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INFLUENCE OF VARIOUS HERBICIDE MIXTURES ON WEED DYNAMICS, GROWTH AND YIELD IN WHEAT (*Triticum aestivum* L.)

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ABSTRACT

A two-year field experiment was conducted during *rabi* seasons of 2016-17 and 2017-18 at Agricultural Farm of Palli Siksha Bhavana, Visva-Bharati, Sriniketan, West Bengal (India) to assess the effects of herbicide mixtures on weed population, weed biomass, weed control efficiency, weed index, crop dry weight and grain yield in wheat crop. Eight herbicide treatments along with weed-free and weedy check were evaluated in a completely randomized block design with three replications. Post-emergence application of sulfosulfuron (25 g ha^{-1}) + metsulfuron methyl (2 g ha^{-1}) 30 days after seed sowing proved very effective against broad-leaved weeds and annual grasses. The above treatment recorded significantly lower density and biomass of weeds as compared to all other treatments. After weed-free plot, maximum crop dry weight (514.35 g m^{-2}) and highest grain yield (3.03 t ha^{-1}) were obtained from sulfosulfuron + metsulfuron methyl (25 g a.i ha^{-1}+ 2 g a.i ha^{-1}) treated plot. All other herbicide mixtures tested also proved very effective in controlling the weeds and increased wheat yield significantly. The herbicide mixtures could be helpful to prevent or delay the development of herbicide resistance in weeds and thus may reduce herbicide residues in soil.

Keywords: Herbicide, metsulfuron, sulfosulfuron, weed, wheat

INTRODUCTION

Wheat (*Triticum aestivum* L.) belongs to *Poaceae* family of plants is the staple food of over 35% of people globally and more than 50% people in India, and ensures world food security (Dass *et al*., 2018). This major cereal crop provides 70-90% of all calories and 66-90% of the protein consumed in developing countries (Agha *et al*., 2016). The importance of wheat is also reflected from a large acreage under its cultivation. Worldwide, wheat is grown over an area of 220 million ha (m ha), about half of which lies in developing countries. In India, wheat is cultivated on an area of 30.6 m ha with annual production of 98.38 million tonnes (m t) and average productivity of 3.22 t ha^{-1} (Chandana *et al*., 2019). Presently, among the cereal crops grown in India wheat comes next to rice in terms of area and production.

Weeds are one of the major constraints in wheat production as they reduce productivity due to competition, allelopathy, by providing habitats for pathogens as well as serving as alternate host for various insects and fungi and increase harvest cost (Abbas *et al*., 2009; Dass *et al*., 2017). Wheat crop is invaded by a large number of fast growing weed species. In India, the average yield losses in wheat due to weeds vary from 10 to 38% across different wheat growing regions depending upon the time and intensity of weed infestation (Yadav *et al.*, 2019). The prominent weeds found in wheat fields are *Anagallis arvensis, Avena fatua, Ageratum conyzoides, Chenopodium album, Cynodon dactylon, Convolvulus arvensis, Digitaria sanguinalis, Gnaphalium indicum, Gomphrena* spp., *Solanum nigrum*, etc.

Chemical weed control is a preferred practice due to scarce and costly labour as well as lesser feasibility of mechanical or manual weeding. The weeds showed multiple herbicide resistance due to continuous use of herbicide having same mode of action and/or class (Singh *et al.*, 2009). For effective management of complex weed flora, there is need to use mixture of existing herbicides, which should have a wide spectrum of weed control (Chopra *et al*., 2015). Mixing two different herbicides and applying them simultaneously widens the spectrum of weed control, saves time and application cost (Rana *et al.,* 2016). Herbicides mixture increases weed control efficacy against complex weed flora (Singh *et al.*, 2011), and also helpful in delaying herbicide resistance. Herbicidal control, on the other hand, will prevent the costly input being taken up by weeds and thus save the management time and cost and increasing the yield and result the higher profit. Considering above facts, the present experiment was planned to assess the effect of tank mix herbicide molecules for broad spectrum weed control in wheat cultivation.

