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Weed control efficiency, productivity and energy relationships of wheat (*Triticum aestivum*) production as influenced by herbicidal weed control in vertisols of central India

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Abstract
The field experiments were conducted at Research Farm of ICAR-IARI, Regional Station, Indore, Madhya Pradesh for two consecutive years during *rabi* season of 2011-12 and 2012-13 to find out the efficacy of different post emergence herbicides to control the complex weed flora in wheat (*Triticum aestivum*). Data collected on weed dynamics indicated that weeds density (both broad and narrow leaved weeds) observed at 60 and 120 days after sowing (DAS) decreased significantly in both the years as compared to weedy check. Post emergence application of ready mix *Clodinafop* + *Metsulfuron* (30 days after spray) at 60 DAS and *Clodinafop* + *Metribuzin* at 120 DAS recorded maximum values of weed control efficiency (WCE) to the tune of 87.4 and 89.4 per cent, respectively. It was also noted that herbicides ready mix *Clodinafop* + *Metsulfuron* recorded negative value -7.7% of weed index (WI) in first year and lowest value i.e. 0.5% during second year, where negative value indicates higher grain yield as compared to weed free treatment. Grain (6.46 and 4.16 t ha^{-1}) and biological yields (15.77 and 8.89 t ha^{-1}) recorded with *Clodinafop* + *Metsulfuron* in both the years were significantly at par with weed free and under application of *Sulfosulfuron* and *Mesosulfuron* + *Iodosulfuron*. Application of ready mix herbicide *Clodinafop* + *Metsulfuron* recorded higher values of energy ratio (9.61and 5.70) and energy productivity (293.8 and 197.0 g MJ^{-1}) in both the years over others including weed free treatment. Thus, it can be concluded that for getting efficient control of multiple weed flora and higher economical and energy efficient wheat yield, *Clodinafop* + *Metsulfuron* @ 60 + 4 gha^{-1} should be applied in wheat at four week crop stage in vertisols of Central India.

Keywords: complex weed flora, energy relationships, herbicides, grain yield, weed dynamics, wheat

Introduction

Like other parts of the country, grassy weeds like little canary grass (*Phalaris minor*) and wild oats (*Avena ludoviciana*) are posing great threat to the productivity of wheat crop in last decade in Central Zone also and infestation of these weeds is increasing year to year in newer areas. Other weeds mainly broad leaved weeds notably common lambsquarter (*Chenopodium album* L.), Indian sweet clover (*Melilotus indica*), Hirankhuri (*Convolvulus arvensis*), toothed bur clover (*Medicago hispida*) etc. were already putting high competition with wheat crop. Gajar grass (*Parthenium hystrophorus*) is also infested as aproblematic weed in crops as well as non-croplands and spreading every year in newer areas. Kaur *et al.* (2013) [1] reported critical limit 15 plants m^{-2} of *Avena ludoviciana*, which significantly decreased the grain yield of wheat. These weeds by putting great competition for resources like nutrients, water, light etc. with wheat crop, causes reduction in wheat yield and impair the quality of produce. The results of different studies indicated that uncontrolled weed growth in wheat crop may reduce grain yield ranging from 15-40% depending upon magnitude, nature and duration of weed infestation (Jat *et al.*, 2003) [2]. Manual and mechanical methods of weeding were the prevalent techniques used by farmers until the end of 1990s. But, 1990s onwards, the nominal farm wages grew and the effect of increased wages has concomitantly increased reliance on herbicides, applied alone or as a component of integrated weed management (Rao *et al.* 2014) [3]. Although manual weeding is the safest and surest method of weed control but adequate and timely availability of manpower especially at critical stage when weeding is needed, it is not available. Moreover, at present manual weeding is also a costly affair and time consuming as well. Due to that chemical weed control now-a-days is gaining popularity. Singh (2013) [4] opined that herbicides are the most successful weed control technology ever developed as they are selective, cost effective, fairly easy to apply, have persistence that can be managed, and offer flexibility in application time. These are also eco-friendly if applied at proper dose, method and time, besides being quite safer in comparison to other pesticides.

