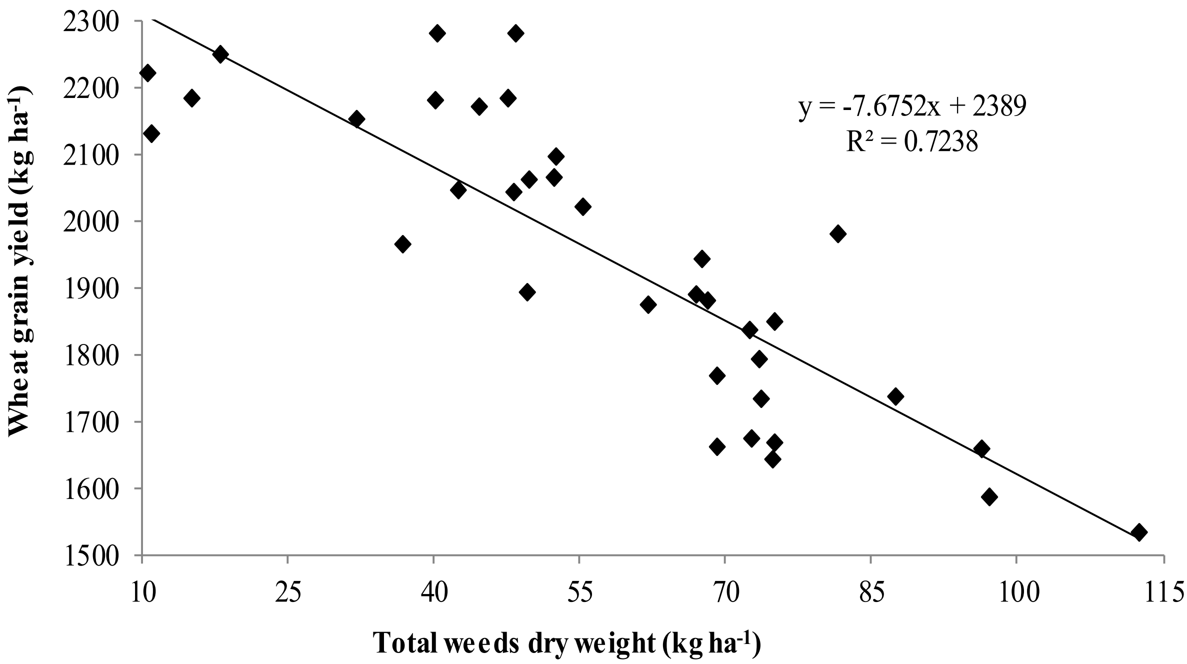

Figure 3. Relationship between total weeds dry weight and wheat grain yield

Table- 3. Yield and yield components of rainfed wheat as affected by weed control treatments.

Treatments	No. of tillers m^{-2}	Spike length (cm)	No. of spikelets/ spike	No. of grains/ spike	Grain yield (kg ha^{-1})
Control	164.8 e	8.13 d	15.5 d	31.6 d	1629.6 f
Hand weeding	193.9 a	8.71 a	16.5 ab	35.2 a	2196.8 a
Mesosulfuron+ iodosulfuron @ 14.4 g a.i. ha^{-1}	188.8 ab	8.66 ab	16.3 abc	34.6 ab	2092.0 ab
Sorghum WE @ 20 L ha^{-1}	171.2cde	8.32bcd	15.9 cd	33.0 cd	1780.9 de
Sunflower WE @ 20 L ha^{-1}	168.4 de	8.26 cd	15.8 cd	32.7 cd	1684.8 ef
Sorghum WE @ 10 L ha^{-1} +SunflowerWE @ 10 L ha^{-1}	175.5 cd	8.40abcd	15.9 cd	33.1 c	1870.4 cd
Sorghum + Sunflower+(mesosulfuron + iodosulfuron) @ 3.6 g a.i. ha^{-1}	179.1bc	8.43abcd	16.1 bc	33.7bc	1948.3 c
Sorghum + Sunflower+(mesosulfuron + iodosulfuron) @ 7.2 g a.i. ha^{-1}	188.9 ab	8.48abcd	16.3abc	33.9 abc	2083.6 b
Sorghum + Sunflower+(mesosulfuron + iodosulfuron) @ 10.8 g a.i. ha^{-1}	192.2 a	8.56abc	16.7 a	34.5 ab	2202.8 a
LSD	**10.29**	**0.39**	**0.53**	**1.36**	**111.14**

WE: Water extract.

