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Effect of herbicide mixtures and dormancy breakers on growth and yield of wheat (*Triticum aestivum* L.)

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Abstract
A field experiment was conducted to study the effect of herbicide mixtures and dormancy breakers on growth and yield of wheat during two consecutive *rabi* seasons of years 2018-19 and 2019-20, respectively. The experiment was laid out in split plot design with five herbicide treatments in main plot *viz*. Clodinafop-propargyl 60 g a.i. ha^{-1} + Carfentrazone-ethyl 20 g a.i. ha^{-1}, Sulfosulfuron 25 g a.i. ha^{-1} + Metsulfuron-methyl 4 g a.i. ha^{-1}, Isoproturon 1000 g a.i. ha^{-1} + 2,4-D 500 g a.i. ha^{-1}, Weedy check and 2-Hand Weeding (25 and 45 DAS) and four dormancy breakers in sub plots *viz*. Control, Potassium nitrate (KNO_3) @ 24 kg ha^{-1}, Sodium azide (NaN_3) @ 11.2 kg ha^{-1} and Gibberellic acid (GA_3) @ 160 g ha^{-1}. The results reported that the higher growth and yield parameters *viz*. plant height, number of tillers, dry matter accumulation, grain yield, straw yield and biological yield were recorded under herbicidal mixture of Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1}. Among the dormancy breakers, Gibberellic acid (GA_3) 160 g ha^{-1} recorded higher values of above characters. However, Harvest index were failed to show any significant effect due to above treatments.

Keywords: herbicide mixtures, dormancy breakers, clodinafop-propargyl and gibberellic acid

Introduction
Wheat is one of the prehistoric crops which provides major energy requirement of human diet across the world. It is of prime importance in the realm of food crops in the world. Furthermore, there is an increasing demand for wheat in new markets beyond its region of climatic adaptation. Increasing global demand for wheat is based on the ability to make unique food products and the increasing consumption of these with industrialization and westernization (Shewry and Hey, 2015) [18]. In chronological perspective, India has made spectacular advancement in productivity and sustainability of wheat over the years. Though wheat yield in India is close to the world average, yet it lags behind to many of the other wheat producing countries like France, U.K., Germany, Egypt and Poland (Govt. of India, 2019) [11].

Weed is one of the major biotic constraints in wheat production as they compete with crop for nutrients, moisture, light and space (Chhokar *et al*., 2012) [6]. They possess many growth characteristics and adaptations which enable them to successfully exploit the numerous ecological niches (Zimdahl, 2013) [25]. Weeds suppress the crop and result in reduction of yield (Verma *et al.*, 2015) [23]. A principle of plant competition is that the first plants to occupy an area have an advantage over latecomers. This principle is of foremost consideration in practical weed control, where cropping practices are always directed to the establishment of the crop ahead of the weeds. The eco-physiological dissimilarities may further make the control of weeds difficult (Singh *et al*., 2015) [22]. Fahad *et al.* (2015) [9] opined that allowing weeds to grow with wheat at the beginning of the season has a greater negative impact on crop yield than allowing the weeds to grow in the crop later in the season. They found that a delay in weed emergence of 60 days resulted in at least 27 per cent higher wheat grain yields relative to the treatment in which weeds emerged simultaneously with wheat. First 30 - 45 days after sowing are considered critical from the stand point of critical crop - weed competition in wheat (Das *et al.*, 2012; Chaudhary *et al*., 2008) [8, 2].

For the control of isoproturon-resistant *P. minor*, clodinafop, fenoxaprop and sulfosulfuron have been found effective (Chhokar *et al.*, 2006) [4]. Clodinafop and fenoxaprop control only grasses whereas; sulfosulfuron controls grasses and some of the broadleaf weeds (Chhokar and Malik 2002) [3].

