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Effects of Weed Management Strategy on Weed Dynamics, Gobhi Mustard Productivity and Profitability under Conservation Agriculture in Central India

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A B S T R A C T

Weed management in conservation agriculture is major issues for attaining sustainable crop yields. The effect of tillage, residue and weed management practices was evaluated on weed population of *Medicago sativa*, *Chichorium intybus*, *Sonchus arvensis* and *Physalis minima* among dicots, as well as the productivity of mustard in the maize-mustard-greengram cropping system during 2015-2017. The experiment was laid out in split plot design with five main plot or tillage and residue management treatments and three sub plot treatments or weed management practices and one unweeded control under zero tillage was alone maintained as additional. Results indicated that total weed density and biomass was maximum in the first year, and declined gradually in second years in especially *Sonchus arvensis* and *Physalis minima*. However, *Medicago sativa* and *Cichorium intybus* was gradually increased during second year at 60 DAT and maturity. In both year CT (M)-CT (Msr) recorded the highest weed density and weed biomass followed by CT (M)-ZT (Msr)-ZT (G). While, the lowest weed biomass was found in ZT+GR (M)-ZT+MR (Msr)-ZT+MsR (G) followed by ZT (M)-ZT+MR (Msr)-ZT+MsR (G). The highest grain and stover yield of mustard was recorded in CT (M)-ZT (Msr)-ZT (G) but CT (M)-CT (Msr) out-yielded all other treatments from 2015 onwards. The highest gross and net returns were found in Pendimethalin *fb* HW and isoproturon under CT (M)-CT (Msr) during the study period. However, net B: C ratio was maximum in isoproturon under CT (M)-CT (Msr) (4.34 %) during 2015-16 and CT (M)-ZT (Msr)-ZT (G) (4.52 %) during 2016-17. Application of pendimethalin at 0.75 kg ha^{-1} along with one hand weeding at 25 DAT recorded the lowest total weed density and biomass. This treatment also recorded higher grain yield but lower net returns compared to pendimethalin 0.75 kg ha^{-1} + isoproturon 1.0 kg ha^{-1}. Overall, application of pendimethalin as PE and isoproturon as POE in ZT proved to be the most effective herbicide strategy for weed management in gobhi mustard leading to higher grain yield and net returns, irrespective of crop establishment practices.

Introduction

Among oilseeds, mustard occupies third position after groundnut and soybean. In India, It is cultivated in 6.7 m ha area with the annual production of 8.0 m t and average productivity of 1.2 t ha^{-1} (Annonymous, 2014). Maize-mustard cropping system is followed in the Western Himalayan Zone and also in the Western dry region including some parts of Madhya Pradesh. Being a relatively short duration crop, harvesting of mustard in

March ahead of wheat crop offers greater scope for inclusion of a legume in the summer season under irrigated conditions. There are several abiotic and biotic stresses which hamper the full yield potential of gobhi mustard. The reasons behind low mustard production are manifold and associated with low soil fertility, especially low levels of soil organic matter in the major production areas, inadequate weed control and other crop management practices. Intensive tillage-based agriculture practices without recycling of organic resources deteriorate the soil quality (Lal *et al.*, 1994), which then reduce, the overall productivity of mustard. Conservation agriculture (CA) is a crop management system based on the three principles of minimum soil disturbance, crop residue retention, and crop rotation (FAO, 2010). It has the potential to improve resource-use efficiency, crop productivity and soil health, while maintaining the environment (Kassam *et al.*, 2009). It is worth mention here that conservation agriculture is practiced presently on about 125 million ha globally (FAO, 2012). Among the various factors of low productivity of crops, competition by weeds is the major one (Bhan and Kewat, 2003). If weeds are not controlled during critical periods of crop-weed competition, there is identical reduction in the yields of gobhi mustard, to the tune of 10-58% (Banga and Yadav, 2001) depending upon the types and intensity of weeds. Though surface residue retention in zero-tillage suppresses weed emergence to a certain extent, residues also restrict manual or mechanical weed control (Mhlanga *et al.*, 2016). Hand weeding is a traditional and effective method of weed control, but untimely and continuous rains as well as unavailability of labour during peak period of demand, are the main limitations of manual weeding. Therefore, it is necessary to find out the alternative methods for reducing the weed load during early growth period of crops to get economical yields. All these methods have been evaluated independently and that too for a single crop or crop season. Literature indicates that no single method is effective and economical for a crop or for a whole cropping system. Thus, management of weeds through integration of tillage methods with herbicides can increase the productivity of the crops by decreasing the biomass and nutrient removal by the weeds.

