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Full Length Article

Herbicide Options for Effective and Economical Weed Management for Sustainable Wheat Production

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Abstract

Weeds are the major threat for all the field crops globally and the development of resistance to the available herbicide's mode of action is offering a huge challenge for sustainable crop production. The present study was carried out at Rice Research Institute, Kala Shah Kaku, Punjab, Pakistan during 2017–2018 and 2018–2019, to find out the most economical and suitable herbicide (sole or in combinations) for weed control in wheat. The study consisted of 18 treatments including 16 herbicide-based weed management (seven commercial herbicides sole or their market available combinations, and nine tank mixtures of different herbicides combinations), one weed free plot and a control as a weedy check. Results revealed that mesosulfuron-methyl + iodosulfuron-methyl-sodium and pinoxaden applied individually or in combination with other herbicides effectively controlled *Phalaris minor*; however, sole application of fluroxypyr meptyle, tribenuron methyl + metsulfuron methyl, carfentrazone-ethyl and fluroxypyr meptyle + amino pyralid were against this weed species. The herbicides fluroxypyr meptyle, fluroxypyr meptyle + amino pyralid, carfentrazone-ethyl, mesosulfuron-methyl + iodosulfuron-methyl-sodium, and tribenuron methyl + metsulfuron methyl proved effective against *Lathyrus aphaca* and *Medicago polymorpha*; however, herbicide pinoxaden and fenoxaprop-p-ethyl failed to control it. The herbicide treatments tribenuron methyl + metsulfuron methyl plus pinoxaden, and mesosulfuron-methyl + iodosulfuron-methyl-sodium plus fluroxypyr meptyle in both the years had highest grain yield after weed free plots. All herbicides' treatments had significantly higher yield as compared to control (weedy check). In conclusion, herbicides combinations mesosulfuron-methyl + iodosulfuron-methyl-sodium plus fluroxypyr meptyle and tribenuron methyl + metsulfuron methyl plus pinoxaden were the most effective and economical to get higher yield by managing wheat weeds.

Keywords: Weed dynamics; Herbicide combinations; Grain yield; Economic analysis

Introduction

Rising food demand for the growing global population is a big challenge for scientists and producers to produce more food ensuring its security in foreseeable future. Wheat (*Triticum aestivum* L.) is the world's most widely grown cereal crop, thanks to its adaptability to a variety of climates (Curtis 2021). It is the major staple food in Pakistan and is cultivated on a large scale in the country. The share of wheat to value addition in agriculture and Gross Domestic Product (GDP) of Pakistan is 8.7 and 1.7%, respectively (GOP 2020).

There are many abiotic and biotic factors that affect wheat yield (Tester and Langridge 2010). Among these yield limiting factors, weeds remain always a major problem. Despite many advances in weed management technology, crop growers still face significant yield losses due to weeds (Harker and O'donovan 2013; Shahzad *et al*. 2016) as these can reduce the yield by utilizing the sunlight, water, space and fertilizer. It has been estimated that weeds can cause 23% wheat yield reduction worldwide (Gaba *et al*. 2016). The major noxious weeds of wheat are *Phalaris minor* (littleseed canarygrass), *Lathyrus aphaca* (yellow pea), *Medicago polymorpha* (bur clover), *Avena fatua* (wild oat), *Melilotus indica* (sweet clover), *Polypogon fugax* (rabbitsfoot grass), *Chenopodium album* (white goosefoot) and *Cirsium arvense* (creeping thistle) (Waheed *et al*. 2009) and their severe infestation causes huge yield loss (Hamid *et al*. 1998). However, among these weeds only littleseed canarygrass can exert a yield decline up to 80% (Singh *et al*. 2012), wild oat up to 40% (Jäck *et al*. 2017), *Poa annua* (annual bluegrass) up to 76% and *Coronopus didymus* (swinecress) up to 75% (Siddiqui *et al*. 2010). Therefore, owing to huge losses imposed by weeds, several on-farm

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techniques to control them are adopted, however, each technique has both merits and demerits depending upon the prevailing weeds flora, soil type, and cropping system. The methods mainly involve the use of weedicides, tillage operations, manual weeding, hoeing, higher seeding density, sowing methods, intercropping, mixed cropping, mulching, cultivation of weed competitive varieties, and use of fertilizer practices (Riaz *et al.* 2006).

Manual weeding (MW) is one of the old-fashioned eradication techniques in many developing countries like Pakistan, India, China, Nepal and Bangladesh. However, recent shortage of agricultural labor, a strenuous and inefficient job to control weeds by MW, this method is becoming less practical (Hossain 2015).

The above mentioned constraints have compelled the researchers to find out the other alternative weed control measures that are most effective and economically viable. Chemical weed control using herbicides is quite a proficient and economical way in controlling weeds (Zargar *et al*. 2019). Herbicidal weed control offers a remarkable reduction in soil erosion, greenhouse gas emissions, fuel consumption and nutrient run-off and also conserves water compared to other soil disturbance weed control techniques *e.g*., tillage, harrowing, *etc*. (Hossain 2015).

Herbicides have the potentiality to reduce weeding costs significantly; however, herbicide resistance has emerged as a challenging issue with particular chemicals and weed species (Walsh and Powles 2014). The International Survey of Herbicide-Resistant Weeds (www.weed-science.org) reveals 388 exceptional cases (biotype × site of action) of chemical-resistant weeds worldwide, with 210 species. Weeds have already shown resistance to 21 out of 25 known herbicide sites of action and to 152 herbicide chemistries (Heap 2019). The resistance against ALS inhibitors is the most common (126 species), followed by triazines (69 resistant species) and ACCase inhibitors (42 resistant species). Repeated application of the same group of the herbicide over time forced the resistance development mechanisms in weeds. The large area having the sole application of glyphosate has evolved weed resistance to glyphosate (Heap 2014). Littleseed canarygrass, the most problematic weed of wheat production system including Pakistan, has evolved resistance to fenoxaprop-p-ethyl and this is the first ever case seen for herbicide-resistant weed in Pakistan (Abbas *et al*. 2016). It was reported that among eight biotypes of littleseed canarygrass, four were resistant to fenoxaprop-p-ethyl even at its double dose than the recommended. The resistance development was due to the repeated use of this chemical over more than fifteen years in Pakistan (Abbas *et al*. 2016). In another field survey study in Pakistan, farmers reported that they were unable to control mainly littleseed canarygrass followed by wild oat and toothed dock through chemicals. These weeds might have developed herbicide resistance to repetitive use of chemical weed control (Hashim *et al*. 2019).

Selective herbicides are used to control broad and narrow leaved weeds in wheat crop (Ahmed *et al*. 2020). Herbicides available in the Pakistani market have a different mode of action. Tribenuron-methyl, Fluroxypyr, iodosulfuron methyl, mesosulfuron-methyl and iodosulfuron-methyl sodium are selective herbicides that are used for controlling broad leaved weeds in wheat. Fluroxypyr and aminopyralid belong to pyridine-carboxylic acid family and they control the weeds by disrupting their cells growth and division in newly forming leaves leading to malformed growth and tumors. Tribenuron-methyl, metsulfuron methyl, mesosulfuron methyl and iodosulfuron methyl belong to sulfonylurea family and inhibit the normal functioning of acetolactate synthase enzyme which is important for protein synthesis. Fenoxaprop-p-ethyl belongs to the family aryloxyphenoxy-propionate and pinoxaden belongs to the family phenylpyrazoline. Both these herbicides cause inhibition of acetyl CoA carboxylase (ACCase) enzyme. Carfentrazone-ethyl belongs to the family triazolinone which causes inhibition of protoporphyrinogen oxidase (PPO) enzyme.

Considering the issue of herbicide resistance, it is urgent to determine the efficacy of different herbicides or herbicides combinations to manage complex weed flora of wheat without depending on a single group for a long time. Alternative herbicides with a different mode of actions are the best options to control resistant weed species as well as to prevent resistance weed evolution. Therefore, the present study was planned to find out the most suitable and economical herbicides or herbicides combinations that can control both broad and narrow leaved weeds effectively.