But after the development of resistance in a major impediment weeds like *Phalaris minor* against *Isoproturon* as well as some other recommended herbicides for grassy weeds like *Fenoxaprop-p-ethyl,* there is a need to seek alternate herbicides. Some herbicides mainly used for broadleaved weeds like 2, 4-D is effective to control weeds but many timed exerts deformity in leaves and earheads of wheat (Balyan *et al.* 1990) [5]. New molecules of broadleaf herbicides like *Metsulfuron methyl* controls the broadleaf weeds (Saha and Rao, 2010) [6] but it is not effective towards grassy weeds. Many herbicides or their mixture (also ready mix) recommended for controlling multiple weed flora in wheat by several research workers like *Isoproturon + 2, 4-D* (Singh *et al.,* 2010; Bharat and Kachroo, 2010 and Chander *et al.,* 2014) [7-9], *Sulfosulfuron* alone or mix with *Metsulfuron methyl* or *2, 4-D* (Meena and Singh, 2011; Singh *et al*., 2010; Bharat and Kachroo, 2010; Dev *et al.,* 2013 and Singh, 2013) [10, 7, 8, 11, 4] *Pinoxaden* (Yadav *et al.,* 2009) [13], *Fenoxaprop* with *Metribuzin* or *Carfentrazone* or *Metsulfuron methyl* (Bharat and Kachroo, 2007; Tiwari *et al.,* 2013 and Chopra *et al.,* 2008) [14-16] and *Clodinafop propargyl* with 2, 4-D or *Metsulfuron methyl* or *Carfentrazone* (Bharat and Kachroo, 2007; Chopra and Chopra, 2012; Jain *et al.,* 2014; Singh, 2013 and Chopra *et al.,* 2015) [14, 17, 18, 4, 19]. The information on the above was meager for heavy soils of Central India to recommend as farmers' practice. Hence, keeping above in view, present investigation was carried out to find out the effect of different herbicides and their mixtures on controlling of complex weed flora in wheat with higher productivity and profitability in vertisols of Central India.

Materials and Methods

Place of study: The field experiment was conducted for two consecutive years during *rabi* seasons of 2011-13 at Research Farm, ICAR-Indian Agricultural Research Institute, Regional Station, Indore. Experimental sites were different in both the years with same treatment and wheat variety. The experimental field was situated between 22°37°N latitude to 75°50°E longitude at 557m above mean sea level and has a semi-arid tropical climate with mean annual rainfall of 758 mm.

Physico-chemical properties of experimental site: The soil of the experimental fist year site was a deep Vertisol (Typic Haplustert) with clayey texture (52% clay) and bulk density of 1.34 Mg m^{-3}, having pH value 7.6, EC 0.23 dSm^{-1} (1:2.5 soil/water ratio), medium in organic carbon (0.58%), available N (258.5 kg ha^{-1}) and available P (18.93 kg ha^{-1}), and high in available K (448.5 kg ha^{-1}).Whereas, the soil of second year trial was nearby site but soil was upland with less soil depth, also medium black with pH value of 7.85, organic carbon (0.39%), available nitrogen (166.5 kg ha^{-1}), phosphorus (11.5 P_2O_5 kg ha^{-1}) and available potassium (398.5 K_2O kg ha^{-1}).

Treatments imposed: Total 14 treatments viz., *Metribuzin* @ 210 g ha^{-1} (W_1), *Clodinafop propargyl* @ 60 g ha^{-1} (W_2), *Pinoxaden* @ 40 g ha^{-1} (W_3), *Sulfosulfuron* @ 25 g ha^{-1} (W_4), *Clodinafop propargyl + Metribuzin* @ 60 + 210 g ha^{-1} (W_5), *Pinoxaden + Metribuzin* @ 40 + 210 g ha^{-1} (W_6), *Sulfosulfuron + Metribuzin* @ 25 + 210 g ha^{-1} (W_7), Ready mix of *Fenoxaprop + Metribuzin* @ 120 + 210 g ha^{-1} (W_8), Ready mix of *Sulfosulfuron + Metsulfuron* @ 32 g ha^{-1} (W_9), Ready mix of *Mesosulfuron + Iodosulfuron* @ 14.4 g ha^{-1} (W_{10}), Ready mix of *Clodinafop propargyl + Metsulfuron methyl* @ 60 + 4 g ha^{-1} (W_{11}), *Isoproturon + 2, 4-D* @ 1000 g + 500ml ha^{-1} (W_{12}), Weedy Check (W_{13}) and Weed Free (W_{14}) were tried in randomized block design with three replications.