The findings of weed species shifts under CA have been inconsistent (Chauhan *et al.*, 2006). Several studies have indicated that CA causes an increase in the density of perennial weeds (Malik *et al.*, 2002). Continued weed control under CA on the other hand influences weed population and density over time, and declines have been reported by Muoni *et al.*, (2016) using different weed control strategies.

Materials and Methods

Experimental site and location

The field experiment was conducted at the Research Farm, of ICAR-Directorate of Weed Research, Adhartal, Jabalpur (M.P.). Jabalpur is situated at 23^0 09' North latitude and 79^0 58' East longitudes with an altitude of 412 m above the mean sea level. The field selected for experimentation was laser-levelled having uniform topography and was fairly infested with location-specific weeds representing this area. All physical facilities *viz.*, labours, agrochemicals, equipments and irrigation water etc. were adequately available as per needs on the research farm. The mean annual rainfall of Jabalpur is 1350 mm, mostly received between mid-June to end-September with a little and occasional rains in remaining parts of the year. The mean monthly temperature goes down to 4 ^{0}C during winter, while the maximum temperature reaches up to 45 ^{0}C during the summer. Generally, relative humidity remains very low during summer (15-30%), moderate during winter (60-75%), and attains higher values (80-95%) during rainy season. To evaluate the physico-chemical properties of soil of the experimental field, sixteen soil samples were drawn randomly from the depth of 0-15 cm from different spots with the help of screw type soil augar. After this, all soil samples were thoroughly mixed together to make a composite sample. After proper drying, the composite sample was powdered finally with the help of pistle and morter and then subjected to analysis in the laboratory. It is obvious from the data that the soil of the experimental field was clayey in texture, neutral in reaction (pH 7.2), medium in organic C (0.68%) and analyzing medium in available nitrogen (215.5 kg ha^{-1}), medium in available phosphorus (12.4 kg ha^{-1}) and high in available potassium (385 kg ha^{-1}).

Treatment detail

The trial had five main treatments and three sub-treatments in a split-plot design with additional one control treatment with three replications. The study was conducted on gross plot size of 18.0 m ×11.4 m with a net plot size of 5.0 m× 2.1 m during each year in the same plot.

The main plot or tillage and residue management treatments *viz.* T_1 conventional tillage- conventional tillage [CT (M)–CT (Msr)], T_2 conventional tillage-zero tillage-zero tillage [CT (M)–ZT (Msr)–ZT (G)], T_3 zero tillage + greengram residue-zero tillage-zero tillage + mustard residue [ZT+GR (M)–ZT (Msr)–ZT+MsR (G)], T_4 zero tillage-zero tillage + maize residue-zero tillage + mustard residue, [ZT (M)–ZT+MR (Msr)–ZT+MsR (G)], T_5 zero tillage + greengram residue- zero tillage + maize residue-zero tillage + mustard residue [ZT+GR (M) –ZT+MR(Msr)–ZT+MsR (G)]; and three sub plot treatments or weed management practices; *viz.* W_1 Isoproturon (PoE) 1000 g/ha, W_2 Pendimethalin (PE) 750 g/ha *fb* isoproturon (PoE) 1000 g/ha, W_3 Pendimethalin 750 g/ha (PE) *fb* HW at 25 DAS, W_4 unweeded control under zero tillage was alone maintained as additional.

The CT treatment plot was ploughed four times (2 cultivator + 2 rotavators up to 15 cm soil depth) followed by levelling before sowing of the crop in each year. The soil was not tilled under ZT. The raised bed with the dimensions of 70 cm width and alternated with furrow of 60 cm in width with a tractor-mounted raised bed planter. However, reshaping of beds was done during second year by a raised bed planter with minimal soil disturbance before transplanting of gobhi mustard in each year. Thereafter, a spray of glyphosate @ 0.5 kg ha^{-1} before 2-3 days transplanting of mustard crop to kill the existing and newly emerged weeds. The herbicide treatments were imposed after transplanting of gobhi mustard. A pre-emergence application of pendimethalin 0.75 kg ha^{-1} was made before two days of transplanting in the respective treatments due to transplant of this crop. Thereafter, the plots were hand weeded at 25 DAS in respective treatments. Post-emergence application of isoproturon 1.0 kg ha^{-1} was done at 25 DAS. The herbicide applications were done with a hand operated knapsack sprayer.