Materials and Methods

Experimental site

The study was conducted at the experimental farm of Rice Research Institute, Kala Shah Kaku, Punjab, Pakistan (31°43'18.7"N 74°15'59.8"E) during the rabi season 2017–2018 and 2018–2019. The pre-sowing soil analysis results of experimental field are given in Table 1.

Field preparation and sowing

The field was prepared by two ploughings with disc plough then two cultivations with cultivator followed by two planking. Wheat cultivar Galaxy was sown after land preparation with rabi drill seeder in 20 cm apart rows at a seed rate of 125 kg ha^{-1}. Sowing was performed on 16th and 13th of November in 2017–2018 and 2018–2019, respectively.

Experimental design, treatments and their application

The experiment was laid out in Randomized Complete Block Design with three replications having 72 m^2 (3.60 m

Table 1: Physicochemical properties of experimental site

Parameters	Soil depth	
	0-6 inch	6-12 inch
Texture	Clay loam	Clay loam
Organic matter (%)	0.41	0.28
Soil pH	8.35	8.10
EC (dS m^{-1})	1.39	0.95
SAR (m mol $L^{-1})^{1/2}$	7.27	7.16
Saturation (%)	44.00	34.00
Nitrogen (%)	0.53	0.29
Available P (mg kg^{-1})	5.60	5.30
Available K (mg kg^{-1})	90.00	69.00

Where, EC = Electrical Conductivity, SAR = Sodium Adsorption Ratio, P = Phosphorus, K = Potassium

× 20 m) plot size. The experiment consisted of a total of 18 treatments (16 were herbicide-based weed management, one hand weeding and one weedy check) and details are given in Table 2. Herbicides were sprayed using a knapsack hand sprayer after first irrigation at 45 days after sowing (DAS) in a moist soil using water solution at the rate of 300 L ha^{-1} determined after calibration. The hand weedings were done manually, and a weedy check plot was left un-weeded for the whole crop season.

Fertilizer Management

Phosphorus (diammonium phosphate) and potassium (sulfate of potash) fertilizers were applied at the rate of 110 and 60 kg ha^{-1}, respectively, at the time of field preparation. Nitrogen (urea) at the rate of 130 kg ha^{-1} was applied in two splits *i.e.*, 1/2 N was applied at sowing and the remaining was immediately after first irrigation.

Data Collection

Naturally occurring weeds in each plot were counted from two randomly selected places by using a quadrate (40 cm by 40 cm) at 25 days after herbicide spray. The weed plants were uprooted from the ground surface, cleaned and washed the roots well, and counted species-wise. The wheat plants were also uprooted from the same area and tillers were counted. The wheat and weed species samples were placed separately in a brown envelope and oven dried at 70°C for constant biomass determination. The crop was harvested at maturity and the grain and straw yield was measured from the center of each plot on an area of 5 m^2. The grain yield was determined at 12% moisture content. At maturity plant height was measured of 10 randomly selected plants. The number of spike m^{-2}, number of spikelets $spike^{-1}$ were counted and 1000-grain weight was also measured.

Statistical analysis

The data for both the years were subjected to analysis of variance (ANOVA) using a statistical software (STAR 2015). The least significance difference (LSD) test at $P \leq 0.05$ was used to compare the treatment means. For all the parameters collected, two years combined model was run and found most of the parameters were significant, therefore, data were presented year wise (STAR 2015).

Results

Efficacy of different weed control treatments (at 25 days after spraying of herbicide) on weed density and biomass of most dominant weed species

Littleseed canarygrass: The weed control method mesosulfuron-methyl + iodosulfuron-methyl-sodium and pinoxaden sole or in combination with other post-emergence herbicides reduced littleseed canarygrass density above 90% during both years of study (Table 3). However, the sole application of fluroxypyr meptyle and carfentrazone-ethyl and tribenuron methyl + metsulfuron methyl were not so effective against this weed. The first two chemicals reduced the density only from 0–6% while for the later it was 4% more as compared to control (Table 3). A similar density of the weed was recorded from the weed control treatments carfentrazone-ethyl, tribenuron methyl + metsulfuron methyl, fluroxypyr meptyle, and fluroxypyr meptyle + amino pyralid.

Similarly, fluroxypyr meptyle, tribenuron methyl + metsulfuron methyl, carfentrazone-ethyl and fluroxypyr meptyle + amino pyralid had a little impact on the biomass of littleseed canarygrass during both years, however, mesosulfuron-methyl + iodosulfuron-methyl-sodium and pinoxaden applied individually or in combination with other herbicides reduced the biomass of the weed more than 90% as compared with control (Table 3). Fenoxaprop-p-ethyl also reduced the density and biomass of littleseed canarygrass but observed lower efficacy than mesosulfuron-methyl + iodosulfuron-methyl-sodium, and pinoxaden (Table 3).

Yellow pea

Compared with season long weedy plots (control), all weed control treatments except the sole application of pinoxaden and fenoxaprop-p-ethyl significantly reduced yellow pea density by 62–96% and 61–100% in 2017–2018 and 2018–2019, respectively (Table 4). The sole application of fenoxaprop-p-ethyl was less effective against yellow pea and reduced weed density only 35% while pinoxaden herbicide found ineffective against this weed in both years (Table 4).

Weed biomass followed a similar trend to weed density in both years and weed control treatments fluroxypyr meptyle, fluroxypyr meptyle + amino pyralid, carfentrazone-ethyl, mesosulfuron-methyl + iodosulfuron-methyl-sodium, and tribenuron methyl + metsulfuron methyl effectively reduced the biomass of this weed, while herbicides pinoxaden and fenoxaprop-p-ethyl failed to

Table 2: Experimental treatments along with chemical composition and doses of different herbicides

Trade Name	Active ingredient (a.i.) *	Dose ha^{-1}
Allymax 66.7 WG	Tribenuron methyl + metsulfuron methyl (Tm + Mtm)	24 g
Axial 50 EC	Pinoxaden (with cloquintocet-mexyl safener) (Pd)	815.10 mL with safenar 500 mL
Atlantis 3.6 WG	Mesosulfuron-methyl + iodosulfuron-methyl-sodium (Msm + Im)	395.20 g
Puma super 69 EW	Fenoxaprop-p-ethyl (Fn)	1235 mL
Starane-M 50 EC	Fluroxypyr meptyle (Flm)	741 mL
Cleanwave	Fluroxypyr meptyle + amino pyralid (Flm +Ap)	790.40 mL
Aim 40 DF	Carfentrazone-ethyl (Ce)	49.40 g
Allymax + Axial	Tribenuron methyl + metsulfuron methyl plus pinoxaden (Tm + Mtm plus Pd)	24 g + 815.10 mL
Allymax + Atlantis	Tribenuron methyl + metsulfuron methyl plus Mesosulfuron-methyl + iodosulfuron-methyl-sodium (Tm + Mtm plus Msm + Im)	24 g + 395.20 g
Allymax + Puma super	Tribenuron methyl + metsulfuron methyl plus Fenoxaprop-p-ethyl (Tm + Mtm plus Fn)	24 g + 1235 mL
Axial + Starane-M	Pinoxaden plus Fluroxypyr meptyle (Pd plus Flm)	815.10 mL + 741 mL
Axial + Cleanwave	Pinoxaden plus Fluroxypyr meptyle + amino pyralid (Pd plus Flm + Ap)	815.10 mL + 790.40 mL
Atlantis + Starane-M	Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle (Msm + Im plus Flm)	395.20 g + 741 mL
Atlantis + Cleanwave	Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle + amino pyralid (Msm + Im plus Flm + Ap)	395.20 g + 790.40 mL
Puma super + Starane-M	Fenoxaprop-p-ethyl plus Fluroxypyr meptyle (Fn plus Flm)	1235 mL + 741 mL
Puma super + Cleanwave	Fenoxaprop-p-ethyl plus Fluroxypyr meptyle + amino pyralid (Fn plus Flm + Ap)	1235 mL + 790.40 mL
Hand weeding (Hw)		
Control (Ct)		