Other information: Wheat variety 'HI 1544' was sown at 20.0 cm apart rows on 9th and 12th November, and harvested on 8th and 5th April in 2011-12 and 2012-13, respectively. Recommended doses of NPK 120 : 60 : 40 (kg ha^{-1}), where 50% N and full doses of P and K were applied as basal uniformly to all the plots and remaining N dose in two equal splits was top-dressed as urea before first and second irrigations in both the years. Herbicides were sprayed at four week crop stage using a spray volume of 600 liters/ha with a knapsack sprayer fitted with flat-fan nozzle. Two hand weedings were done at 25 and 45 days after sowing for imposition of weed free treatment. Crop was raised under irrigated conditions and all the recommended packages of practices were followed to grow a healthy crop. Data on weed count and weed dry weight from an area enclosed in a quadrate of 1.0 m^2 at 2 places from each plot were recorded at 60 and 120 days after sowing. Data on weed density and dry weights were subjected to square root transformation ($\sqrt{x}$ + 0.5). Weed control efficiency and weed index were computed as per standard formula and phyto-toxicity observed at 0 to 10 scales, where 0 is no-toxicity to 10 as highest (100%) phyto-toxicity level in affected plot. Data on yield attributes and yield of wheat were observed at the time of harvest. Mean comparisons of the treatments were made by the standard statistical method as suggested by Gomez and Gomez (1984) [20]. Energy inputs and outputs were calculated using the energy equivalents viz., manpower 1.96 MJ/hour, dry fodder 18 MJ kg^{-1}, nitrogen 60.6 MJ kg^{-1}, P_2O_5 11.1 MJ kg^{-1}, K_2O 6.7 MJ kg^{-1} etc. as suggested by Panesar and Bhatnagar (1987) [21], and Devasenapathy *et al.* (2009) [22].

Result and Discussion

Effect on weeds density and dry weight

Data recorded on weed species composition (%) before spray in both the years in control plots showed that during 2011-12 at institute farm was *Chenopodium album* (43.1%), *Melilotus indica* (13.0%), *Parthenium hystrophorus* (8.3%), *Convolvulus arvensis* (5.8%), *Avena ludoviciana* (6.3%), Phalaris minor (4.9%) and others (18.6%), while in 2012-13 at farmers field *Chenopodium indica* (23.4%), *Melilotus alba* (9.2%), *Convolvulus arvensis* (2.8%), *Avena ludoviciana* (13.8%), *Phalaris minor* (28.4%) and others (22.4%).

Data on weed dynamics indicated that all herbicides significantly decreased the weed density and weed dry weights per square meter compared with weedy check in both the years (Table 1). Among herbicides, *Clodinafop + Metribuzin* and a ready mix herbicide *Clodinafop + Metsulfuron* were found most effective and recorded highest reduction in weed population and weed dry weights in both the years. Variation in reduction in weed numbers and dry weights due to different herbicides might be due to their differential selectivity towards grassy and broadleaf weeds. Chopra and Chopra (2012) [17] also recorded pre-mix *Clodinafop + Metsulfuron* (60 + 4) as the most effective herbicide mixture for controlling the complex weed flora in wheat. These results are in close conformity with the findings of Singh (2013) [4] and Tomar and Tomar (2014) [23].

Weed control efficiency (WCE) and weed index (WI)

Computation of weed control efficiency (Table 1) showed that highest values of weed control efficiency owing to effective control of complex weed flora recorded with the application of *Clodinafop* + *Metsulfuron* ready-mix and C*lodinafop* + *Metribuzin* at both crop stages of 60 and 120 DAS in both the years were almost same but substantially higher over other herbicidal treatments except the application of ready mixes of *Sulfosulfuron* + *Metsulfuron* and *Mesosulfuron* + *Iodosulfuron* in different years. Whereas, application of *Sulfosulfuron* + *Metsulfuron* ready mix at 60 DAS during first year and *Mesosulfuron* + *Iodosulfuron* ready mix at both the stages in second year recorded values were nearer to above herbicidal mixtures. A higher value of WCE with above herbicidal mixtures was the function of efficient control of weeds and their significant reduction in the plots treated with above herbicides. Chopra and Chopra (2012) [17] and Tomar and Tomar (2014) [23] also reported highest value of WCE with application of *Clodinafop* + *Metsulfuron*. In case of weed index, some of the herbicides viz., *Clodinafop* + *Metsulfuron* ready-mix, S*ulfosulfuron* sole and C*lodinafop* sole and weedy check during first year recorded negative values of weed index, which shows higher grain yields of wheat than weed free treatment. While in second year data showed that among herbicides, *Clodinafop* + *Metsulfuron* ready mix herbicide recorded the lowest value (0.5) of weed index followed by *Mesosulfuron* + *Iodosulfuron* ready-mix herbicide (3.8) owing to minimum reduction in wheat yield in comparison to weed free treatment. Similar findings were also reported by Tomar and Tomar (2014) [23]. Negative values of weed index during first year under some of the treatments might be due to composition of weed flora, where majority of weed population was of broadleaved weeds, which might have putted symbiotic effect and benefitted the wheat crop resulted higher wheat yields and recorded lower values of WI. Whereas, trampling effect, which may occurred during frequent weeding in weed free treatment to put a weed free environment of the treatment resulted reduction in wheat yield. Whereas, greater values of weed index were observed due to poor grain yields obtained in high weed density with lower WCE values of weedy check and plots of other herbicidal treatments in both the years.