Crop establishment of transplanted mustard

For the transplanted mustard, 210 – 250 g of seed is being sown in the seedbed or seedling trays for planting in a hectare for plants that are spaced at 70 x 60 cm apart. Plants can be thinned or transplanted when they are 10 cm tall. Transplanting of mustard has also been reported by (Sharma *et al.*, 2007). Transplanting reduces days to maturity and results in higher seed yield. A uniform dose of 100 kg N ha^{-1}, 60 kg P ha^{-1}, and 20 kg K ha^{-1} was applied as a basal dressing. The N, P and

K were applied through urea, single super phosphate and muriate of potash, respectively. The crop was sown during the fourtnight of September and transplanted in mid-October and finally harvested during the last week of March in each year.

Grain and stover yields

The yield attributes such as number of siliquae plant^{-1}, length of siliquae and number of seeds siliqua^{-1} of mustard crops was calculated from 10 random plants from each treatment. The grain and stover yields of mustard were obtained from the net plot area of 5.0 x 2.1 m was harvested manually, dried in the sun for 2-3 days, and threshed with thresher. The grain and stover yields were recorded at the moisture content of 12.5% and 18.0%, respectively.

Weed observations

The data on weeds were recorded using a quadrat of 0.5 m × 0.5 m. The quadrat was randomly placed four times in each plot. Inside the quadrat, the number of weed species present was recorded. The samples for weed biomass were collected and oven dried at 60 °C for 72 h, thereafter, weighed and expressed in g m^{-2}. Sampling for weed species count and biomass was done at 30, 60 DAT and maturity during the entire growing season in each year.

Economic analysis

A partial budget analysis was conducted to assess the economic benefits of each weed control strategy. A comparison was done for the total cost of production, gross returns, and net benefits of the treatments. The cost of inputs (seed, fertilizer, and pesticide) and labour for field operations was taken for calculating the total cost of production. The prevailing minimum support price for the gobhi mustard was considered and gross returns were worked out by multiplying the quantity and price of produce. Further, net benefits were calculated by deducting the total cost of production from gross receipts every year.

Statistical Analysis

The data obtained on various observations were suitably tabulated and subjected to statistical analysis for split plot design and one control was carried out as given by Sharma, (2012). The standard techniques of the analysis of variance (ANOVA) and the treatments were tested by F test as shown below. Critical difference at 5% level of significance CD (P=0.05) was determined for each character to compare the differences among treatment means. The data on weed count and weed biomass were subjected to square root transformation i.e. $\sqrt{x+0.5}$ before carrying out analysis of variance and comparisons were made on transformed values only.

Results and Discussion

Weed density (No./m^2) and biomass (g/m^2)

The data recorded on density and biomass of associated weeds at 60 DAT *viz*., *Medicago sativa*, *Sonchus arvensis*, *Cichorium intybus* and *Physalis minima* as influenced by different weed control treatments are presented in Table 1 and 2. The density and biomass of associated weeds were increased with time and thereafter declined. Major weed flora is given as species-wise which are presented here. The comparison among the treatment means have been made on transformed values.

It is evident from the data presented in Table 1 and 2 that among tillage practices, the density and biomass of *Medicago sativa*, *Sonchus arvensis* and *Cichorium intybus* were maximum in conventional tillage [CT (M)-CT (Msr)] and *Physalis minima* was higher under zero-tilled mustard without maize residue [CT (M)-ZT (Msr)-ZT (G)] during both years.