*within the parentheses is the short treatment name used in the manuscript

Table 3: Effect of different weed control methods on weed density and dry weight of littleseed canarygrass during 2017–2018 and 2018–2019

Treatments	2017–2018				2018–2019 at 25 days after spraying of herbicide			
	Number m^{-2}	% decrease (–) or increase (+) over control	Dry Weight ($g\ m^{-2}$)	% decrease (–) or increase (+) over control	Number m^{-2}	% decrease (–) or increase (+) over control	Dry Weight ($g\ m^{-2}$)	% decrease (–) or increase (+) over control
Tm + Mtm	453.12	+3.94	38.60	+6.78	317.19	–19.76	7.54	–81.50
Pd	45.31	–89.61	1.78	–95.08	35.94	–90.91	5.13	–87.41
Msm + Im	20.00	–95.41	1.10	–96.96	28.12	–92.89	1.73	–95.76
Fn	100.69	–76.90	8.65	–76.07	72.19	–81.74	10.58	–74.04
Flm	435.94	0.00	37.60	+4.01	334.38	–15.41	33.56	–17.66
Flm + Ap	321.88	–26.16	30.30	–16.18	220.31	–44.27	29.31	–28.09
Ce	406.25	–6.81	33.39	–7.63	126.56	–67.98	12.31	–69.80
Tm + Mtm plus Pd	18.25	–95.81	2.19	–93.94	0.00	–100.00	0.00	–100.00
Tm + Mtm plus Msm + Im	20.56	–95.28	2.31	–93.61	0.00	–100.00	0.00	–100.00
Tm + Mtm plus Fn	39.06	–91.04	2.43	–93.28	46.88	–88.14	10.25	–74.85
Pd plus Flm	26.88	–93.83	1.98	–94.52	25.00	–93.68	2.35	–94.23
Pd plus Flm + Ap	20.31	–95.34	1.74	–95.19	7.81	–98.02	0.63	–98.45
Msm + Im plus Flm	37.19	–91.47	2.31	–93.61	28.12	–92.89	1.66	–95.93
Msm + Im plus Flm + Ap	46.88	–89.25	2.81	–92.23	9.38	–97.63	1.15	–97.18
Fn plus Flm	150.00	–65.59	14.32	–60.39	130.00	–67.11	12.56	–69.19
Fn plus Flm + Ap	23.44	–94.62	0.97	–97.32	35.94	–90.91	2.55	–93.74
Hw	35.62	–91.83	5.29	–85.37	25.00	–93.68	5.54	–86.41
Ct	435.94	0.00	36.15	0.00	395.31	0.00	40.76	0.00
LSD ($P \leq 0.05$)	168.78	–	12.88	–	85.04	–	10.78	–

Where, Tm + Mtm=Tribenuron methyl + metsulfuron methyl; Pd = Pinoxaden (with cloquintocet-mexyl safener); Msm + Im=Mesosulfuron-methyl + iodosulfuron-methyl-sodium; Fn = Fenoxaprop-p-ethyl; Flm = Fluroxypyr meptyle; Flm + Ap=Fluroxypyr meptyle + amino pyralid; Ce = Carfentrazone-ethyl; Tm + Mtm plus Pd = Tribenuron methyl + metsulfuron methyl plus pinoxaden; Tm + Mtm plus Msm + Im = Tribenuron methyl + metsulfuron methyl plus Mesosulfuron-methyl + iodosulfuron-methyl-sodium; (Tm + Mtm plus Fn = Tribenuron methyl + metsulfuron methyl plus Fenoxaprop-p-ethyl; Pd plus Flm = Pinoxaden plus Fluroxypyr meptyle; Pd plus Flm + Ap = Pinoxaden plus Fluroxypyr meptyle + amino pyralid; Msm + Im plus Flm = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle; Msm + Im plus Flm + Ap = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle + amino pyralid; Fn plus Flm = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle; Fn plus Flm + Ap = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle + amino pyralid; Hw = hand weeding; Ct = Control

reduce the biomass of this weed as compared to weedy plots (Table 4).

Bur clover

Relative to the control plots, the plots applied with fluroxypyr meptyle, fluroxypyr meptyle + amino pyralid, mesosulfuron-methyl + iodosulfuron-methyl-sodium, and carfentrazone-ethyl and their combinations with other post-emergence herbicides provided excellent control of bur clover and reduced density by 82–100% in 2017–2018 and 87–100% in 2018–2019 (Table 5). While, lower weed control percentage was observed for the weed control method tribenuron methyl + metsulfuron methyl or its combination with pinoxaden, pinoxaden alone and fenoxaprop-p-ethyl. The weed control methods fenoxaprop-p-ethyl and pinoxaden produced no impact on this weed and had similar weed density and biomass to control (Table 5).

Number of wheat tillers m^{-2} and dry weight at 70 DAS

All the weed control treatments had a significant impact of total tiller density m^{-2} in both years and increased tiller density by 72–168% and 33–220% in 2017–2018 and

Table 4: Effect of different weed control methods on weed density and dry weight of yellow pea during 2017–2018 and 2018–2019

Treatments	2017–2018				2018–2019 at 25 days after spraying of herbicide			
	Number m^{-2}	% decrease (–) or increase (+) over control	Dry Weight (g m^{-2})	% decrease (–) or increase (+) over control	Number m^{-2}	% decrease (–) or increase (+) over control	Dry Weight (g m^{-2})	% decrease (–) or increase (+) over control
Tm + Mtm	13.44	–74.70	0.57	–35.23	14.06	–60.53	0.85	–11.46
Pd	90.62	+70.59	4.56	+418.18	34.06	–4.38	1.73	+80.21
Msm + Im	21.25	–60.00	1.20	+36.36	8.00	–77.54	0.26	–72.92
Fn	34.38	–35.28	2.38	+170.45	40.62	14.04	2.81	192.71
Flm	5.88	–88.93	0.37	–57.95	0.00	–100.00	0.00	–100.00
Flm + Ap	39.06	–26.47	0.69	–21.59	0.00	–100.00	0.00	–100.00
Ce	28.12	–47.06	0.76	–13.64	0.00	–100.00	0.00	–100.00
Tm + Mtm plus Pd	10.06	–81.06	0.23	–73.86	7.81	–78.07	0.28	–70.83
Tm + Mtm plus Msm + Im	4.38	–91.75	1.28	+45.45	4.69	–86.83	0.26	–72.92
Tm + Mtm plus Fn	18.12	–65.89	1.37	+55.68	10.94	–69.29	0.16	–83.33
Pd plus Flm	12.5	–76.47	0.31	–64.77	0.00	–100.00	0.00	–100.00
Pd plus Flm + Ap	12.5	–76.47	0.17	–80.68	5.00	–85.96	0.00	–100.00
Msm + Im plus Flm	20.31	–61.77	0.34	–61.36	0.00	–100.00	0.00	–100.00
Msm + Im plus Flm + Ap	6.25	–88.23	0.14	–84.09	4.00	–88.77	0.14	–85.42
Fn plus Flm	2.00	–96.23	0.54	–38.64	0.00	–100.00	0.00	–100.00
Fn plus Flm + Ap	9.38	–82.34	0.84	–4.55	3.00	–91.58	0.13	–86.46
Hw	21.88	–58.81	0.57	–35.23	2.00	–94.39	0.11	–88.54
Ct	53.12	0.00	0.88	0.00	35.62	0.00	0.96	0.00
LSD ($P \leq 0.05$)	25.43	–	1.21	–	10.44	–	0.62	–