MATERIALS AND METHODS

The experiment was laid out at Agricultural Farm, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, West Bengal (India) during *rabi* seasons of 2016-17 and 2017-18 in a completely randomized block design with each treatment replicated three times. The soil of experimental field was sandy loam in texture, acidic in reaction (pH 5.61) and low in organic carbon (0.37) and available nitrogen (126.34 kg ha^{-1}) but medium in available phosphorus (25.11 kg ha^{-1}) and available potassium (131.29 kg ha^{-1}). Electrical conductivity of soil was 0.2 dS m^{-1}. The treatments comprised of clodinafop propargyl + metsulfuron methyl (60 g a.i. ha^{-1} + 4 g a.i. ha^{-1}), clodinafop propargyl + 2,4-D (60 g a.i. ha^{-1} + 400 g a. i. ha^{-1}), sulfosulfuron + metsulfuron methyl (25 g a.i ha^{-1} + 2 g a.i ha^{-1}), pinoxaden + carfentrazone (50 g a.i ha^{-1} + 20 g a.i ha^{-1}), pinoxaden + metsulfuron methyl (50 g a.i ha^{-1} + 4 g a.i ha^{-1}), pinoxaden + 2, 4-D (50 g a.i ha^{-1} + 500 g a.i ha^{-1}), pinoxaden + sulfosulfuron (50 g a.i ha^{-1} + 25 g a.i ha^{-1}), isoproturon + 2, 4-D (1000 g a.i ha^{-1} + 500 g a.i ha^{-1}), unweeded control and weed-free check. All the herbicides were applied as tank mix and sprayed 30 days after crop sowing (DAS) of wheat. Water was applied @ 450 L ha^{-1}. Recommended dose of fertilizer used was 100:50:50 kg N:P_2O_5:K_2O ha^{-1}, respectively, which was applied through urea, SSP and MOP. Half of the nitrogen, full dose of phosphorus and potassium were applied before sowing. Remaining half of nitrogen was applied in two equal splits at crown root initiation and maximum tillering stages of crop. Crop was sown at a row spacing of 20 cm. The weekly average maximum and minimum temperature during the cropping season (December-March) from 48^{th} week of 2016 to 13^{th} week of 2017 ranged from 23.3 to 37.66°C and 9.20 to 25.36°C, respectively, and from 48^{th} week of 2017 to 13^{th} week of 2018 ranged from 22.26 to 34.01°C and 6.99 to 20.91°C, respectively. The total rainfall received during the crop season (December-March) of 2016-17 and 2017-18 was 8.5 and 11.4 mm, respectively.

Population of different categories of weeds at 45, 65 and 85 DAS was recorded by placing the 0.5 m^2 quadrate randomly in the sampling area. Weeds were counted species-wise and differentiated into categories of grass and broad leaf weeds (BLWs) and were expressed as number m^{-2}. The weed samples for dry weight were collected from the area used for weed count on the same dates (45, 65, 85 DAS). The weeds were uprooted from the area under each quadrate placed in each plot. Weeds were cleaned by washing, kept in sunlight for few hours and were kept in a hot air oven for drying at 70°C for 72 h or more till constant weights were recorded. Samples were kept in desiccators for cooling in dehumidified condition. Then dry weights were recorded with an electronic balance and expressed as g m^{-2}. The mean data of weeds were subjected to square root transformation [$\sqrt{(x+0.5)}$] to normalize their distribution. Weed control efficiency (WCE) was determined by using the formula given by Mani *et al*. (1973).

$$\text{WCE (\%)} = \frac{\text{Weed dry matter in control plot} - \text{Weed dry matter in treated plot} \times 100}{\text{Weed dry matter in control plot}}$$

Weed index (WI) was determined by using the following formula given by Gill and Kumar (1966).

$$\text{WI (\%)} = \frac{\text{Average crop yield in weed free plot} - \text{Average crop yield in plot under treatment} \times 100}{\text{Average crop yield in weed free plot}}$$

To study the influence of different treatments on dry matter production, three plant samples from each plot were selected randomly at 45, 60, 75 and 90 DAS, air-dried and kept in an hot air oven at 70°C for 72 h. The dry weight of samples was recorded by using electrical balance and expressed in g m^2. Crop growth rate (CGR) was determined with the help of formula given by Radford (1967).

$$\text{CGR (g m}^{-2}\text{ day}^{-1}) = \frac{w2 - w1}{t2 - t1}$$

Where, w_2 and w_1 are the final and initial total dry weights (g) of all plants per unit land area (m^2) at the time t_2 and t_1, respectively. The crop was harvested from the whole area of the plot then dried and threshed and then the grains were cleaned. The straw yield from each plot was weighed separately using a weighing balance. Both grain and straw yield was expressed in t ha^{-1}.

The data obtained was statistically analyzed using analysis of variance (ANOVA) method Panse and Sukhatme (1978). Wherever necessary the data was transformed to $\sqrt{(X+0.5)}$ prior to statistical analysis and the values were compared for significant difference.

RESULTS AND DISCUSSION

The experimental field was found infested with both grassy and broad-leaved weeds. The most dominant grassy weeds observed were *Digiteria sanguinalis* and *Cynodon dactylon*; while amongst the broad-leaved weeds *Spilanthes acmella, Gnaphailun indicum, Solanum nigrum, Ageratum conyzoides* and *Chenopodium album* were most dominant.