Sulfosulfuron is not effective against some of the broadleaved weeds like toothed dock (*Rumex dentatus* L.), little mallow (*Malva parviflora* L.), field bind weed (*Convolvulus arvensis* L.), and black night shade (*Solanum nigrum* L.). To manage these broad leaved weeds, Carfentrazone ethyl found to be highly effective but is not effective against grassy weeds (Chhokar *et al.* 2007) [5]. Simulatenously, metsulfuron was also found to be effective against several broadleaf weeds (Singh and Singh, 2005) [21]. Several broadleaved weeds revealed that carfentrazone and triasulfuron provided similar control to that of already recommended 2, 4-D (Walia and Singh, 2007) [24].

Moreover, it was realized that even after selecting the efficacious herbicide, many a time weed control was not effective due to dormancy of weed seeds in soil under adverse climatic condition. Therefore, for effective season long weed control, these dormant seeds in the soil could be stimulated to germinate and then be killed with tillage or herbicides, it might be possible to deplete the weed seed reserve in the soil. To be feasible, a germination stimulator would have to be economical, easily applied, and effective. Ideally, it would induce the entire seed reserve of a target species to germinate. Chemicals that have long been known to stimulate germination include thiourea and potassium nitrate. Nitrate particularly increases germination in many species, and has been suggested as a means of artificially inducing wild oat (*Avena fatua* L.) germination so that they may be destroyed before the crop is planted (Sexsmith and Pittman 1963) [16]. Simultaneously, Das and Das (2018) [7] reported that the significance interaction between herbicide and dormancy breaker for the weed management in wheat.

However, information regarding herbicide mixtures and dormancy breakers in wheat production in Uttar Pradesh is lacking. Keeping in view the above discussed facts of sufficient information and sparce related research, the present investigation was undertaken to find out the effect of herbicide mixtures and dormancy breakers on growth and yield of wheat in Varanasi conditions.

Material and Methods

The experiment was conducted during two consecutive *rabi* seasons of years 2018-19 and 2019-20, respectively at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, situated at latitude of 25º 18' North and longitude of 83º 03' East, with altitude of 128.93 meters above the mean sea level. Soil of the experiment field had sandy loam in texture, slightly alkaline in reaction, low in electrical conductivity, low in organic carbon, available nitrogen and medium in available phosphorus and potassium. The experiment was laid out in split plot design with five herbicide treatments in main plot *viz*. Clodinafop-propargyl 60 g a.i. ha^{-1} + Carfentrazone-ethyl 20 g a.i. ha^{-1}, Sulfosulfuron 25 g a.i. ha $^{-1}$ + Metsulfuron-methyl 4 g a.i. ha^{-1}, Isoproturon 1000 g a.i. ha $^{-1}$ + 2,4-D 500 g a.i. ha^{-1}, Weedy check and 2-Hand Weeding (25 and 45 DAS) and four dormancy breakers in sub plots *viz.* Control, Potassium nitrate (KNO_3) @ 24 kg ha^{-1}, Sodium azide (NaN_3) @ 11.2 kg ha^{-1} and Gibberellic acid (GA_3) @ 160 g ha^{-1}. The treatments were replicated three times. The recommended dose of fertilizers (120:60:60 kg N:P:K ha^{-1}) were applied through prilled urea for nitrogen, di-ammonium phosphate for phosphorus, muriate of potash for potash. Full di-ammonium phosphate, potash and 1/3 part of urea were applied at the time of sowing and 2/3 part of prilled urea was broadcasted in the three equal splits at 30 and 45 DAS. Wheat variety "HD-2967" were used for the investigations. The data relating to each character were analyzed as per the procedure of analysis of variance and significance was tested by "F" test (Gomez and Gomez 1984) [10].

Results and Discussions

Effect of herbicide mixtures on growth characters

Herbicide mixtures influenced significantly almost all the growth parameters *viz*, plant height, number of tillers and dry matter accumulation at harvest stage (Table 1).