Among weed management practices, density and biomass of the weeds were significantly higher under unweeded control where no weed control measures were adopted and it was at par with isoproturon in *Cichorium intybus* during both years. However, none of the weed management practices surpassed pendimethalin *fb* HW as it curbed the density and biomass of all type of weeds to larger extent during both years. The density and biomass of both the weed species decreased significantly with the application of pendimethalin and isoproturon compared with unweeded control. The best control of *Sonchus arvensis* was obtained by pendimethalin + hand weeding, followed by pendimethalin + isoproturon. Pendimethalin with hand weeding or isoproturon recorded equal effect on *Sonchus arvensis*, *Cichorium intybus* and *Physalis minima* at 30 DAS, but at 60 DAS, pendimethalin + isoproturon had significantly higher density and biomass than pendimethalin + hand weeding. On the other hand, greater density and biomass of *Medicago sativa*, particularly at 60 DAS. The effect of post-emergence isoproturon alone was relatively poor than when pendimethalin was applied as pre-emergence.

The average of three (other) weed management practices with respect to density and biomass of all weeds compared to control was significant, during both the years. The interaction between tillage and weed management practices was not significant.

Total weed density and biomass

Total weed density and biomass at 60, DAT were determined by summing up the density of individual weeds under each treatment. The data thus obtained have been presented in Table 3. The total weed density and biomass was affected by tillage and weed management treatments. The total weed density and biomass increased up to 60 DAT under all the treatment and declined later during both years.

Among tillage, all the treatments were on par with each other with respect to total weed density and biomass at 60 DAT during both years. However, numerically it was recorded higher under conventional tillage [CT (M)-CT (Msr)] followed by zero-tilled mustard without retention of maize residue [CT (M)-ZT (Msr)-ZT (G)].

Among weed management, total density and biomass of the weeds at 60 DAT were significantly higher under unweeded control where weeds were allowed to grow throughout the growing season during both years. The total density and biomass of weeds was reduced under pendimethalin *fb* HW during both years. The average of three weed management practices with respect to total weed density and biomass compared to control was significant, during both the years and on mean basis.

Discussion on weeds

Dominant weed flora

The dominant weeds associated with gobhi mustard in the experimental field were mainly comprised of dicot weeds like *Medicago sativa*, *Sonchus arvensis*, *Cichorium intybus* and *Physalis minima* only. Almost similar weed flora associated with mustard was reported by Bazaya *et al.,* (2006).

Density and dry weight of weeds

The dynamics of weeds and weed biomass differs under conventional and conservation tillage.

Table.1 Effect of tillage, residue and weed management on weed density at 60 DAT of mustard