Effect of herbicidal treatments on weeds

Weed density: Data on population of total number of weeds as observed in 45, 65 and 85 DAS has been presented in Table 1. Total weed population was significantly influenced due to different weed control treatments at all stages of crop growth during both the study years. Next to weed-free plot, PoE application of sulfosulfuron + metsulfuron @ 25 g a.i. ha^{-1} + 2 g a.i. ha^{-1} has been found most effective to control the weeds as compared to other herbicide at all the stages and this treatment was at par with pinoxaden + sulfosulfuron @ 50 g a.i ha^{-1} + 25 g a.i ha^{-1}, pinoxaden + metsulfuron methyl @ 50 g a.i ha^{-1} + 4 g a.i ha^{-1} and clodinafop propargyl + metsulfuron methyl @ 60g a.i. ha^{-1} + 4 g a.i. ha^{-1} treatments. From the pooled data of 45, 65 and 85 DAS, it was clear that sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 2 g a.i. ha^{-1} reduced weed density by 73.4, 65.65 and 59.32%, respectively, as compared to unweeded control plot. By and large, all the herbicidal treatments reduced weed population significantly over unweeded control at 45, 65 and 85 DAS of crop growth, because all the

Table 1: Effect of herbicide mixtures on weed population (No. m^{-2}) at different growth stages

Treatments (g a.i ha^{-1})	45 DAS			65 DAS			85 DAS		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Clodinafop propargyl (60) + Metsulfuron methyl (4)	10.02 (99.84)	10.07 (100.85)	10.04 (100.34)	8.44 (71.14)	8.61 (74.03)	8.55 (72.58)	6.72 (45.35)	6.88 (47.12)	6.83 (46.23)
Clodinafop propargyl (60) + 2,4-D (400)	10.18 (103.49)	10.31 (105.82)	10.25 (104.65)	9.02 (81.51)	9.29 (86.11)	9.16 (83.81)	7.89 (62.40)	8.10 (65.12)	8.01 (73.76)
Sulfosulfuron (25) + Metsulfuron methyl (2)	8.85 (78.18)	9.02 (81)	8.94 (79.59)	5.96 (35.85)	6.24 (38.44)	6.12 (37.14)	3.87 (14.81)	4.08 (16.31)	4.00 (15.56)
Pinoxaden (50) + Carfentrazone (20)	10.35 (107.10)	10.50 (109.72)	10.43 (108.41)	9.61 (92.41)	9.80 (95.72)	9.72 (94.06)	8.26 (68.67)	8.37 (69.74)	8.34 (69.20)
Pinoxaden (50) + Metsulfuron methyl (4)	9.70 (93.55)	9.81 (95.82)	9.75 (94.69)	7.84 (61.39)	8.10 (65.25)	7.98 (63.32)	5.90 (35.17)	6.25 (38.54)	6.10 (36.85)
Pinoxaden (50) + 2,4-D (500)	10.73 (114.73)	10.92 (118.86)	10.83 (116.79)	9.97 (98.99)	10.12 (102.17)	10.05 (100.6)	8.74 (76.31)	8.93 (79.28)	8.84 (77.79)
Pinoxaden (50) + Sulfosulfuron (25)	9.45 (88.88)	9.60 (91.75)	9.53 (90.31)	6.94 (47.76)	7.19 (51.19)	7.07 (49.48)	5.02 (25.22)	5.23 (27.14)	5.15 (26.18)
Isoproturon (1000 g) + 2,4-D (500)	11.07 (122.13)	11.20 (125.06)	11.14 (123.59)	10.21 (103.69)	10.37 (107.02)	10.29 (105.4)	9.06 (82.69)	9.33 (86.72)	9.21 (84.70)
Unweeded control	14.20 (201.07)	15.28 (232.91)	14.75 (216.99)	16.83 (283.16)	17.08 (291.30)	16.96 (287.2)	17.98 (323.29)	17.85 (318.25)	17.92 (320.77)
Weed free check	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
SEm (±)	0.41	0.40	0.40	0.42	0.43	0.36	0.57	0.33	0.30
$CD_{0.05}$	1.19	1.17	1.16	1.22	1.23	1.03	1.64	0.96	0.88
CV (%)	7.51	7.19	7.23	8.52	8.42	7.12	13.22	7.57	7.02

*Figures in parenthesis are the original values. The data was transformed to $\sqrt{(X+0.5)}$ before analysis.

Table 2: Effect of herbicide mixtures on total weed dry weight (g m^{-2}) at different growth stages