Where, Tm + Mtm = Tribenuron methyl + metsulfuron methyl; Pd = Pinoxaden (with cloquintocet-mexyl safener); Msm + Im = Mesosulfuron-methyl + iodosulfuron-methyl-sodium; Fn = Fenoxaprop-p-ethyl; Flm = Fluroxypyr meptyle; Flm + Ap = Fluroxypyr meptyle + amino pyralid; Ce = Carfentrazone-ethyl; Tm + Mtm plus Pd = Tribenuron methyl + metsulfuron methyl plus pinoxaden; Tm + Mtm plus Msm + Im = Tribenuron methyl + metsulfuron methyl plus Mesosulfuron-methyl + iodosulfuron-methyl-sodium; (Tm + Mtm plus Fn = Tribenuron methyl + metsulfuron methyl plus Fenoxaprop-p-ethyl; Pd plus Flm = Pinoxaden plus Fluroxypyr meptyle; Pd plus Flm + Ap = Pinoxaden plus Fluroxypyr meptyle + amino pyralid; Msm + Im plus Flm = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle; Msm + Im plus Flm + Ap = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle + amino pyralid; Fn plus Flm = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle; Fn plus Flm + Ap = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle + amino pyralid; Hw = hand weeding; Ct = Control

Table 5: Effect of different weed control methods on weed density and dry weight of Bur clover during 2017–2018 and 2018–2019

Treatments	2017–2018				2018–2019 at 25 days after spraying of herbicide			
	Number m^{-2}	% decrease (–) or increase (+) over control	Dry Weight (g m^{-2})	% decrease (–) or increase (+) over control	Number m^{-2}	% decrease (–) or increase (+) over control	Dry Weight (g m^{-2})	% decrease (–) or increase (+) over control
Tm + Mtm	29.69	+26.66	0.92	+35.29	4.69	–81.00	0.15	0.00
Pd	32.81	+39.97	1.74	+155.88	20.31	–17.74	1.72	+1046.67
Msm + Im	6.25	–73.34	0.22	–67.65	3.00	–87.85	0.15	+0.00
Fn	34.38	+46.67	0.75	+10.29	23.44	–5.06	1.14	+660.00
Flm	0.00	–100.00	0.00	–100.00	0.00	–100.00	0.00	–100.00
Flm + Ap	0.00	–100.00	0.00	–100.00	0.00	–100.00	0.00	–100.00
Ce	4.69	–79.99	0.19	–72.06	3.12	–87.36	0.22	+46.67
Tm + Mtm plus Pd	0.00	–100.00	0.00	–100.00	0.00	–100.00	0.00	–100.00
Tm + Mtm plus Msm + Im	7.81	–66.68	0.39	–42.65	0.00	–100.00	0.00	–100.00
Tm + Mtm plus Fn	3.12	–86.69	0.05	–92.65	0.00	–100.00	0.00	–100.00
Pd plus Flm	14.06	–40.02	0.84	+23.53	0.00	–100.00	0.00	–100.00
Pd plus Flm + Ap	9.38	–59.98	0.11	–83.82	3.00	–87.85	0.11	–26.67
Msm + Im plus Flm	6.25	–73.34	0.23	–66.18	0.00	–100.00	0.00	–100.00
Msm + Im plus Flm + Ap	6.25	–73.34	0.26	–61.76	3.00	–87.85	0.10	–33.33
Fn plus Flm	4.00	–82.94	0.72	+5.88	3.00	–87.85	0.09	–40.00
Fn plus Flm + Ap	0.00	–100.00	0.00	–100.00	0.00	–100.00	0.00	–100.00
Hw	3.12	–86.69	0.18	–73.53	3.00	–87.85	0.07	–53.33
Ct	23.44	0.00	0.68	0.00	24.69	0.00	0.15	0.00
LSD ($P \leq 0.05$)	15.50	–	0.79	–	3.97	–	0.32	–

Where, Tm + Mtm = Tribenuron methyl + metsulfuron methyl; Pd = Pinoxaden (with cloquintocet-mexyl safener); Msm + Im=Mesosulfuron-methyl + iodosulfuron-methyl-sodium; Fn = Fenoxaprop-p-ethyl; Flm = Fluroxypyr meptyle; Flm + Ap = Fluroxypyr meptyle + amino pyralid; Ce = Carfentrazone-ethyl; Tm + Mtm plus Pd = Tribenuron methyl + metsulfuron methyl plus pinoxaden; Tm + Mtm plus Msm + Im = Tribenuron methyl + metsulfuron methyl plus Mesosulfuron-methyl + iodosulfuron-methyl-sodium; (Tm + Mtm plus Fn = Tribenuron methyl + metsulfuron methyl plus Fenoxaprop-p-ethyl; Pd plus Flm = Pinoxaden plus Fluroxypyr meptyle; Pd plus Flm + Ap = Pinoxaden plus Fluroxypyr meptyle + amino pyralid; Msm + Im plus Flm = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle; Msm + Im plus Flm + Ap = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle + amino pyralid; Fn plus Flm = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle; Fn plus Flm + Ap = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle + amino pyralid; Hw = hand weeding; Ct = Control

2018–2019, respectively as compared to weedy check plots (Table 6). The highest tiller density was recorded with mesosulfuron-methyl + iodosulfuron-methyl-sodium (460 tiller m^{-2}) in 2017–2018 and mesosulfuron-methyl + iodosulfuron-methyl-sodium plus fluroxypyr meptyle + amino pyralid (591 tiller m^{-2}) in 2018–2019 as compared to weedy check plots (Table 6). Similarly, all the weed control treatments either sole or in combination increased the total wheat biomass insignificantly in both years. All the treatments increased the wheat biomass by 25–90% and 20–95% in first and second year, respectively. Maximum biomass was achieved in hand weeded plots in 2017–18 and

Table 6: Effect of different weed control methods on wheat tiller density and wheat tiller dry weight during 2017–2018 and 2018–2019

Treatments	2017–2018				2018–2019			
	Number of tillers m^{-2}	% increase over control	Dry weight (g m^{-2})	% increase over control	Number of tillers m^{-2}	% increase over control	Dry weight (g m^{-2})	% increase over control
Tm+Mtm	305.00	77.45	1018.75	39.32	375.31	103.55	1115.62	55.55
Pd	354.69	106.36	1179.69	61.33	389.06	111.01	1235.94	72.33
Msm+Im	460.oo	167.63	1078.12	47.44	507.81	175.41	1398.44	94.99
Fn	398.44	131.81	1051.56	43.80	354.69	92.37	1123.44	56.64
Flm	295.31	71.81	915.62	25.21	245.3	33.04	862.50	20.26
Flm+Ap	350.00	103.63	980.31	34.06	256.25	38.98	916.50	27.79
Ce	290.62	69.08	934.38	27.78	368.75	99.99	959.38	33.77
Tm+Mtm plus Pd	432.81	151.81	1309.38	79.06	421.88	128.81	1309.38	82.57
Tm+Mtm plus Msm+Im	396.88	130.91	1153.12	57.69	415.62	125.41	1212.50	69.06
Tm + Mtm plus Fn	354.69	106.36	1175.00	60.68	418.75	127.11	1176.56	64.05
Pd plus Flm	325.00	89.09	1215.62	66.24	354.69	92.37	1267.19	76.69
Pd plus Flm+Ap	331.25	92.72	1154.69	57.91	410.94	122.88	1321.88	84.31
Msm+Im plus Flm	404.69	135.45	1218.75	66.67	515.62	179.65	1342.19	87.15
Msm+Im plus Flm+Ap	442.19	157.27	1140.62	55.98	590.62	220.33	1278.12	78.21
Fn plus Flm	368.75	114.54	1139.06	55.77	303.12	64.40	1139.06	58.82
Fn plus Flm+Ap	442.19	157.27	1256.25	71.79	468.75	154.23	1270.31	77.12
Hw	382.81	122.72	1382.81	89.10	504.69	173.72	1364.06	90.20
Ct	171.88	0.00	731.25	0.00	375.31	103.55	717.19	0.00
LSD (P≤ 0.05)	80.72	–	144.88	–	108.70	–	155.33	–