Treatment	Weed density (no. m^{-2})							
	Medicago sativa		*Sonchus arvensis*		*Cichorium intybus*		*Physalis minima*	
	2015-16	**2016-17**	**2015-16**	**2016-17**	**2015-16**	**2016-17**	**2015-16**	**2016-17**
Tillage and residue management (T)								
CT (M)-CT(Msr)	(27.78) 5.32	(86.56) 9.33	(9.22) 3.12	(6.22) 2.59	(4.22) 2.17	(4.67) 2.27	(11.22) 3.42	(4.56) 2.25
CT (M)-ZT (Msr)-ZT (G)	(26.56) 5.20	(83.33) 9.16	(8.22) 2.95	(6.00) 2.55	(5.56) 2.46	(5.11) 2.37	(9.67) 3.19	(5.00) 2.35
ZT+GR (M)-ZT (Msr)-ZT+MsR (G)	(22.67) 4.81	(84.44) 9.22	(7.67) 2.86	(5.56) 2.46	(4.33) 2.20	(5.67) 2.48	(9.33) 3.14	(3.78) 2.07
ZT (M)-ZT+MR (Msr)-ZT+MsR (G)	(25.67) 5.12	(84.56) 9.22	(7.22) 2.78	(5.11) 2.37	(4.22) 2.17	(4.78) 2.30	(11.11) 3.41	(4.11) 2.15
ZT+GR (M)-ZT+MR (Msr)-ZT+MsR (G)	(23.33) 4.88	(84.00) 9.19	(6.00) 2.55	(5.78) 2.51	(4.67) 2.27	(4.78) 2.30	(10.56) 3.32	(4.33) 2.20
SEm ±	**0.06**	**0.02**	**0.17**	**0.05**	**0.20**	**0.11**	**0.06**	**0.05**
LSD (p=0.05)	**0.20**	**0.07**	**0.55**	**0.17**	**0.64**	**0.35**	**0.20**	**0.18**
Weed management (W)								
Isoproturon	(39.93) 6.36	(104.47) 10.25	(12.07) 3.54	(10.20) 3.27	(7.13) 2.76	(9.47) 3.16	(8.73) 3.04	(4.07) 2.14
Pendimethalin *fb* isoproturon	(25.80) 5.13	(86.00) 9.30	(7.80) 2.88	(3.80) 2.07	(3.80) 2.07	(3.40) 1.97	(11.73) 3.50	(5.73) 2.50
Pendimethalin *fb* HW	(9.87) 3.22	(63.27) 7.99	(3.13) 1.91	(3.20) 1.92	(2.87) 1.83	(2.13) 1.62	(10.67) 3.34	(3.27) 1.94
SEm ±	**0.05**	**0.03**	**0.13**	**0.05**	**0.18**	**0.17**	**0.04**	**0.05**
LSD (p=0.05)	**0.15**	**0.08**	**0.38**	**0.16**	**0.54**	**0.49**	**0.12**	**0.16**
Control vs others								
Control	(64.11) 8.04	(172.89) 13.17	(11.56) 3.47	(16.33) 4.10	(8.89) 3.06	(14.67) 3.89	(22.67) 4.81	(12.67) 3.63
Other	(25.20) 5.07	(84.58) 9.22	(7.67) 2.86	(5.73) 2.50	(4.60) 2.26	(5.00) 2.35	(10.38) 3.30	(4.36) 2.20
SEd ±	**0.12**	**0.06**	**0.30**	**0.13**	**0.42**	**0.38**	**0.09**	**0.12**
LSD (p=0.05)	**0.24**	**0.13**	**0.62**	**0.26**	**0.88**	**0.80**	**0.19**	**0.25**
Interaction (T X W)								
SEm ±	**0.11**	**0.06**	**0.29**	**0.12**	**0.41**	**0.37**	**0.09**	**0.12**
LSD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Data in parentheses are square root transformed

CT = Conventional tillage, ZT = Zero tillage, M = Maize, Msr = Mustard, G = Greengram, GR = Greengram residue, MR = Maize residue, MsR= Mustard residue

Table.2 Effect of tillage, residue and weed management on weed dry weight at 60 DAT of mustard