The maximum value of growth characters were observed under two hand weeding (25 and 45 DAS) which was significantly superior to rest of the treatments during both the years of experimentation. Among the different herbicide mixtures, (H_2) Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1} recorded significantly higher plant height (79.79 and 81.90 cm) over (H_1) Clodinafop-propargyl 60 g a.i. ha^{-1} + Carfentrazone-ethyl 20 g a.i. ha^{-1} and (H_3) Isoproturon 1000 g a.i. ha^{-1} + 2-4, D 500 g a.i. ha^{-1} during both the experimental years. Whereas, least plant height was noted under (H_4) Weedy check treatment.

Among the different herbicidal mixture treatments, (H_2) Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1} recorded significantly higher number of tillers (411.15 and 420.72 $running^{-1}$ meter) over (H_1) Clodinafop-propargyl 60 g a.i. ha^{-1} + Carfentrazone-ethyl 20 g a.i. ha^{-1} and (H_3) Isoproturon 1000 g a.i. ha^{-1} + 2-4, D 500 g a.i. ha^{-1} during both the experimental years. Whereas, least number of tillers was noted under (H_4) Weedy check treatment.

Herbicide mixture (H_2) Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1} recoded significantly higher dry matter accumulation (1276.51 and 1304.25 g m^{-2}) which was statistically at par with (H_1) Clodinafop-propargyl 60 g a.i. ha^{-1} + Carfentrazone-ethyl 20 g a.i. ha^{-1} during both the years. However, least dry matter accumulation was noted under weedy check treatment.

Highest plant height and maximum dry matter accumulation by crop plants under weed control treatments is an indirect effect on account of least competition for plant growth inputs *viz*. light, space, water and nutrients etc. Under reduced weed density and weed dry matter, plant gets sufficient space for optimum expression of leaves and tillers as early as possible (Gupta, 2012) [12]. Thus, under least crop- weed competition, adequate availability of light, optimum temperature, space along with improvement in physiological and morphological characters of the plants can be reasoned for greater photosynthetic rate thereby more accumulation of dry matter (Brar *et al*. (2009) [1] and Singh *et al*. (2009) [20].

Effect of dormancy breakers on growth characters

Dormancy breakers also showed significant variation in plant height (Table 1). At harvest, dormancy breaker of (D_3) Gibberellic acid (GA_3) 160 g ha^{-1} recorded highest plant height (80.26 and 82.75 cm) followed by (D_2) Sodium azide (NaN_3) 11.2 kg ha^{-1}, (D_1) Potassium nitrate (KNO_3) 24 kg ha^{-1} and (D_0) Control, respectively during both the years of investigations. Dormancy breakers, (D_3) Gibberellic acid (GA_3) 160 g ha^{-1} recorded maximum number of tillers (405.12 and 411.35) followed by (D_2) Sodium azide (NaN_3) 11.2 kg ha^{-1}, (D_1) Potassium nitrate (KNO_3) 24 kg ha^{-1} and (D_0) Control, respectively during both the years of investigations.

Dry matter accumulation significantly affected by dormancy breakers. The highest dry matter accumulation (1275.09 and 1303.15 g m^{-2}) was noted under (D_3) Gibberellic acid (GA_3) 160 g ha^{-1} treatment which was statistically at par with rest of the treatments except control during both the years. Whereas, minimum dry matter accumulation was noted under (D_0) control treatment. Similar results were also found by Sixsmith and Pittman 1963; Das and Das (2018) [16, 7].

Table 1: Effect of herbicide mixtures and dormancy breakers on growth characters of wheat at harvest