Treatments (g a.i ha^{-1})	45 DAS			65 DAS			85 DAS		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Clodinafop propargyl (60) + Metsulfuron methyl (4)	1.66 (2.26)	1.77 (2.65)	1.72 (2.46)	2.37 (5.13)	2.47 (5.6)	2.42 (5.37)	3.14 (9.34)	3.19 (9.67)	3.16 (9.51)
Clodinafop propargyl (60) + 2,4-D (400)	1.75 (2.56)	1.87 (3.01)	1.81 (2.79)	2.47 (5.61)	2.56 (6.05)	2.52 (5.83)	3.23 (9.94)	3.31 (10.46)	3.27 (10.2)
Sulfosulfuron (25) + Metsulfuron methyl (2)	1.33 (1.28)	1.33 (1.28)	1.33 (1.28)	2.08 (3.84)	2.22 (4.45)	2.16 (4.15)	2.86 (7.68)	2.95 (8.19)	2.90 (7.94)
Pinoxaden (50) + Carfentrazone (20)	1.83 (2.85)	1.94 (3.25)	1.88 (3.05)	2.55 (6.01)	2.67 (6.65)	2.61 (6.33)	3.31 (10.48)	3.44 (11.34)	3.38 (10.91)
Pinoxaden (50) + Metsulfuron methyl (4)	1.54 (1.87)	1.63 (2.16)	1.59 (2.01)	2.27 (4.64)	2.35 (5.04)	2.31 (4.84)	3.03 (8.71)	3.14 (9.37)	3.09 (9.04)
Pinoxaden (50) + 2,4-D (500)	1.90 (3.1)	2.00 (3.53)	1.95 (3.31)	2.63 (6.42)	2.73 (6.97)	2.68 (6.69)	3.36 (10.78)	3.49 (11.68)	3.42 (11.23)
Pinoxaden (50) + Sulfosulfuron (25)	1.44 (1.58)	1.46 (1.63)	1.45 (1.60)	2.16 (4.17)	2.29 (4.72)	2.22 (4.45)	2.94 (8.15)	3.05 (8.78)	2.99 (8.47)
Isoproturon (1000 g) + 2,4-D (500)	1.98 (3.42)	2.09 (3.86)	2.03 (3.64)	2.71 (6.85)	2.81 (7.41)	2.76 (7.13)	3.41 (11.12)	3.54 (12.05)	3.48 (11.59)
Unweeded control	5.02 (24.72)	4.98 (24.28)	5.00 (24.5)	6.21 (38.08)	6.36 (39.93)	6.29 (39.00)	7.08 (49.7)	7.17 (50.88)	7.13 (50.29)
Weed free check	0.71 (0)	0.71 (0)	0.71(0)	0.71(0)	0.71(0)	0.71 (0)	0.71(0)	0.71(0)	0.71(0)
SEm (±)	0.10	0.12	0.08	0.08	0.09	0.11	0.12	0.08	0.15
$CD_{0.05}$	0.29	0.33	0.23	0.24	0.26	0.33	0.35	0.23	0.43
CV (%)	8.37	9.54	7.17	7.17	7.55	7.31	11.08	7.10	7.67

*Figures in parenthesis are the original values. The data was transformed to $\sqrt{(X+0.5)}$ before analysis.

herbicide mixtures in different treatments were broad spectrum in nature and had the ability to control weed population. Pal *et al*. (2015), Patel *et al*. (2017) and Kumar *et al*. (2017) also reported the similar results.

Weed dry weight: Weed biomass varied with year and herbicide treatments (Table 2). In both years, all herbicide mixtures reduced weed biomass compared with the weedy check. Maximum weed dry weight was found in unweeded plot and minimum in weed-free plot. Among different herbicide mixtures, sulfosulfuron (25 g ha^{-1}) + metsulfuron methyl (2 g ha^{-1}) was found to be the most effective against broad leaf weeds and annual grasses, and recorded significantly lower biomass of these weeds. After sulfosulfuron + metsulfuron methyl (25 g ha^{-1} + 2 g ha^{-1}), the next best treatments were pinoxaden + sulfosulfuron @ 50 g a.i ha^{-1} + 25 g a.i ha^{-1}, pinoxaden + metsulfuron methyl @ 50 g a.i ha^{-1} + 4 g a.i ha^{-1} and these were at par with sulfosulfuron + metsulfuron methyl (25 g ha^{-1} + 2 g ha^{-1}). Post emergence application of sulfosulfuron (25 g ha^{-1}) + metsulfuron methyl (2 g ha^{-1}) was very effective and could reduce the weed biomass upto 94.76% as compared to the unweeded control plot. Sulfonylurea group of herbicides are the low dose herbicides as compared to conventional herbicides and are characterized by broad spectrum weed control and good crop selectivity. This class of herbicides acts through inhibition of acetolactate synthase (also known as acetohydroxy acid synthase). These results are in line with Katara *et al*. (2015) and Kumar *et al.* (2019).

Weed control efficiency and weed index: Weed control efficiency (WCE) at 45 DAS and weed index (WI) value are presented in Table 3. The highest WCE of 94.76% was recorded with PoE application of sulfosulfuron + metsulfuron methyl (25 g ha^{-1} + 2 g ha^{-1}) which was closely followed (93.43%) by PoE application of pinoxaden 50 g a.i ha^{-1} + sulfosulfuron 25 g a.i ha^{-1} over weedy check. Choudhary and Kaur (2017) also reported similar trends. The weed index which denotes the percent reduction in grain yield as compared to the weed-free plot indicated that unweeded treatments reduced the grain yield of wheat to the tune of 53.84%. Reduction in grain yield under different herbicidal treatments was ranging between 3.98 and 19.05%. The minimum reduction in grain yield was noted with PoE application of sulfosulfuron + metsulfuron methyl (25 g ha^{-1} + 2 g ha^{-1}), followed by pinoxaden 50 g a.i ha^{-1} + sulfosulfuron 25 g a.i ha^{-1}. Kuamr *et al*. (2013) and Tiwari *et al.* (2015) also reported the same result trends.