Treatment	Weed dry weight (g m^{-2})							
	Medicago sativa		*Sonchus arvensis*		*Cichorium intybus*		*Physalis minima*	
	2015	2016	2015	2016	2015	2016	2015	2016
Tillage and residue management (T)								
CT (M)-CT(Msr)	(2.40) 1.70	(8.13) 2.94	(18.08) 4.31	(12.40) 3.59	(10.61) 3.33	(9.50) 3.16	(3.06) 1.89	(3.30) 1.95
CT (M)-ZT (Msr)-ZT (G)	(2.26) 1.66	(7.69) 2.86	(17.14) 4.20	(11.84) 3.51	(8.80) 3.05	(11.06) 3.40	(3.00) 1.87	(3.34) 1.96
ZT+GR (M)-ZT (Msr)-ZT+MsR (G)	(1.89) 1.55	(7.77) 2.88	(16.03) 4.07	(11.63) 3.48	(8.68) 3.03	(12.50) 3.61	(2.81) 1.82	(2.53) 1.74
ZT (M)-ZT+MR (Msr)-ZT+MsR (G)	(2.16) 1.63	(7.59) 2.84	(14.26) 3.84	(10.64) 3.34	(9.38) 3.14	(10.39) 3.30	(3.00) 1.87	(2.88) 1.84
ZT+GR (M)-ZT+MR (Msr)-ZT+MsR (G)	(2.10) 1.61	(7.68) 2.86	(11.64) 3.48	(11.81) 3.51	(7.21) 2.78	(10.43) 3.31	(2.79) 1.81	(2.90) 1.84
SEm ±	**0.02**	**0.01**	**0.24**	**0.03**	**0.31**	**0.13**	**0.14**	**0.01**
LSD (p=0.05)	**0.06**	**0.04**	**0.77**	**0.09**	**1.03**	**0.44**	**0.45**	**0.04**
Weed management (W)								
Isoproturon	(3.35) 1.96	(9.77) 3.21	(24.32) 4.98	(20.85) 4.62	(15.59) 4.01	(20.01) 4.53	(2.73) 1.80	(2.78) 1.81
Pendimethalin *fb* isoproturon	(2.29) 1.67	(7.91) 2.90	(15.49) 4.00	(7.79) 2.88	(6.45) 2.64	(7.52) 2.83	(3.48) 1.99	(3.96) 2.11
Pendimethalin *fb* HW	(0.83) 1.15	(5.63) 2.48	(6.49 2.64	(6.35) 2.62	(4.77) 2.29	(4.80) 2.30	(2.58) 1.75	(2.23) 1.65
SEm ±	**0.02**	**0.01**	**0.17**	**0.05**	**0.24**	**0.24**	**0.12**	**0.03**
LSD (p=0.05)	**0.05**	**0.04**	**0.50**	**0.15**	**0.72**	**0.70**	**0.36**	**0.07**
Control vs others								
Control	(5.73) 2.50	(16.38) 4.11	(22.31) 4.78	(31.70) 5.67	(18.01) 4.30	(30.65) 5.58	(8.19) 2.95	(8.91) 3.07
Other	(2.16) 1.63	(7.77) 2.88	(15.43) 3.99	(11.67) 3.49	(8.94) 3.07	(10.78) 3.36	(2.93) 1.85	(2.99) 1.87
SEd ±	**0.04**	**0.03**	**0.40**	**0.12**	**0.56**	**0.55**	**0.29**	**0.06**
LSD (p=0.05)	**0.09**	**0.06**	**0.82**	**0.25**	**1.17**	**1.15**	**0.59**	**0.12**
Interaction (T X W)								
SEm ±	**0.04**	**0.03**	**0.38**	**0.12**	**0.55**	**0.53**	**0.28**	**0.06**
LSD (p=0.05)	**0.12**	**0.09**	**1.13**	**0.34**	**1.60**	**1.57**	**0.81**	**0.16**

*Data in parentheses are square root transformed

CT = Conventional tillage, ZT = Zero tillage, M = Maize, Msr = Mustard, G = Greengram, GR = Greengram residue, MR = Maize residue, MsR= Mustard residue

Table.3 Effect of tillage, residue and weed management on total weed density, dry weight, seed and stover yield at harvest of mustard

Treatment	Total weed density		Total weed biomass		Seed yield (t ha^{-1})	Stover yield (t ha^{-1})
	60 DAS		60 DAS			
Tillage and residue management (T)	2015-16	2016-17	2015-16	2016-17	Mean both year	Mean both year
T1	(52.44) 7.28	(112.33) 10.62	(34.14) 5.89	(33.33) 5.82	4.04	8.02
T2	(50.00) 7.11	(109.33) 10.48	(31.20) 5.63	(33.93) 5.87	3.90	7.88
T3	(44.00) 6.67	(110.11) 10.52	(29.41) 5.47	(34.43) 5.91	3.70	7.60
T4	(48.22) 6.98	(109.11) 10.47	(28.79) 5.41	(31.50) 5.66	3.78	7.74
T5	(44.56) 6.71	(111.33) 10.58	(23.74) 4.92	(32.82) 5.77	3.75	7.72
SEm	**0.10**	**0.04**	**0.15**	**0.05**	**0.03**	**0.06**
CD	**0.32**	**0.14**	**0.50**	**0.16**	**0.11**	**0.20**
Weed management (W)						
W1	(67.87) 8.27	(140.93) 11.89	(46.00) 6.82	(53.41) 7.34	3.73	7.62
W2	(49.13) 7.05	(118.20) 10.89	(27.71) 5.31	(27.18) 5.26	3.84	7.74
W3	(26.53) 5.20	(72.20) 8.53	(14.67) 3.89	(19.02) 4.42	3.94	8.02
SEm	**0.05**	**0.09**	**0.09**	**0.08**	**0.02**	**0.04**
CD	**0.14**	**0.27**	**0.27**	**0.24**	**0.05**	**0.12**
Control vs others						
Control	(107.22) 10.38	(206.78) 14.40	(54.25) 7.40	(87.64) 9.39	2.83	6.78
Others	(47.84) 6.95	(110.44) 10.53	(29.46) 5.47	(33.20) 5.81	3.84	7.79
SEd	**0.11**	**0.22**	**0.21**	**0.19**	**0.04**	**0.10**
CD	**0.23**	**0.45**	**0.45**	**0.39**	**0.08**	**0.20**
Interaction (T X W)						
SEm	**0.11**	**0.21**	**0.21**	**0.18**	**0.04**	**0.09**
CD	**NS**	**NS**	**0.61**	**0.53**	**0.11**	**0.28**