Treatments	Plant height (cm)		No. of tillers (running^{-1} m)		Dry matter accumulation (g m^{-2})	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Herbicide mixture (H)						
H_1: Clodinafop-propargyl 60 g a.i. ha^{-1} + Carfentrazone-ethyl 20 g a.i. ha^{-1}	76.09	78.28	383.26	390.35	1225.15	1252.10
H_2: Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1}	79.79	81.90	411.15	420.72	1276.51	1304.25
H_3: Isoproturon 1000 g a.i. ha^{-1} + 2,4-D 500 g a.i. ha^{-1}	73.73	76.91	328.37	335.74	1179.87	1205.85
H_4: Weedy Check	68.23	69.53	398.14	304.56	1092.89	1116.94
H_5: 2-Hand weeding (25 and 45 DAS)	88.64	87.53	477.35	478.41	1438.12	1469.76
S.Em±	2.28	2.52	11.90	12.11	36.11	37.13
LSD (*p*=0.05)	7.44	7.56	35.75	36.35	108.74	112.54
Dormancy breaker (D)						
D_0: Control	75.17	74.82	363.45	373.16	1187.78	1213.91
D_1: Potassium nitrate (KNO_3) 24 Kg ha^{-1}	76.55	78.82	374.36	380.34	1245.73	1273.13
D_2: Sodiun azide (NaN_3) 11.2 Kg ha^{-1}	77.55	78.93	385.74	392.17	1261.16	1288.91
D_3: Gibberellic acid (GA_3) 160 g ha^{-1}	80.26	82.75	405.12	411.35	1275.09	1303.15
S.Em±	1.42	1.59	8.27	8.47	28.12	29.02
LSD (*p*=0.05)	4.10	4.60	24.84	25.78	84.75	87.74
Interaction (HxD)	NS	NS	NS	NS	NS	NS

Effect of herbicide mixtures on yield

Herbicide mixtures influenced significantly yield *viz*, grain yield, straw yield and biological yield of wheat (Table 2).

Significantly higher (4720 and 4857 kg ha^{-1}) grain yield of wheat was noted under two hand weeding at 25 and 45 DAS during both the years. Among the herbicidal treatments, (H_2) Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1} exerted significantly higher grain yield (4591 and 4650 kg ha^{-1}) which was statistically at par with (H_1) Clodinafop-propargyl 60 g a.i. ha^{-1} + Carfentrazone-ethyl 20 g a.i. ha^{-1} during both the years. However least grain yield was observed under weedy check.

Significantly higher (6823 and 6994 kg ha^{-1}) straw yield of wheat was noted under two hand weeding at 25 and 45 DAS during both the years. Among the herbicidal treatments, (H_2) Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1} exerted significantly higher straw yield (6720 and 6888 kg ha^{-1}) which was statistically at par with (H_3) Isoproturon 1000 g a.i. ha^{-1} + 2-4, D 500 g a.i. ha^{-1} and (H_1) Clodinafop-propargyl 60 g a.i. ha^{-1} + Carfentrazone-ethyl 20 g a.i. ha^{-1} during both the years. However least straw yield was observed under weedy check.

Significantly higher (11543 and 11851 kg ha^{-1}) straw yield of wheat was noted under two hand weeding at 25 and 45 DAS during both the years. Among the herbicidal treatments, (H_2) Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1} exerted significantly higher biological yield (11311 and 11620 kg ha^{-1}) which was statistically at par with (H_1) Clodinafop-propargyl 60 g a.i. ha^{-1} + Carfentrazone-ethyl 20 g a.i. ha^{-1} during both the years. However least biological yield was observed under weedy check.

This might be due to better expression of yield attributes in these plants to poor resurgence frequency and growth of weeds as evident from weed dry matter studies in these plots. The better expression of yield attributes were obtain with weed controlling through Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1}. Weeds are the built-in-traits, presence of which has an ill effect on crop yield due to competition of recourses in producing higher biomass and uptake of nutrients from the soil. Various authors have also reported improved yield attributes with reduced weed density and dry matter (Patel *et al*., 2004; Meena and Singh, 2011; Sheikhhasan *et al*., 2012; Singh, 2012 and Pal *et al*., 2016) [15, 13, 17, 19, 14]. Herbicidal mixture failed to show any significant effect on harvest index of wheat. Among the herbicidal mixtures, application of (H_2) Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1} and two hand weeding at 25 and 45 DAS recorded maximum harvest index but the difference was found to be non-significant during both the years.