Table 3: Effect of herbicide mixtures on WCE (%) at 45 DAS and WI (%)

Treatments (g a.i ha^{-1})	WCE at 45 DAS			WI		
	2016-17	2017-18	Pooled mean	2017-18	2016-17	Pooled mean
Clodinafop propargyl (60) + Metsulfuron methyl (4)	90.84	89.01	89.93	10.79	10.09	10.20
Clodinafop propargyl (60) + 2,4-D (400)	89.62	87.56	88.59	12.06	11.99	11.61
Sulfosulfuron (25) + Metsulfuron methyl (2)	94.83	94.69	94.76	4.13	4.42	3.98
Pinoxaden (50) + Carfentrazone (20)	88.45	86.55	87.50	15.24	14.51	14.98
Pinoxaden (50) + Metsulfuron methyl (4)	92.42	91.03	91.72	8.57	8.52	8.26
Pinoxaden (50) + 2,4-D (500)	87.49	85.32	86.40	17.14	16.40	16.42
Pinoxaden (50) + Sulfosulfuron (25)	93.60	93.26	93.43	6.35	5.99	5.59
Isoproturon (1000 g) + 2,4-D (500)	86.15	83.84	84.99	19.68	18.93	19.05
Unweeded control	0.00	0.00	0.00	55.24	52.68	53.84
Weed free check	100.0	100.0	100.0	0.00	0.00	0.00
SEm (±)	1.08	0.60	0.51	4.56	4.68	3.21
$CD_{0.05}$	3.13	1.75	1.49	13.24	13.61	9.33
CV (%)	2.04	1.16	0.98	48.23	51.89	34.75

Table 4: Effect of herbicide mixtures on plant dry weight (g m^{-2}) of wheat

Treatments (g a.i ha^{-1})	45 DAS			60 DAS			75 DAS			90 DAS		
	2016-17	2017-18	Pooled mean	2016-17	2017-18	Pooled mean	2016-17	2017-18	Pooled mean	2016-17	2017-18	Pooled mean
Clodinafop propargyl (60) + Metsulfuron methyl (4)	61.66	55.07	58.37	150.71	144.88	147.80	320.71	321.11	320.91	484.38	489.53	486.96
Clodinafop propargyl (60) + 2,4-D (400)	60.46	53.72	57.09	146.00	140.44	143.22	314.12	315.44	314.78	476.39	482.60	479.50
Sulfosulfuron (25) + Metsulfuron methyl (2)	65.87	63.78	64.82	165.57	161.40	163.48	344.80	343.72	344.26	516.74	517.97	514.35
Pinoxaden (50) + Carfentrazone (20)	59.21	52.00	55.61	140.27	135.39	137.83	304.05	307.19	305.62	462.65	471.05	466.85
Pinoxaden (50) + Metsulfuron methyl (4)	62.40	57.87	60.13	155.80	152.40	154.10	329.49	331.00	330.25	496.75	502.52	499.64
Pinoxaden (50) + 2,4-D (500)	57.32	50.61	53.97	133.95	131.87	132.91	293.82	302.33	298.08	449.97	464.86	457.41
Pinoxaden (50) + Sulfosulfuron (25)	64.32	60.41	62.36	160.86	156.16	158.51	336.01	336.06	336.03	504.60	509.31	506.96
Isoproturon (1000) + 2,4-D (500)	55.24	48.67	51.96	127.91	126.62	127.27	285.71	293.89	289.80	439.88	454.41	447.81
Unweeded control	46.15	47.36	46.75	94.91	102.67	98.79	208.56	209.39	208.97	314.99	325.78	320.38
Weed free check	67.03	68.39	67.71	168.55	168.16	168.36	350.54	352.22	351.38	525.46	529.06	527.26
SEm (±)	2.48	3.86	2.50	9.33	5.92	6.01	17.76	17.50	17.04	22.42	19.60	19.39
$CD_{0.05}$	7.17	11.18	7.24	26.97	17.12	17.37	51.36	50.62	49.28	64.84	56.70	56.09
CV (%)	7.16	12.00	7.49	11.18	7.22	7.26	9.96	9.74	9.52	8.31	7.15	7.14

Effect of herbicidal treatments on crop

Crop dry weight: The data on the dry weight of wheat as influenced by different herbicide combinations recorded at various intervals during both the years is presented in Table 4. The mean dry matter accumulation was highest under weed-free condition and lowest under weedy check at 45, 60, 75 and 90 DAS, respectively. Among the herbicide treatments, the highest dry matter accumulation at 45, 60, 75 and 90 DAS was recorded in application of sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 2 g a.i ha^{-1} in both the years (2016-17 and 2017-18). The application of sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 2 g a.i ha^{-1} increased 60.54% crop dry weight at 90 DAS. The probable reasons for recording higher dry matter accumulation under sulfosulfuron + metsulfuron (25 g a.i. ha^{-1} + 2g a.i. ha^{-1}) application may be attributed to the fact that due to less competition with weeds the wheat plants got favourable environment for more availability of moisture and nutrients and reduced removal of nutrients by lower weed population which resulted in higher dry matter accumulation in wheat plants. Similar trends were also observed by Kaur *et al.* (2017) and Singh *et al*. (2019).