Phyto-toxicity

Plot-wise observation on phyto-toxicity on the scale of 0 to 10 (0 means no effect and 10 means 100% plants of plot were affected) showed that despite of satisfactory control of multiple weed flora, application of *Metribuzin* @ 210 g ha^{-1} either sole or mixed with other herbicides viz., C*lodinafop*, P*inoxaden* and S*ulfosulfuron* or as ready mix herbicide *Fenoxaprop* + *Metribuzin* recorded phyto-toxicity of different strength in both the years (Table 1). During first year maximum toxicity was observed with the treatment *Sulfosulfuron* + *Metribuzin* followed by *Pinoxaden* + *Metribuzin*. Whereas, during second year overall toxicity strength was slightly lower and maximum toxicity was observed with *Pinoxaden* + *Metribuzin* (3.67) followed by *Clodinafop* + *Metribuzin*. This study indicates that *Metribuzin* applied @ 210 kg $ha^{-1}$was found harmful in vertisols to wheat crop and it was more aggressive when such dose was mixed with other herbicides to control mixed weed flora. The reason of phyto-toxicity may be either applied dose is higher or not suitable for wheat. Whereas, increased aggressiveness when it is mixed with other herbicides might be due to its poor compatibility with other herbicides which increased the intensity of its toxicity. Sharma (2003) [24], Bharat and Kachroo (2007) [14] and Tomar and Tomar (2014) [23] also recorded phyto-toxicity due to application of *Metribuzin* in wheat crop.

Effect on wheat yield attributes and yield

Data recorded on wheat yield attributes viz., number of earheads m^{-2}, no. of grains/earhead and 1000 grain weight (g) showed that all herbicidal treatment brought out significant effect on all above yield attributes (Table 2). In both the years, weed free treatment recorded highest values of all above traits except no. of earheads m^{-2} during 2011-12, where application of *Clodinafop* + *Metsulfuron* observed highest value i.e. 378.5 earheads m^{-2}. The values recorded with weed free treatment were followed by *Clodinafop* + *Metsulfuron.* Whereas, application of *Metribuzin* alone or mixed as well as ready mix with other herbicides, exerted the phyto-toxicity and significantly decreased all wheat yield attributes in both the years. Overall, all yield attributes recorded under weed free and application of *Clodinafop* + *Metsulfuron* were statistically at par in both the years. In case of grain and biological yields, among herbicides application of ready mix herbicide *Clodinafop* + *Metsulfuron* @ 60 + 4 g ha^{-1} recorded maximum grain (6.46 and 4.16 t ha^{-1}), and biological (15.77 and 8.89 t ha^{-1}) yields in first and second years, respectively, which were followed by application of *Sulfosulfuron* in first year and mix application of *Mesosulfuron* + *Iodosulfuron* during second year. However, in second year, grain and biological yields recorded under weed free treatment were slightly higher by 0.48 and 1.69 per cent, respectively over *Clodinafop* + *Metsulfuron* application. During 2011-12, grain yield recorded with application of *Clodinafop* + *Metsulfuron* was statistically at par with the treatments *Sulfosulfuron*, *Pinoxaden*, weedy check, weed free, *Mesosulfuron* + *Iodosulfuron* and *Sulfosulfuron* + *Metsulfuron* but significantly higher over rest of the treatments. It was also noted that during 2011-12, application of herbicides like *Clodinafop* + *Metsulfuron*, *Sulfosulfuron* sole and *Pinoxaden* sole recorded 7.67, 7.33 and 3.00 per cent higher grain yields, respectively over weed free treatment. Increased yield under weedy check and other treatments compared with weed free treatment during first year might be due to the possibilities of positive symbiotic effect of broadleaved weeds that benefitted the wheat crop by additional nutritional supplementation. However, during 2012-13 when experiment was conducted at another location have comparatively higher number of narrowleaved weeds, weed free treatment recorded maximum grain (4.18 t ha^{-1}) and biological (9.04 t ha^{-1}) yields. These yields especially grain yields were statistically at par with herbicides application viz., *Clodinafop* + *Metsulfuron*, *Mesosulfuron* + *Iodosulfuron* and *Clodinafop* but significantly higher over rest of the treatments. Difference in grain and biological yields under different treatments was the function of varied yield attributes viz., number of earheads m^{-2}, grains $earhead^{-1}$ and 1000 grain weights. Higher yields under the application of herbicides viz., *Clodinafop* + *Metsulfuron* and *Mesosulfuron* + *Iodosulfuron* or under weed free treatments might be due to maximum control of weeds, which increased the availability of nutrients, space and light to the wheat crop by reducing crop weed competition resulted improvements in growth attributes and yields. Bharat and Kachroo (2007) [14], Chopra and Chopra (2012) [17] and Chopra *et al.* (2015) [19] also reported similar results. Dev *et al.* (2013) [11] an excellent control of weeds with *Sulfosulfuron* application @ 25 g/ha along-with maximum values of yield attributes and yield. There was no certain trend observed for harvest index in both the years.