Where Tm+Mtm=Tribenuron methyl + metsulfuron methyl; Pd=Pinoxaden (with cloquintocet-mexyl safener); Msm+Im=Mesosulfuron-methyl + iodosulfuron-methyl-sodium; Fn=Fenoxaprop-p-ethyl; Flm=Fluroxypyr meptyle; Flm+Ap=Fluroxypyr meptyle + amino pyralid; Ce=Carfentrazone-ethyl; Tm+Mtm plus Pd=Tribenuron methyl + metsulfuron methyl plus pinoxaden; Tm+Mtm plus Msm+Im=Tribenuron methyl + metsulfuron methyl plus Mesosulfuron-methyl + iodosulfuron-methyl-sodium; (Tm + Mtm plus Fn=Tribenuron methyl + metsulfuron methyl plus Fenoxaprop-p-ethyl; Pd plus Flm=Pinoxaden plus Fluroxypyr meptyle; Pd plus Flm+Ap=Pinoxaden plus Fluroxypyr meptyle + amino pyralid; Msm+Im plus Flm=Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle; Msm+Im plus Flm+Ap=Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle + amino pyralid; Fn plus Flm= Fenoxaprop-p-ethyl plus Fluroxypyr meptyle; Fn plus Flm+Ap= Fenoxaprop-p-ethyl plus Fluroxypyr meptyle + amino pyralid; Hw=hand weeding; Ct=Control

Table 7: Effect of different weed control methods on total weed density and total dry weight during 2017–2018 and 2018–2019

Treatments	2017–2018				2018–2019			
	Number m^{-2}	% decrease (–) or increase (+) over control	Dry weight (g m^{-2})	% decrease (–) or increase (+) over control	Number m^{-2}	% decrease (–) or increase (+) over control	Dry weight (g m^{-2})	% decrease (–) or increase (+) over control
Tm+Mtm	496.25	–3.17	40.09	+6.31	335.94	–26.27	8.58	–79.51
Pd	168.74	–67.08	8.08	–78.57	90.31	–80.18	2.14	–94.89
Msm+Im	47.50	–90.73	2.52	–93.32	39.12	–91.41	14.53	–65.30
Fn	169.45	–66.94	11.78	–68.76	136.25	–70.10	33.56	–19.85
Flm	441.82	–13.79	37.97	+0.69	334.38	–26.61	29.31	–30.00
Flm+Ap	360.94	–29.57	30.99	–17.82	220.31	–51.65	12.53	–70.07
Ce	439.06	–14.33	34.34	–8.94	129.68	–71.54	0.28	–99.33
Tm+Mtm plus Pd	28.31	–94.48	2.42	–93.58	7.81	–98.29	0.26	–99.38
Tm+Mtm plus Msm+Im	32.75	–93.61	3.98	–89.45	4.69	–98.97	10.41	–75.14
Tm + Mtm plus Fn	60.30	–88.23	3.85	–89.79	57.82	–87.31	2.35	–94.39
Pd plus Flm	53.44	–89.57	3.13	–91.70	25.00	–94.51	0.74	–98.23
Pd plus Flm+Ap	42.19	–91.77	2.02	–94.64	15.81	–96.53	1.66	–96.04
Msm+Im plus Flm	63.75	–87.56	2.88	–92.36	28.12	–93.83	1.39	–96.68
Msm+Im plus Flm+Ap	59.38	–88.41	3.21	–91.49	16.38	–96.40	12.56	–70.00
Fn plus Flm	156.00	–69.56	15.58	–58.68	133.00	–70.81	2.68	–93.60
Fn plus Flm+Ap	32.82	–93.60	1.81	–95.20	38.94	–91.45	5.72	–86.34
Hw	60.62	–88.17	6.04	–83.98	30.00	–93.42	41.87	0.00
Ct	512.50	0.00	37.71	0.00	455.62	0.00	8.58	–79.51
LSD (P≤ 0.05)	184.69	–	11.31	–	180.25	–	10.58	–

Where Tm+Mtm=Tribenuron methyl + metsulfuron methyl; Pd=Pinoxaden (with cloquintocet-mexyl safener); Msm+Im=Mesosulfuron-methyl + iodosulfuron-methyl-sodium; Fn=Fenoxaprop-p-ethyl; Flm=Fluroxypyr meptyle; Flm+Ap=Fluroxypyr meptyle + amino pyralid; Ce=Carfentrazone-ethyl; Tm+Mtm plus Pd=Tribenuron methyl + metsulfuron methyl plus pinoxaden; Tm+Mtm plus Msm+Im=Tribenuron methyl + metsulfuron methyl plus Mesosulfuron-methyl + iodosulfuron-methyl-sodium; (Tm + Mtm plus Fn=Tribenuron methyl + metsulfuron methyl plus Fenoxaprop-p-ethyl; Pd plus Flm=Pinoxaden plus Fluroxypyr meptyle; Pd plus Flm+Ap=Pinoxaden plus Fluroxypyr meptyle + amino pyralid; Msm+Im plus Flm=Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle; Msm+Im plus Flm+Ap=Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle + amino pyralid; Fn plus Flm= Fenoxaprop-p-ethyl plus Fluroxypyr meptyle; Fn plus Flm+Ap= Fenoxaprop-p-ethyl plus Fluroxypyr meptyle + amino pyralid; Hw=hand weeding; Ct=Control

in plots where mesosulfuron-methyl + iodosulfuron-methyl-sodium was applied and it was followed by hand weeded plots (Table 6).

Total number of weeds m^{-2} and total biomass at 70 DAS

All the chemical applications either sole or in combinations reduced both weed density and significantly as compared to weedy check during both the years. In case of sole application, mesosulfuron-methyl + iodosulfuron-methyl-sodium reduced the weed density by 91 and 92% in 2017–2018 and 2018–2019, respectively. Likewise, all the combinations have weed density reduction by 88–94% and 90–99% in 2017–2018 and 2018–2019, respectively as compared to weedy check plots except fenoxaprop-p-ethyl plus fluroxypyr meptyle that reduced the density only by 70 and 59% (Table 7). In case of weed biomass, all the chemical applications either sole or in combinations reduced total weed biomass significantly as compared to weedy check plots during both the years (Table 7). In case of sole

Table 8: Effect of different weed control measures on grain yield components and grain yield during 2017–2018 and 2018–2019

Treatments	2017–2018						2018–2019					
	Number of spikes m^{-2}	Number of grains $spike^{-1}$	1000 grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest Index	Number of spikes m^{-2}	Number of grains $spike^{-1}$	1000 grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest Index
Tm + Mtm	305.00	35.3	39.56	3.50	7.35	0.32	375.31	27.5	43.86	3.11	8.65	0.26
Pd	354.69	32.0	46.65	4.10	9.70	0.30	389.06	31.6	40.89	4.21	10.15	0.29
Msm + Im	460.00	39.8	42.68	4.49	9.80	0.31	507.81	40.5	36.58	4.72	9.50	0.33
Fn	398.44	31.5	51.33	3.06	7.10	0.30	354.69	32.8	39.66	3.32	9.50	0.26
Flm	295.31	32.9	39.01	3.05	6.90	0.31	245.30	29.0	44.88	3.03	6.95	0.3
Flm + Ap	350.00	33.1	61.04	2.71	8.60	0.24	256.25	39.1	46.04	2.66	5.95	0.31
Ce	290.62	35.3	39.69	2.20	5.10	0.30	368.75	29.7	44.51	2.24	7.65	0.23
Tm + Mtm plus Pd	432.81	38.2	46.98	5.21	11.15	0.32	421.88	39.1	48.76	5.38	12.20	0.31
Tm + Mtm plus Msm + Im	396.88	36.7	44.09	4.82	10.15	0.32	415.62	36.2	46.94	4.82	10.15	0.32
Tm + Mtm plus Fn	354.69	35.6	48.15	3.73	7.95	0.32	418.75	35.6	36.02	4.03	10.25	0.28
Pd plus Flm	325.00	29.7	50.04	4.48	13.23	0.25	354.69	27.5	33.75	4.86	9.50	0.34
Pd plus Flm + Ap	331.25	28.7	43.47	4.77	9.40	0.34	410.94	39.1	40.76	4.77	9.40	0.34
Msm + Im plus Flm	404.69	39.1	39.18	5.31	5.60	0.49	515.62	41.6	46.96	5.25	8.15	0.39
Msm + Im plus Flm + Ap	442.19	35.6	39.35	4.50	7.25	0.38	590.62	40.2	37.28	4.92	9.35	0.34
Fn plus Flm	368.75	34.3	41.25	4.06	10.50	0.28	303.12	35.7	42.52	4.16	8.10	0.34
Fn plus Flm + Ap	442.19	31.0	45.30	3.87	5.75	0.40	468.75	37.8	50.23	4.64	7.65	0.38
Hw	382.81	34.8	39.51	5.55	7.25	0.43	504.69	40.9	62.09	5.32	12.95	0.29
Ct	171.88	23.6	38.87	2.04	5.25	0.28	184.38	27.9	36.54	2.16	7.00	0.24
LSD ($P \leq 0.05$)	70.93	8.48	10.91	0.89	8.48	0.14	83.31	4.79	9.46	0.94	7.84	0.12