Crop growth rate: Data pertaining to crop growth rate (CGR) of wheat crop have been embodied in Table 5. An appraisal of Table 5 clearly reveals that weed-free plot recorded maximum crop growth rate *viz*., 6.71, 12.20 and 11.72 g m^{-2} day^{-1} at 45-60, 60-75 and 75-90 DAS, respectively, which was greater than that recorded in all other herbicide treatments. Among the herbicide mixture treatments, the highest crop growth rate was recorded in treatment sulfosulfuron @ 25 g ha^{-1} + metsulfuron @ 2 g ha^{-1} at 45-60, 60-75 and 75-90 DAS during both the years. The probable reasons for higher crop growth rate under sulfosulfuron (25 g a.i. ha^{-1}) + metasufuron (2 g a.i. ha^{-1}) application may be due to more dry matter accumulation in plants because of reduce crop weed competition. Katara *et al.* (2015) also reported the similar results.

Table 5: Effect of herbicide mixtures on crop growth rate (g m^{-2} day^{-1}) of wheat

Treatments (g a.i ha^{-1})	45 – 60 DAS			60 – 75 DAS			75 – 90 DAS		
	2016-17	2017-18	Pooled mean	2016-17	2017-18	Pooled mean	2016-17	2017-18	Pooled mean
Clodinafop propargyl (60) + Metsulfuron methyl (4)	5.94	5.99	5.96	11.33	11.75	11.54	10.91	11.23	11.07
Clodinafop propargyl (60) + 2,4-D (400)	5.70	5.78	5.74	11.21	11.67	11.44	10.82	11.14	10.98
Sulfosulfuron (25) + Metsulfuron methyl (2)	6.65	6.51	6.58	11.95	12.49	12.22	11.46	11.62	11.54
Pinoxaden (50) + Carfentrazone (20)	5.40	5.56	5.48	10.92	11.45	11.19	10.57	10.92	10.75
Pinoxaden (50) + Metsulfuron methyl (4)	6.23	6.30	6.26	11.58	11.91	11.74	11.15	11.43	11.29
Pinoxaden (50) + 2,4-D (500)	5.11	5.42	5.26	10.66	11.36	11.01	10.41	10.83	10.62
Pinoxaden (50) + Sulfosulfuron (25)	6.44	6.38	6.41	11.68	12.33	12.00	11.24	11.55	11.39
Isoproturon (1000 g) + 2,4-D (500)	4.84	5.20	5.02	10.52	11.15	10.84	10.28	10.70	10.49
Unweeded control	3.25	3.69	3.47	7.58	7.11	7.35	7.10	7.76	7.43
Weed free check	6.77	6.65	6.71	12.13	12.27	12.20	11.66	11.79	11.72
SEm (±)	0.61	0.39	0.41	0.76	0.80	0.56	0.76	0.63	0.52
$CD_{0.05}$	1.76	1.12	1.18	2.21	2.31	1.61	2.19	1.82	1.51
CV (%)	18.75	11.68	12.40	12.06	12.20	8.65	12.42	10.01	8.45

Grain and straw yield: The data on grain yield as influenced by different herbicide mixtures recorded during both the years is presented in Table 6. The weed control treatments resulted in a significant increase in grain yield as compared to the weedy check. The maximum grain yield of 3.16 t ha^{-1} was recorded in weed-free plots which was at par with sulfosulfuron 25 g a.i ha^{-1} + metsulfuron methyl 2 g a.i ha^{-1} (3.03 t ha^{-1}), pinoxaden 50 g a.i ha^{-1} + sulfosulfuron 25 g a.i ha^{-1} (2.97 t ha^{-1}), pinoxaden 50