Energy relationships

Computation of energy input, energy output, energy ratio and energy productivity on the basis of energy values used as inputs and energy produced as output showed that although there was slight reduction in energy input values of second year (2012-13) compared with first year but values related to energy output, energy ratio and energy productivity recorded in first year were substantially higher than second year (Table 3). Maximum input energy was used under weed free treatment in both the years, mainly due to comparatively higher consumption of energy on weeding under weed free treatment than herbicidal weed control. Difference in output energy was the outcome of wheat productivity. While maximum values of energy ratio and energy productivity were registered under the treatment *Clodinafop + Metsulfuron* mix during both the years. Despite of higher yield of wheat under weed free treatment in second year, it did not record maximum values of energy ratio and energy productivity due to higher usage of energy input. Whereas, higher values of energy ratio and energy productivity under application of *Clodinafop + Metsulfuron* was the function of almost similar wheat yields and due to proportionately lower increase in consumption of energy input. *Metribuzin* application either alone or mixed with other chemicals substantially decreased the energy out values of different treatments due to reduction in yields of wheat. Among herbicidal treatments, differences in input energy values, decreased the values of energy ratios and energy productivity under different herbicidal treatments. Singh (2013) [12] also reported highest values above traits under the application of *Clodinafop + Metsulfuron*.

Table 1: Weed density, dry weights, weed control efficiency, weed index and phyto-toxicity as influenced by treatment variables