Where, Tm + Mtm = Tribenuron methyl + metsulfuron methyl; Pd = Pinoxaden (with cloquintocet-mexyl safener); Msm + Im = Mesosulfuron-methyl + iodosulfuron-methyl-sodium; Fn = Fenoxaprop-p-ethyl; Flm = Fluroxypyr meptyle; Flm + Ap = Fluroxypyr meptyle + amino pyralid; Ce = Carfentrazone-ethyl; Tm + Mtm plus Pd = Tribenuron methyl + metsulfuron methyl plus pinoxaden; Tm + Mtm plus Msm + Im = Tribenuron methyl + metsulfuron methyl plus Mesosulfuron-methyl + iodosulfuron-methyl-sodium; (Tm + Mtm plus Fn = Tribenuron methyl + metsulfuron methyl plus Fenoxaprop-p-ethyl; Pd plus Flm = Pinoxaden plus Fluroxypyr meptyle; Pd plus Flm + Ap = Pinoxaden plus Fluroxypyr meptyle + amino pyralid; Msm + Im plus Flm = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle; Msm + Im plus Flm + Ap = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle + amino pyralid; Fn plus Flm = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle; Fn plus Flm + Ap = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle + amino pyralid; Hw = hand weeding; Ct = Control

application, mesosulfuron-methyl + iodosulfuron-methyl-sodium reduced weed biomass by 91 and 93% in 2017–2018 and 2018–2019, respectively. Similarly, all the combinations have weed biomass reduction by 18–95% and 20–98% in 2017–2018 and 2018–2019 (Table 7), respectively as compared to season long weedy plots except tribenuron methyl + metsulfuron methyl and fluroxypyr meptyle in 2017–2018 (Table 7).

Grain yield components and grain yield

Number of spikes m^{-2} of wheat was significantly affected by weed control treatments (Table 8). All the chemical sole or in combination produced higher numbers of spikes as compared with the control. The weed control treatments *viz*., manual hand weeding, mesosulfuron-methyl + iodosulfuron-methyl-sodium either applied alone (460 and 508 spikes m^{-2}) or in combination with fluroxypyr meptyle + amino pyralid (442 and 590 spikes m^{-2}) and fluroxypyr meptyle (404 and 515 spikes m^{-2}) produced relatively higher number of spikes than other weed control treatments (172 and 184 spikes m^{-2}) during 2017–18 and 2018–19, respectively. Whereas, lower spike density (295 and 245 spikes m^{-2}) among the chemical treatments was observed with fluroxypyr meptyle in 2017–2018 and 2018–2019, respectively (Table 8). As far as number of grains $spike^{-1}$ is concerned, it was recorded that the plots applied with the sole application of mesosulfuron-methyl + iodosulfuron-methyl-sodium (40 and 41 grains $spike^{-1}$), its combinations with fluroxypyr meptyle (39 and 42 grains $spike^{-1}$) and fluroxypyr meptyle + amino pyralid (36 and 40 grains $spike^{-1}$) during 2017–2018 and 2018–2019, respectively (Table 8). The treatment tribenuron methyl + metsulfuron methyl plus pinoxaden (38 and 39 grains $spike^{-1}$) also produced higher number of grains $spike^{-1}$ as compared to other treatments during first and second year respectively. The lowest number of grains $spike^{-1}$ (24 and 28) was observed from control treatment during both years (Table 8). Among different herbicide treatments, maximum 1000 grain weight was achieved from fluroxypyr meptyle + amino pyralid (61.04 g) followed by applications of fenoxaprop-p-ethyl (51.33 g), pinoxaden plus fluroxypyr meptyle (50.04g) and tribenuron methyl + metsulfuron methyl plus pinoxaden (48.15 g) as compared with the control during the year 2017–18 (Table 8). In the second year (2018–2019) maximum 1000 grain weight was observed from the weed free plots (62.09 g) followed by herbicide application of fenoxaprop-p-ethyl plus fluroxypyr meptyle + amino pyralid (50.23 g) and tribenuron methyl + metsulfuron methyl plus pinoxaden (48.76 g) (Table 8). The minimum 1000 grain weight was observed (38.87 and 36.54 g) for weed check plot in 2017-2018 and 2018–2019, respectively (Table 8).

All weed control treatments improved grain yield over control during both years (Table 8). The highest grain yield (5.55 t ha^{-1}) was recorded from manual weeding followed by chemical weed control by mesosulfuron-methyl + iodosulfuron-methyl-sodium plus fluroxypyr meptyle (5.31 t ha^{-1}) during 2017–2018, whereas in 2018–2019 mesosulfuron-methyl + iodosulfuron-methyl-sodium plus fluroxypyr meptyle (5.38 t ha^{-1}) produced more grain yield over all the treatments including hand weeding. The grain

Table 9: Production cost (US \$ ha^{-1}) of different weed control measures during 2017–2018 and 2018–2019

Production cost (US \$ ha^{-1})								
Treatments	Weed Management cost	Land preparation/ sowing cost	Seed cost	Fertilizer cost	Irrigation cost	Crop Management cost	Harvesting cost	Total production cost
Tm + Mtm	10.50	43.23	38.59	163.64	37.05	48.17	37.05	378.22
Pd	14.67	43.23	38.59	163.64	37.05	48.17	37.05	382.39
Msm + Im	16.98	43.23	38.59	163.64	37.05	48.17	37.05	384.70
Fn	16.98	43.23	38.59	163.64	37.05	48.17	37.05	384.70
Flm	19.68	43.23	38.59	163.64	37.05	48.17	37.05	387.41
Flm + Ap	10.03	43.23	38.59	163.64	37.05	48.17	37.05	377.76
Ce	8.10	43.23	38.59	163.64	37.05	48.17	37.05	375.83
Tm + Mtm plus Pd	25.16	43.23	38.59	163.64	37.05	48.17	37.05	392.89
Tm + Mtm plus Msm + Im	27.48	43.23	38.59	163.64	37.05	48.17	37.05	395.20
Tm + Mtm plus Fn	27.48	43.23	38.59	163.64	37.05	48.17	37.05	395.20
Pd plus Flm	34.35	43.23	38.59	163.64	37.05	48.17	37.05	402.07
Pd plus Flm + Ap	24.70	43.23	38.59	163.64	37.05	48.17	37.05	392.42
Msm + Im plus Flm	36.66	43.23	38.59	163.64	37.05	48.17	37.05	404.39
Msm + Im plus Flm + Ap	27.02	43.23	38.59	163.64	37.05	48.17	37.05	394.74
Fn plus Flm	36.66	43.23	38.59	163.64	37.05	48.17	37.05	404.39
Fn plus Flm + Ap	27.02	43.23	38.59	163.64	37.05	48.17	37.05	394.74
Hw	123.50	43.23	38.59	163.64	37.05	48.17	37.05	491.22
Ct	0.00	43.23	38.59	163.64	37.05	48.17	37.05	367.72