Table 2: Effect of herbicide mixtures and dormancy breakers on Grain yield, straw yield and biological yield (Q ha^{-1}) of wheat

Treatments	Yield (Q ha^{-1})						Harvest index (%)	
	Grain yield		Straw yield		Biological yield			
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Herbicide mixture (H)								
H_1: Clodinafop-propargyl 60 g a.i. ha^{-1} + Carfentrazone-ethyl 20 g a.i. ha^{-1}	41.76	43.50	62.21	63.76	103.97	107.54	0.40	0.40
H_2: Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1}	45.91	46.50	67.20	68.88	113.11	116.20	0.41	0.40
H_3: Isoproturon 1000 g a.i. ha^{-1} + 2,4-D 500 g a.i. ha^{-1}	40.35	41.34	62.38	63.94	102.73	105.30	0.39	0.39
H_4: Weedy Check	33.37	34.21	50.73	52.00	84.11	86.50	0.39	0.40
H_5: 2-Hand weeding (25 and 45 DAS)	47.20	48.57	68.23	69.94	115.43	118.51	0.41	0.41
S.Em ±	1.34	1.52	1.84	1.99	3.23	3.29	0.01	0.01
LSD (*p*=0.05)	4.11	4.57	5.47	5.98	9.74	9.93	NS	NS
Dormancy breaker (D)								

D_0: Control	38.49	39.52	58.12	59.57	96.61	99.10	0.40	0.40
D_1: Potassium nitrate (KNO_3) 24 Kg ha^{-1}	41.92	43.50	62.35	63.91	104.27	108.90	0.40	0.40
D_2: Sodiun azide (NaN_3) 11.2 Kg ha^{-1}	42.46	45.27	63.31	65.55	105.77	109.41	0.40	0.40
D_3: Gibberellic acid (GA_3) 160 g ha^{-1}	44.01	46.75	64.82	66.45	108.83	112.71	0.40	0.40
S.Em ±	0.98	1.06	1.55	1.60	2.45	2.61	0.00	0.00
LSD (p=0.05)	2.97	3.18	4.74	4.87	7.74	7.95	NS	NS
Interaction (H x D)	NS	NS	NS	NS	NS	NS	NS	NS

Effect of dormancy breakers on yield

Dormancy breakers also influenced significantly yield *viz*, grain yield, straw yield and biological yield of wheat (Table 2).

Significantly higher grain yield of 4401 and 4675 kg ha^{-1} was observed under (D_3) Gibberellic acid (GA_3) 160 g ha^{-1} which was statistically at par with (D_2) Sodium azide (NaN_3) 11.2 kg ha^{-1} and (D_1) Potassium nitrate (KNO_3) 24 kg ha^{-1} during both the years. However, minimum grain yield was observed with (D_0) control treatment. Dormancy breakers also significantly influenced the straw yield of wheat. Significantly higher straw yield of 6482 and 6645 kg ha^{-1} was observed under (D_3) Gibberellic acid (GA_3) 160 g ha^{-1} which was statistically at par with (D_2) Sodium azide (NaN_3) 11.2 kg ha^{-1} and (D_1) Potassium nitrate (KNO_3) 24 kg ha^{-1} during both the years. However, minimum straw yield was observed with (D_0) control treatment.

Significantly higher biological yield of 10883 and 11271 kg ha^{-1} was observed under (D_3) Gibberellic acid (GA_3) 160 g ha^{-1} which was statistically at par with (D_2) Sodium azide (NaN_3) 11.2 kg ha^{-1} and (D_1) Potassium nitrate (KNO_3) 24 kg ha^{-1} during both the years. However, minimum biological yield was observed with (D_0) control treatment.

Dormancy breakers failed to show any significant effect on harvest index of wheat and all the treatments showed a similar harvest index value a.i. 0.40 during both the experimental years. Similar results were also found by Sexsmith and Pittman 1963; Das and Das (2018) [16, 7].

Conclusions

From the above overall study, it is recommended that to obtain higher growth attributes and yield with minimum weed infestation of wheat should be grown under application of Sulfosulfuron 25 g a.i. ha^{-1} + metsulfuron 4 g a.i. ha^{-1} and Gibberellic acid (GA_3) 160 g ha^{-1} under ago-climatic conditions of Varanasi region of Eastern Uttar Pradesh.

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