Treatment	Doses (g ha^{-1})	Weed density*m^{-2}				Weed dry weight* (g m^{-2})				Weed control efficiency (%)				Weed Index (%)		Phyto-toxicity*	
		2011-12		2012-13		2011-12		2012-13		2011-12		2012-13					
		60 DAS	120 DAS	60 DAS	120 DAS	60 DAS	120 DAS	60 DAS	120 DAS	60 DAS	120 DAS	60 DAS	120 DAS	2011-12	2012-13	2011-12	2012-13
Metribuzin	210	4.19 (17.3)	3.73 (13.7)	5.20 (26.7)	4.86 (23.3)	4.17 (17.1)	3.59 (12.6)	4.86 (23.8)	4.51 (19.9)	75.1	66.6	69.2	54.7	18.8	24.4	2.67	2.33
Clodinafop	60	3.43 (11.3)	2.87 (8.0)	4.21 (17.5)	3.00 (8.7)	3.41 (11.2)	3.65 (13.2)	4.69 (21.7)	3.30 (10.4)	83.8	80.5	79.8	83.1	4.0	7.2	0	0
Pinoxaden	40	3.61 (12.7)	2.55 (6.3)	4.56 (19.5)	3.43 (11.5)	3.65 (13.6)	3.37 (11.1)	4.53 (20.2)	3.46 (11.7)	81.8	84.6	77.5	77.7	-3.0	26.3	0	0
Sulfosulfuron	25	3.85 (14.3)	2.66 (6.7)	3.98 (15.5)	2.90 (8.0)	3.68 (13.4)	3.20 (9.7)	4.24 (17.9)	2.35 (5.1)	79.5	83.6	82.1	84.5	-7.3	8.6	0	0
Clodinafop + Metribuzin	60+210	3.01 (9.0)	2.25 (4.7)	3.59 (12.5)	2.29 (5.0)	3.11 (9.3)	3.59 (12.4)	3.61 (12.7)	2.05 (3.7)	87.1	88.5	85.6	90.3	5.5	11.0	4.00	3.00
Pinoxaden + Metribuzin	40+210	4.03 (16.0)	3.28 (10.3)	5.36 (28.5)	3.37 (11.0)	4.21 (17.3)	4.13 (16.7)	4.00 (15.7)	2.56 (6.1)	77.0	74.9	67.2	78.6	28.2	27.7	6.33	3.67
Sulfosulfuron + Metribuzin	25+210	4.23 (17.7)	3.63 (13.0)	4.52 (20.0)	3.39 (11.2)	4.45 (19.7)	4.39 (18.9)	4.01 (16.0)	2.04 (3.7)	74.0	68.3	76.9	78.2	27.7	24.4	7.33	2.00
Fenoxaprop + Metribuzin	120+210	4.09 (16.3)	3.48 (11.7)	4.28 (18.3)	3.89 (15.2)	4.99 (24.6)	3.66 (12.9)	3.16 (9.6)	2.89 (8.0)	76.6	71.4	57.9	70.5	26.7	27.0	3.00	2.67
Sulfosulfuron + Metsufuron	32	4.23 (9.0)	3.01 (8.7)	4.20 (17.5)	2.98 (8.5)	3.69 (13.2)	3.70 (13.8)	3.70 (13.2)	2.15 (4.2)	87.1	78.8	79.8	83.5	1.5	13.4	0	0
Mesosulfuron+ Iodosufuron	14.4	4.09 (10.0)	2.60 (6.3)	3.62 (11.7)	2.55 (6.3)	2.97 (8.4)	3.09 (9.1)	3.66 (13.1)	2.11 (4.0)	85.6	84.6	86.5	87.5	1.2	3.8	0	0
Clodinafop + Metsuulfuron	60+4	3.06 (9.4)	2.32 (5.0)	3.34 (10.7)	2.44 (5.5)	2.48 (5.7)	2.55 (6.1)	3.29 (10.4)	2.04 (3.7)	87.1	87.8	87.7	89.3	-7.7	0.5	0	0
Isoproturon + 2,4-D	1000 + 500	3.16 (9.7)	2.84 (7.7)	6.10 (36.8)	4.98 (24.5)	3.30 (10.6)	2.65 (6.7)	5.69 (32.3)	4.66 (21.3)	86.1	81.2	57.6	52.4	7.8	21.0	0	0
Weedy	-	8.35 (69.7)	6.42 (41.0)	9.32 (86.8)	7.18 (51.5)	8.65 (75.2)	8.93 (80.4)	9.59 (92.4)	6.76 (45.6)	0	0	0	0	-2.5	26.8	0	0
Weed free	-	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	100	100	100	100	0	0	0	0
S Em±		0.31	0.27	0.31	0.32	0.35	0.30	0.34	0.22	-	-	-	-	-	-	-	-
CD (P=0.05)		0.90	0.79	0.91	0.94	1.02	0.86	0.99	0.63	-	-	-	-	-	-	-	-

* Figures are transformed values $\sqrt{x + 0.5}$ and values in parenthesis are actual figures. **DAS – Days after sowing and * Phyto-toxicity recorded on 0-10 scale, where 0 means nil toxicity and 10 means full plot population toxicity.