Where, PKR is Pakistan's currency. US\$1 = PKR 160. (Weeding cost = 25 man days x US\$ 4.9375 per day). Tm + Mtm = Tribenuron methyl + metsulfuron methyl; Pd = Pinoxaden (with cloquintocet-mexyl safener); Msm + Im = Mesosulfuron-methyl + iodosulfuron-methyl-sodium; Fn = Fenoxaprop-p-ethyl; Flm = Fluroxypyr meptyle; Flm + Ap = Fluroxypyr meptyle + amino pyralid; Ce = Carfentrazone-ethyl; Tm + Mtm plus Pd = Tribenuron methyl + metsulfuron methyl plus pinoxaden; Tm + Mtm plus Msm + Im = Tribenuron methyl + metsulfuron methyl plus Mesosulfuron-methyl + iodosulfuron-methyl-sodium; (Tm + Mtm plus Fn = Tribenuron methyl + metsulfuron methyl plus Fenoxaprop-p-ethyl; Pd plus Flm = Pinoxaden plus Fluroxypyr meptyle; Pd plus Flm + Ap = Pinoxaden plus Fluroxypyr meptyle + amino pyralid; Msm + Im plus Flm = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle; Msm + Im plus Flm + Ap = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle + amino pyralid; Fn plus Flm = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle; Fn plus Flm + Ap= Fenoxaprop-p-ethyl plus Fluroxypyr meptyle + amino pyralid; Hw = hand weeding; Ct = Control

Table 10: Economics of different weed control measures on grand income, net profit and cost-benefit ratio for 2017–2018 and 2018–2019

Treatments		2017-2018					2018-2019				
	Total cost (US \$ ha^{-1})	Grain yield income (\$ ha^{-1})	Straw income (\$ ha^{-1})	Grand income (\$ ha^{-1})	Net profit (\$ ha^{-1})	Cost-benefit ratio	Grain yield income (\$ ha^{-1})	Straw income (\$ ha^{-1})	Grand Income (\$ ha^{-1})	Net profit (\$ ha^{-1})	Cost-benefit ratio
Tm + Mtm	378.22	875.00	57.42	932.42	554.20	1.47	778	67.58	845.08	466.86	1.23
Pd	382.39	1025.00	75.78	1100.78	718.39	1.88	1053	79.30	1131.80	749.41	1.96
Msm + Im	384.70	1122.50	76.56	1199.06	814.36	2.12	1180	74.22	1254.22	869.52	2.26
Fn	384.70	765.00	55.47	820.47	435.77	1.13	830	74.22	904.22	519.52	1.35
Flm	387.41	762.50	53.91	816.41	429.00	1.11	758	54.30	811.80	424.39	1.10
Flm + Ap	377.76	677.50	67.19	744.69	366.93	0.97	665	46.48	711.48	333.73	0.88
Ce	375.83	550.00	39.84	589.84	214.02	0.57	560	59.77	619.77	243.94	0.65
Tm + Mtm plus Pd	392.89	1302.50	87.11	1389.61	996.72	2.54	1345	95.31	1440.31	1047.43	2.67
Tm + Mtm plus Msm + Im	395.20	1205.00	79.30	1284.30	889.10	2.25	1205	79.30	1284.30	889.10	2.25
Tm + Mtm plus Fn	395.20	932.50	62.11	994.61	599.41	1.52	1008	80.08	1087.58	692.38	1.75
Pd plus Flm	402.07	1120.00	103.36	1223.36	821.29	2.04	1215	74.22	1289.22	887.15	2.21
Pd plus Flm + Ap	392.42	1192.50	73.44	1265.94	873.52	2.23	1193	73.44	1265.94	873.52	2.23
Msm + Im plus Flm	404.39	1327.50	43.75	1371.25	966.86	2.39	1313	63.67	1376.17	971.79	2.40
Msm + Im plus Flm + Ap	394.74	1125.00	56.64	1181.64	786.90	1.99	1230	73.05	1303.05	908.31	2.30
Fn plus Flm	404.39	1015.00	82.03	1097.03	692.64	1.71	1040	63.28	1103.28	698.89	1.73
Fn plus Flm + Ap	394.74	967.50	44.92	1012.42	617.68	1.56	1160	59.77	1219.77	825.03	2.09
Hw	367.72	510.00	56.64	1444.14	952.92	1.94	1330	101.17	1431.17	939.95	1.91
Ct	491.22	1387.50	41.02	551.02	183.29	0.50	540	54.69	594.69	226.97	0.62

Where, PKR is currency of Pakistan, PKR 160 = US\$1, market price of wheat = 250 \$ t^{-1}, market price of straw = 3.85 \$ t^{-1}, grand income = [(wheat grain yield × market price of wheat t^{-1}) + (straw yield × market price of straw t^{-1})], net profit= (grand income – total cost of production). benefit-cost ratio = net benefit / total cost of production); Tm + Mtm = Tribenuron methyl + metsulfuron methyl; Pd = Pinoxaden (with cloquintocet-mexyl safener); Msm + Im = Mesosulfuron-methyl + iodosulfuron-methyl-sodium; Fn = Fenoxaprop-p-ethyl; Flm = Fluroxypyr meptyle; Flm + Ap = Fluroxypyr meptyle + amino pyralid; Ce = Carfentrazone-ethyl; Tm + Mtm plus Pd = Tribenuron methyl + metsulfuron methyl plus pinoxaden; Tm + Mtm plus Msm + Im = Tribenuron methyl + metsulfuron methyl plus Mesosulfuron-methyl + iodosulfuron-methyl-sodium; (Tm + Mtm plus Fn = Tribenuron methyl + metsulfuron methyl plus Fenoxaprop-p-ethyl; Pd plus Flm = Pinoxaden plus Fluroxypyr meptyle; Pd plus Flm + Ap = Pinoxaden plus Fluroxypyr meptyle + amino pyralid; Msm + Im plus Flm = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle; Msm + Im plus Flm + Ap = Mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle + amino pyralid; Fn plus Flm = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle; Fn plus Flm + Ap = Fenoxaprop-p-ethyl plus Fluroxypyr meptyle + amino pyralid; Hw = hand weeding; Ct = Control

yield (2.04 and 2.2 t ha^{-1}) was lowest for the control treatment in first and second year (Table 8). The straw yield significantly affected by the weed control methods and most of the treatments had higher straw yield over the control during both years (Table 8). In 2017–2018, maximum straw yield (13.23 t ha^{-1}) was produced from the treatment pinoxaden plus fluroxypyr meptyle followed by tribenuron methyl + metsulfuron methyl plus pinoxaden (11.15 t ha^{-1}) and fenoxaprop-p-ethyl plus fluroxypyr meptyle (10.50 t ha^{-1}). In 2018–2019 (Table 8), the highest straw yield was achieved in hand weeding treatment (12.95 t ha^{-1}) followed by tribenuron methyl + metsulfuron methyl plus pinoxaden

(12.20 t ha^{-1}) and tribenuron methyl + metsulfuron methyl plus fenoxaprop-p-ethyl (10.25 t ha^{-1}). The lowest straw yield was recorded from the sole application of fluroxypyr meptyle + amino pyralid (5.95 t ha^{-1}) followed by Fluroxypyr meptyle (6.95 t ha^{-1}) and control treatment (7.00 t ha^{-1}). For the harvest index, the highest was observed in mesosulfuron-methyl + iodosulfuron-methyl-sodium plus fluroxypyr meptyle (0.49 and 0.39) and fenoxaprop-p-ethyl plus fluroxypyr meptyle + amino pyralid (0.40 and 0.38) in 2017–2018 and 2018–2019, respectively as compared to weedy check plots where it was minimum in both the years (Table 8).

Cost-benefit ratio (CBR)

The highest CBR was achieved with tribenuron methyl + metsulfuron methyl plus pinoxaden (2.54 and 2.67) and mesosulfuron-methyl + iodosulfuron-methyl-sodium plus Fluroxypyr meptyle (2.39 and 2.40) in 2017–2018 and 2018–2019, respectively as compared to control treatment (Table 9 and 10).