Table.4 Effect of weed management on weed control efficiency (%) at harvest of mustard (means across tillage and residue treatments)

Treatment	Weed control efficiency (%)		
	60 DAS		
Weed management (W)	2015-16	2016-17	Mean
Isoproturon	15.27	39.05	27.16
Pendimethalin *fb* isoproturon	48.91	69.93	59.42
Pendimethalin *fb* HW	72.96	78.88	75.92

Table.5 Associated weed flora in mustard

Botanical name	English common name	Family	Weed density (m^{-2})		Relative density (%) 60 DAS	
			60 DAT	60 DAT	60 DAT	60 DAT
Narrow-leaved weeds			2015-16	2016-17	2015-16	2016-17
Medicago sativa	Toothed clover	Fabaceae	64.11	172.89	59.79	82.16
Sonchus arvensis (L.)	Field sowthistle	Asteraceae	11.56	10.20	10.78	4.85
Physalis minima	Native gooseberry	Solanaceae	8.89	14.67	8.29	6.97
Cichorium intybus	Blue daisy	Asteraceae	22.67	12.67	21.14	6.02
Total			**107.23**	**210.43**		

Table.6 Correlation coefficient between yield attributes [number of siliquae plant $^{-1}$, length of siliquae (cm), seeds siliqua^{-1} and test weight (g)] and total weed dry weight (g m^{-2}) at 60 DAS of mustard (Mean data of 2015-16 and 2016-17)

-	Number of siliquae plant^{-1}	Length of siliquae (cm)	Seeds siliqua^{-1}	Test weight (g)	Total weed dry weight(g m^{-2})
Number of siliquae plant^{-1}	1				
Length of siliquae (cm)	0.95*	1			
Seeds siliqua^{-1}	0.942*	0.916*	1		
Test weight (g)	0.972*	0.892*	0.926*	1	
Total weed dry weight(g m^{-2})	-0.793	-0.875	-0.814	-0.771	1

*Significant at (p= 0.05)

Table.7 Correlation coefficient between yield [seed and stover yield (t ha^{-1})] and total weed dry weight (g m^{-2}) at 60 DAS of mustard (Mean data of 2015-16 and 2016-17)

	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Total weed dry weight(g m^{-2})
Seed yield (t ha^{-1})	1		
Stover yield (t ha^{-1})	0.988*	1	
Total weed dry weight(g m^{-2})	-0.858	-0.881	1

*Significant at (p= 0.05)

Plate.1 Crop performance at different growth stages in transplanted mustard

Excellent growth of transplanted mustard at about 65 days of growth

Transplanted mustard fully laiden with siliqua at ripening stage

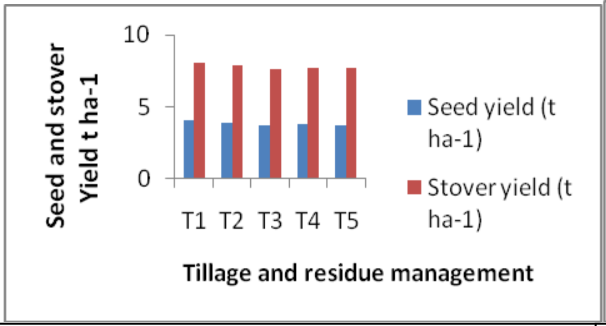

Fig 1. Effect of tillage and residue management on seed and stover yield of mustard