Table 2: Yield attributes and yields of wheat as influenced by treatment variables

Treatment	Doses (g/ha)	No. of earhead m^{-2}		No. of grains/earhead		1000 grain weight (g)		Grain yield (t ha^{-1})		Biological yield (t ha^{-1})		Harvest Index	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Metribuzin	210	310.3	326.7	35.9	21.2	43.2	39.7	4.87	3.16	11.20	7.71	43.5	41.0
Clodinafop	60	345.3	369.2	40.8	25.6	41.4	41.1	5.76	3.88	14.83	8.24	38.8	47.1
Pinoxaden	40	353.7	335.8	38.4	22.5	45.7	43.1	6.18	3.08	15.13	7.39	40.8	41.7
Sulfosulfuron	25	353.7	326.7	40.7	23.4	45.6	42.1	6.44	3.82	15.40	8.74	41.8	43.7
Clodinafop + Metribuzin	60+210	292.0	340.8	40.5	20.9	43.8	40.5	5.67	3.72	13.07	8.43	43.4	44.1
Pinoxaden + Metribuzin	40+210	249.3	339.2	40.6	20.7	40.0	37.9	4.31	3.02	10.23	7.22	42.1	41.8
Sulfosulfuron + Metribuzin	25+210	306.7	373.3	34.0	16.7	41.6	40.3	4.34	3.16	10.34	7.43	42.0	42.5
Fenoxaprop + Metribuzin	120+210	271.3	305.0	39.2	18.6	42.7	41.1	4.40	3.05	10.82	7.42	40.7	41.1

Sulfosulfuron + Metsufuron	32	360.0	364.2	38.3	24.3	43.0	41.0	5.91	3.62	15.03	8.63	39.1	41.9
Mesosulfuron+ Iodosufuron	14.4	350.0	339.5	40.8	28.5	41.8	42.7	5.93	4.02	14.33	8.80	41.4	45.7
Clod. + Metsul.	60+4	378.5	351.7	37.8	28.1	45.2	43.2	6.46	4.16	15.77	8.89	41.0	46.8
Isoproturon + 2,4-D	1000 + 500	362.3	338.3	35.9	23.2	42.6	42.3	5.53	3.30	13.59	8.08	40.7	40.8
Weedy	-	347.5	357.5	40.7	20.7	43.6	41.5	6.15	3.06	15.63	7.25	39.3	42.2
Weed free	-	365.3	383.3	45.9	28.8	45.9	44.0	6.00	4.18	15.60	9.04	38.5	46.2
S Em±	-	10.6	9.5	2.91	1.40	1.03	0.78	0.23	0.11	0.51	0.25	-	-
CD (P=0.05)	-	30.8	27.7	8.46	4.06	2.99	2.27	6.75	3.07	14.96	7.26	-	-

Table 3: Energy relationships as influenced by treatment variables

Treatment	Doses (g/ha)	Energy input ($x10^3$ MJ ha^{-1})		Energy output ($x10^3$ MJ ha^{-1})		Energy ratio		Energy productivity (grain in g MJ^{-1})	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Metribuzin	210	21.89	21.01	150.7	103.3	6.89	4.92	222.5	150.4
Clodinafop	60	21.89	21.01	185.7	111.5	8.48	5.31	263.1	184.6
Pinoxaden	40	21.95	21.07	202.7	99.1	9.24	4.70	281.6	146.2
Sulfosulfuron	25	21.94	21.07	202.7	117.6	9.23	5.58	293.5	181.3
Clodinafop + Metribuzin	60+210	21.93	21.06	175.8	113.6	8.02	5.39	258.5	176.6
Pinoxaden + Metribuzin	40+210	21.98	21.11	137.4	96.9	6.25	4.59	196.1	143.1
Sulfosulfuron + Metribuzin	25+210	21.98	21.11	138.8	99.8	6.31	4.73	197.4	149.7
Fenoxaprop + Metribuzin	120+210	22.03	21.16	144.9	99.5	6.58	4.70	199.7	144.2
Sulfosulfuron + Metsufuron	32	21.95	21.07	191.9	115.8	8.74	5.50	269.3	171.8
Mesosulfuron+ Iodosufuron	14.4	21.96	21.08	192.2	118.8	8.75	5.64	270.0	190.7
Clodinafop + Metsulfuron	60+4	21.99	21.11	211.3	120.3	9.61	5.70	293.8	197.0
Isoproturon + 2,4-D	1000 + 500	22.17	21.29	182.0	108.3	8.21	5.13	249.4	155.0
Weedy	-	21.83	20.95	208.9	97.3	9.57	4.65	281.8	146.0
Weed free	-	22.41	21.54	208.2	122.2	9.29	5.67	267.7	194.1

Conclusions
On the basis of two years study, it is inferred that post emergence application of *Clodinafop* @ 60 g/ha + *Metsulfuron* @ 4 g/ha was found most effective, productive and energy efficient herbicides combination for efficient control of multiple weed flora of wheat in vertisols of Central India.

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