Relationship between weed biomass and wheat grain Yield

The above-ground biomass of weeds and yield of wheat were negatively correlated with each other in each year, as weeds biomass increased, the analogous decline in wheat grain yield was observed. Regression results depicted that each 1 g m^{-2} weed biomass increase resulted in a decrease of 56 and 64 kg ha^{-1} of wheat grain yield at harvest during 2017–2018 and 2018–2019, respectively (Fig. 1a, b).

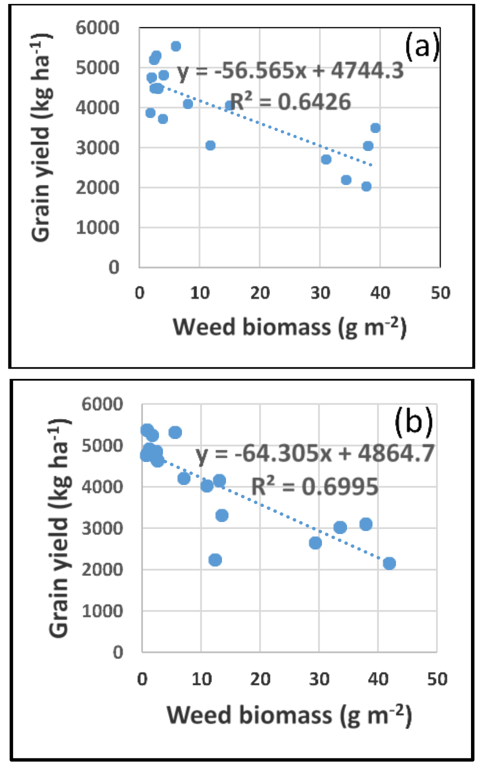

Fig. 1: Relationship between weeds biomass and wheat grain yield during 2017-2018 (**a**) and 2018-2019 (**b**)

Discussion

Application of mixed herbicides can prevent evolution of herbicide-resistant weeds because of using more than one active ingredient (Galon *et al.* 2018). The results showed reduction in density and biomass of littleseed canarygrass in all herbicide combinations except sole application of fluroxypyr meptyle, tribenuron methyl + metsulfuron methyl, carfentrazone-ethyl and cluroxypyr meptyle + amino pyralid that remained ineffective to suppress this weed. Fenoxaprop-p-ethyl, pinoxaden and Mesosulfuron-methyl + iodosulfuron-methyl-sodium decreased the density and biomass of littleseed canarygrass efficiently either applied alone or in different combinations. Some of the previous studies also reported decline in total weeds density by 96% with application of mesosulfuron-methyl + iodosulfuron-methyl-sodium at the rate of 14.4 g a.i. ha^{-1} (Razzaq *et al*. 2012) because the herbicides inhibiting the activity of Acetyl CoA carboxylase (ACCase) enzyme proved effective against littleseed canarygrass. Moreover, in another study, pinoxaden, fenoxaprop plus metribuzin and mesosulfuron plus iodosulfuron were equally effective on littleseed canarygrass when applied at main stem and one tiller stage of wheat. Application of pinoxaden at main stem and three tiller stage of wheat, gave more than 90% control of littleseed canarygrass and the highest wheat grain yield (Rasool *et al*. 2017). However, these results are contrary to those of Chhokar and Sharma (2008) who observed resistance of littleseed canarygrass to ACCase inhibitors, photosynthesis at the photosystem II site A and acetolactate synthase inhibition in India.

The results of this study demonstrated effectiveness of fluroxypyr meptyle, fluroxypyr meptyle + amino pyralid, carfentrazone-ethyl, Mesosulfuron-methyl + iodosulfuron-methyl-sodium and tribenuron methyl + metsulfuron methyl against density and biomass of yellow pea. The control of the weed may be ascribed to action of the herbicides on normal functioning of ALS and the disruption of cell division in meristematic tissues. Pinoxaden and fenoxaprop-p-ethyl were failed to control the weed possibly due to resistance of the weed against ACCase mode of action. In a previous study, it was also found that plastids of dicotyledonous plants contain herbicide-resistant multisubunit ACCases (Tong 2013). Bur clover also demonstrated similar response against all treatments as observed in case of yellow pea. Fenoxaprop-p-ethyl and pinoxaden were also found helpless against these weeds. The control of the weeds from other treatments was obtained due to the vulnerability of the weed towards ALS and disruption of mitotic cell division modes of actions. The weed was among the broad-leaved weeds that were found resistant to ACCase mode of action (Tong 2013).

Wheat tiller density was improved by all weed control treatments and it might be attributed to better weed control which decreased crop weed competition so the resources were better utilized by the crop to produce higher number of productive tillers per unit area (Hussain *et al.* 2014). Combined application of herbicides increased number of tillers better than sole application due to efficient weed management. The low tiller density from control plots may be due to higher crop-weed competition during the study (Cheema and Akhtar 2005; Hussain *et al*. 2017; Naeem *et al*. 2021). Hence, weeds are the worst competitors for draining more resources like space, light, air etc. due to vigorous growth (Leghari *et al.* 2015). Herbicide combinations, controlling both type of weeds (broad leaf and grasses) and hand weeding improved number of grains spike^{-1} better than sole herbicide application. The study results depicted that the number of grains spike^{-1} can be increased by controlling weeds (Alvi *et al*. 2004). Therefore, it is inevitable to manage grassy and broad leaf weeds for obtaining higher number of grains spike^{-1} in wheat which contribute mainly to grain yield. Similarly, grain weight is another important component mainly contributing to grain yield and our study demonstrated that good growth conditions observed for weed free plots produced healthier crop ultimately having more grain weight. This might be because of better source sink relationship at grain formation stage (Hussain *et al*. 2003; Alvi *et al*. 2004).

Grain yield contributing parameters and grain yield were affected significantly by chemical weed management and increased grain yield over control treatment. This increase in grain yield may be ascribed to better weed control leading to more number of fertile tillers, better crop growth, higher number of grains spike^{-1} and heavier grains. Hand weeding increased the yield to maximum level due to efficient weed management. All herbicide combinations also increased yield to almost similar level as attained by hand weeding. Earlier studies also reported similar wheat yield by hand weeding and application of mesosulfuron-methyl + iodosulfuron-methyl-sodium 3.6 WG & 14.4 g a.i. ha^{-1} (Ashraf and Akhlaq 2007; Hussain *et al*. 2014). Lower crop yields obtained from the control treatment may be attributed to intensive weed-crop competition, depleting the soil from essential nutrients and eventually depriving of the crop requirements. Results of our study confirmed earlier findings that weeds compete with crop for essential resources and eventually lower crop yields (Khan and Marwat 2006; Leghari *et al*. 2015). The results of the study depicted a negative correlation between weeds biomass and wheat grain yield. Weed biomass is adversely correlated with grain yield of wheat. Results showed that the increased biomass of weeds correspondingly reduced the wheat biomass and grain yield in both years. The reason might be that weeds consume the major portion of the nutrients, reducing their availability to the wheat plants and resulting in low wheat biomass and grain production (Khan and Marwat 2006).

Conclusion

It is imperative to control both broad and narrow leaf weeds for obtaining maximum wheat crop yields that can be achieved by the application of either broad spectrum herbicides or herbicide combinations capable of controlling both types of weeds. Results of this study concluded that herbicides combinations mesosulfuron-methyl + iodosulfuron-methyl-sodium plus fluroxypyr meptyle, and tribenuron methyl + metsulfuron methyl plus pinoxaden were the most effective and economical to get higher economical yield by managing wheat weeds.

Author Contributions

THA and SI planned, designed, executed the experiments and wrote the manuscript, MUS analyzed the data statistically, SH wrote the discussion, UBK compiled the data and SA revised and improved the language of the manuscript.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Ethics Approval

The authors declare that the work is written with due consideration of ethical standards. The study was conducted in accordance with the ethical principles approved by the Ethics Committee of Federal State Budgetary Educational Establishment of Higher Education “Bashkir State Agrarian University” (Protocol № 6 of 13.06.2020).

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