Table 6: Effect of herbicide mixtures on grain and straw yield of wheat

Treatments (g a.i ha^{-1})	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})		
	2016-17	2017-18	Pooled mean	2016-17	2017-18	Pooled mean
Clodinafop propargyl (60) + Metsulfuron methyl (4)	2.81	2.85	2.83	4.19	4.16	4.18
Clodinafop propargyl (60) + 2,4-D (400)	2.77	2.79	2.78	4.14	4.09	4.12
Sulfosulfuron (25) + Metsulfuron methyl (2)	3.02	3.03	3.03	4.38	4.35	4.37
Pinoxaden (50) + Carfentrazone (20)	2.67	2.71	2.69	4.03	4.01	4.02
Pinoxaden (50) + Metsulfuron methyl (4)	2.88	2.90	2.89	4.22	4.20	4.21
Pinoxaden (50) + 2,4-D (500)	2.61	2.65	2.63	3.97	3.96	3.97
Pinoxaden (50) + Sulfosulfuron (25)	2.95	2.98	2.97	4.30	4.30	4.30
Isoproturon (1000 g) + 2,4-D (500)	2.53	2.57	2.55	3.90	3.90	3.90
Unweeded control	1.41	1.50	1.46	2.64	2.70	2.67
Weed free check	3.15	3.17	3.16	4.53	4.53	4.53
SEm (±)	0.14	0.15	0.12	0.16	0.18	0.17
$CD_{0.05}$	0.39	0.42	0.34	0.47	0.52	0.49
CV (%)	8.37	9.34	7.53	7.03	7.70	7.27

g a.i ha^{-1} + metsulfuron methyl 4 g a.i ha^{-1} (2.89 t ha^{-1}) and clodinafop propargyl 60 g a.i ha^{-1} + metsulfuron methyl 4 g a.i ha^{-1} (2.83 t ha^{-1}). An increase in grain yield in herbicide mixture sulfosulfuron + metsulfuron could be attributed to the poor weed growth, higher crop dry matter, more number of ears and test weight of plants recorded under the treatment. Sahu *et al.* (2018), Kumar *et al.* (2018) and Shaktawat *et al.* (2019) also reported the same result trends. It was found that in weed free treatment straw yield was highest in both the years. Among herbicide treated plots sulfosulfuron + metsulfuron at 0.025 + 0.002 kg ha^{-1} was best treatment and recorded 63.67% more straw yield than weedy check. These results can be attributed to marked improvement in dry matter accumulation, yield attributes and weed control efficiency. These results are in agreement with the findings of Sasode *et al*. (2017), Mathukia *et al.* (2018) and Sahu *et al.* (2018).

Conclusion: It may be concluded that among different herbicide mixtures post emergence application of sulfosulfuron (25 g a.i. ha^{-1}) + metsulfuron (2 g a.i. ha^{-1}) is most effective for controlling the complex weed flora and thus improving the wheat yield.

REFERENCES

Abbas, S.H., Muhammad, S., Muhammad, M., Mujahid, Y.M., Mahmood-ul-Hassan and Saleem, R. 2009. Weed density and grain yield of wheat as affected by spatial arrangements and weeding techniques under rainfed conditions of Pakistan. *Journal of Agricultural Science*, **46**: 354-359.

Agha, J., Dass, A., Rajanna, G.A., Sarkar, S.K. and Rana, K.S. 2016. Influence of varying nitrogen levels on performance of wheat (*Triticum aestivum* L.) under semi-arid hot climate of Kandahar, Afghanistan. *Annals of Agricultural Research,* **37**: 347-352.

Chandana, V.M., Singh, R.S., Kumar, M. and Patak, RK. 2019. Effect of weed management practices on late sown wheat. *International Journal of Chemical Studies*, **7**(3): 4447-4449.

Chhokar R.S., Sharma R.K., Pundir A.K. and Singh R.K. 2007. Evaluation of herbicides for control of *Rumex dentatus*, *Convolvulus arvensis* and *Malva parviflora*. *Indian Journal of Weed Science,* **39**: 214-218.

Chopra, N.K., Chopra, N. and Choudhary, D. 2015. Bioefficacy of sole and tankmix of pinoxaden and clodinofop with carfentazone and metsulfuron for control of complex weed flora in wheat. *Indian Journal of Agronomy*, **60**: 104-108.

Choudhary, D., Singh, P.K., Chopra, N.K. and Rana, S.C. 2016. Effect of herbicides and herbicide mixtures on weeds in wheat. *Indian Journal of Agricultural Research*, **50**: 107-112.

Dass, A., Kushwaha H.L., Khura, T.K., Sahoo, P.K., Dhar, S., Singh, M.K. and Mani, I. 2018. Machine-planted system of wheat intensification improves wheat productivity 2018. pp. 596-597. **In**: *XXI Biennial National Symposium of Indian Society of Agronomy*, 24-26 October, 2018, MPUAT, Udaipur, Rajasthan, India.

Dass, A., Shekhawat, K., Choudhary, Anil K., Sepat, S., Rathore, S.S., Mahajan, G. and Chauhan, B.S. 2017. Weed management in rice using crop-competition. *Crop Protection*, **95**: 45-52.

Gill and Kumar, V. 1966. Chemical weed control in onion. *Indian Journal of Horticultural Sciences*, **29**: 53-58.

Katara, P., Kumar, S. and Rana, S.S. 2015. Influence of pinoxaden in combination with other herbicides on nutrient depletion by weeds in wheat. *Indian Journal of Weed Science*, **47**: 371-375.