Table-4. Economic Analysis

Treatments	T1	T2	T3	T4	T5	T6	T7	T8	T9	Remarks
Total grain yield	1629.6	2196.8	2092.0	1780.9	1684.8	1870.4	1948.3	2083.6	2202.8	kg/ha
10% less	163.0	219.7	209.2	178.1	168.5	187.0	194.8	208.4	220.3	kg/ha
Adjusted yield	1466.6	1977.1	1882.8	1602.8	1516.3	1683.4	1753.5	1875.2	1982.5	To bring at farmers level
Gross income	476.6	642.5	611.9	520.9	492.8	547.1	569.9	609.4	644.3	US$ 0.325/kg
Hand weeding	0	105.0	0	0	0	0	0	0	0	30 man day /ha, US$.3.50/man day
Cost of herbicide	0	0	25.0	0	0	0	6.3	12.5	18.8	US$. 1.74/g a.i.
Cost of water extracts	0	0	0	12.0	10.0	11.0	5.5	5.5	5.5	US$. 0.30 &0.25/L SWE &SunWE
Sprayer rent	0	0	1.0	2.0	2.0	2.0	1.0	1.0	1.0	US$.1.0/spray
Spray labour	0	0	3.5	7.0	7.0	7.0	3.5	3.5	3.5	US$.3.50/man/day/ha
Cost that vary	0	105.0	29.5	21.0	19.0	20.0	16.3	22.5	28.8	US$.
Net benefit	476.6	537.5	582.4	499.9	473.8	527.1	553.6	586.9	615.5	US$

T1=Control, T2=Hand weeding, T3=mesosulfuron + iodosulfuron) @ 14.4 g a.i. ha-1, T4=Sorghum WE @ 20 L ha-1 T5=Sunflower WE @ 20 L ha-1, T6=Sorghum WE @ 10 L ha-1 +SunflowerWE @ 10 L ha-1, T7=Sorghum + Sunflower+(mesosulfuron + iodosulfuron) @ 3.6 g a.i. ha-1, T8=Sorghum + Sunflower+(mesosulfuron + iodosulfuron) @ 7.2 g a.i. ha-1, T9=Sorghum + Sunflower+(mesosulfuron + iodosulfuron) @ 10.8 g a.i. ha-1

Table-5. Marginal Analysis.

Treatments	Costs that vary (US$)	Marginal cost (US$)	Net benefit (US$)	Marginal benefit (US$)	Marginal Rate of return (%)
Control	0	-	476.6	-	0
Sorghum + Sunflower+(mesosulfuron + iodosulfuron) @ 3.6 g a.i. ha^{-1}	16.3	16.3	553.6	77	472.4
Sunflower WE @ 20 L ha^{-1}	19.0	-	473.8	-	D
Sorghum WE @ 10 L ha-1 +SunflowerWE @ 10 L ha^{-1}	20.0	-	527.1	-	D
Sorghum WE @ 20 L ha^{-1}	21.0	-	499.9	-	D
Sorghum + Sunflower+(mesosulfuron + iodosulfuron) @ 7.2 g a.i. ha^{-1}	22.5	6.2	586.9	33.3	537.1
Sorghum + Sunflower+(mesosulfuron + iodosulfuron) @ 10.8 g a.i. ha^{-1}	28.8	6.3	615.5	28.6	454.0
mesosulfuron + iodosulfuron) @ 14.4 g a.i. ha^{-1}	29.5	-	582.4	-	D
Hand weeding	105.0	-	537.5	-	D

D stands for dominated