Kaur, S., Kaur, T. and Bhullar, M.S. 2017. Control of mixed weed flora in wheat with sequential application of pre- and post-emergence herbicides. *Indian Journal of Weed Science,* **49**: 29-32.

Kumar, M., Ghosh, D. and Singh, R. 2018. Effect of crop establishment and weed management practices on growth and yield of wheat. *Indian Journal of Weed Science*, **50**: 129-132.

Kumar, R.N.V., Verma, S.K., Doharey, R.K., Kumari, A. and Raju. 2019. Effect of herbicides on weed control efficiency (%), yield attributes, yield and profitability of wheat (*Triticum aestivum* L.). *Journal of Pharmacognosy and Phytochemistry*, **8(**2): 118-121.

Kumar, R., Singh, R.S., Jaidev and Kumar, M. 2017. Effect of herbicides on weeds, grain yield and soil health in wheat. *Indian Journal of Weed Science*, **49**: 88-89.

Kumar, S., Rana, S.S., Ramesh and Chander, N. 2013. Herbicide combinations for broad-spectrum weed control in wheat. *Indian Journal of Weed Science*, **45**: 29-33.

Mani, V.S., Pandita, M.L., Gautam, S.K. and Bhawagadas. 1973. Weed killing chemicals in potato cultivation. *PANS*, **23**(8), 17-18.

Mathukia, R.K., Sagarka, B.K., Panara, D.M. and Gohil, B.S. 2018. Efficacy of some post-emergence herbicides and their mixtures against complex weed flora in wheat. *International Journal of Economic Plants*, **5**: 23-26.

Pal, S., Sharma, R., Sharma, H.B., Singh, R. and Babu, S. 2015. Bioefficacy and selectivity of different herbicides against weed flora in wheat (*Triticum aestivum*). *Indian Journal of Agricultural Sciences*, **85**(5): 655–660.

Pansey, V.G. and Sukahante, P.V.C. 1978. S*tatistical Methods for Agriculture Workers.* Indian Council of Agricultural Research, New Delhi, India.

Patel, B.D., Chaudhari, D.D., Patel, V.J., Patel, H.K., Mishra, A. and Parmar, D.J. 2017. Influence of broad spectrum herbicides on yield and complex weed flora of wheat (*Triticum aestivum* L.). *Research on Crops*, **18**: 433-437.

Radford, P.J. 1967. Growth analysis formula: Their use and abuse. *Crops Sciences*, **7:** 171-175.

Rana, M.C., Sharma, R. and Rana, S.S. 2016. Evaluation of combinations of herbicides to manage mixed weed flora in wheat. *International Journal of Advances in Agricultural Science and Technology,* **3**(6): 40-48.

Sahu, R., Sharda, K., Kumar, D. and Mandal, S.K. 2018. Weed population, weed biomass and grain yield of wheat as influenced by herbicides application. *Indian Journal of Weed Science,* **50**: 302-304.

Sasode, D.S., Gupta, V., Joshi, E., Arora, A., Dixit, J.P. and Panse, R. 2017. Management of diverse weed flora of wheat by herbicide combinations. *Indian Journal of Weed Science*, **49**: 147-150.

Shaktawat, R.P.S., Somvanshi, S.P.S., Bhadoria, S.S. and Singh H.P. 2019. Assessment of premix broad spectrum herbicides for weed management in wheat (*Triticum aestivum* L.). *Journal of Krishi Vigyan*, **7**(2): 11-14.

Singh, R.S., Kumar, R., Kumar, M. and Pandey, D. 2019. Effect of herbicides to control weeds in wheat. *Indian Journal of Weed Science*, **51**: 75-77.

Singh, S. Punia, S.S. Yadav, A. and Hooda, V.S. 2011. Evaluation of carfentrazone ethyl + metsulfuron methyl against broadleaf weeds of wheat. *Indian Journal of Weed Science*, **43**: 12-22.

Singh, S., Punia, S.S. and Malik, R.K. 2009. Multiple resistance in isoproturon resistant biotypes of *Phalaris minor* in India. Abstract. 280. **In**: *Weed Science Society of America (49th Annual Meeting) and Southern Weed Science Society (62nd meeting)*. Feb. 9-13, 2009. Hilton in Walt Disney World Resort, Orlando, Florida, USA.

Tiwari, A., Verma, B.K., Dev, J. and Kumar, R. 2015. Bioefficacy of clodinafop propargyl + metsulfuron methyl against complex weed flora in wheat. *Indian Journal of Weed Science*, **47**: 422-424.

Yadav, H.L., Gupta, A.K., Kumar, S. and Gupta, S. 2019. Comparative efficacy of herbicides applied in wheat and their residual effect on the succeeding crops. *International Journal of Current Microbiology and Applied Sciences*, **8**(4): 1866-1874.