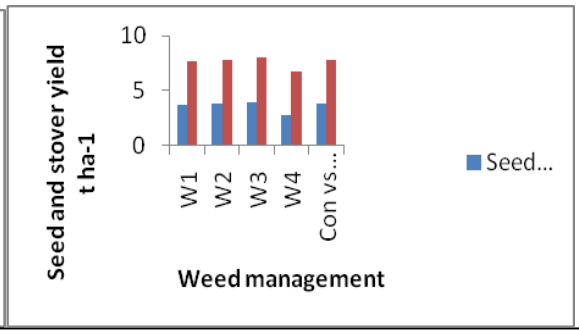

Fig 2. Effect of weed management on seed and Stover yield of mustard

The weed population and weed biomass under ZT was less than the CT as because ZT minimizes soil disturbance, which led to poor condition for weed emergence. In transplanted mustard, among tillage practices, the population and biomass of weeds was maximum under conventional tillage [CT (M)-CT (Msr)] treatment during both years due to friable seedbed and better aeration which favour the germination of weed seeds. However, in case of zero tillage, it is *vice-versa*. The population and biomass of weeds was minimum under zero-tilled mustard with maize residue retention ZT+GR (M)-ZT+MR (Msr)-ZT+MsR (G) due to retention of crop residue on the soil surface which reduces the weed population and biomass in the succeeding crop because of residue laden condition can suppress weed seedling emergence, delay the time of emergence, and allow the crop to gain an advantage over weeds that ultimately reduce the need for control of weeds (Bazaya *et al.*, 2004).

Weed management practices were found to reduce the weed density and weed biomass than unweeded control. However, identical reduction in density and biomass of weeds were observed when weeds were controlled either through chemical or mechanical means during both years at 25 DAT. The lowest weed density was recorded under pendimethalin *fb* HW, followed by pendimethalin *fb* isoproturon in both the years.

This might be due to the some killing activity and persistence nature of the herbicides in gobhi mustard. In ZT mustard, no ploughing and slightly higher soil moisture may invite early weed germination than CT mustard. Application of pendimethalin as pre-emergence may lead to the better control of this early weed flush under ZT condition and sequential application of isoproturon or hand weeding also played a role. It might have controlled the subsequent flushes of weeds and led to the higher weed control efficiency in mustard. The results are in conformity with the findings of Singh and Chauhan (2010).

Weed control efficiency recorded under different weed management practices varied significantly and same have been presented in (Table 4). Weed control efficiency of a treatment has strong relationship with weed biomass. The maximum weed control efficiency was recorded under pendimethalin *fb* HW due to complete check on weeds, confirming the view of Mukundam *et al.*, (2011). The weed control efficiency was zero under weedy check plots due to uninterrupted growth of these weeds as no weed control measures were adopted in weedy check plots, followed by isoproturon due to less phytotoxicity effect on weeds (Bullied *et al.*, 2003).

Seed and stover yield

Data related to seed and stover yield of gobhi mustard are presented in Table 3. During both years of experiment, the seed and stover yield of mustard was significantly influenced by both the factors i.e. tillage and weed management and data are presented in Table 3 and figure 1 and 2.

Seed and stover yield of mustard was higher under conventional tillage [CT (M)-CT (Msr)] during both years and on mean basis and which closely followed by [CT (M)-ZT (Msr)-ZT (G)]. Among weed management practices, the seed and stover yield was maximum under pendimethalin *fb* HW during both years and as well as on mean basis and this treatment was on par with pendimethalin *fb* isoproturon. The only application of isoproturon as POE was found less effective in enhancing seed and stover yield.

The lowest grain yield was recorded in 2015-16, On the other hand significantly lower seed and stover yield was recorded under weedy check treatment. The average of three weed management practices with respect to seed and stover yield compared to control was significant while the interaction of tillage and weed management was found not significant during both the year on mean basis data also.

1000 seed weight

Test weight of gobhi mustard was not affected due to tillage and weed management practices as significant differences did not exist among different treatments. However, super values were recorded in plots receiving weed treatment along with hand weeding during both years and on mean basis data also. Test weight was slightly higher during 2016-17 as compared to 2015-16. The average of three weed management practices compared to control as well as interaction between tillage and weed management in terms of seed weight was not significant.

Discussion on seed and stover yield

Among tillage practices, the highest yield was associated with conventional tillage [CT (M)-CT (Msr), followed by CT (M)-ZT (Msr)-ZT (G) than ZT due to better crop establishment in transplanted mustard crop which might have resulted from greater sink and good growth and development in reproductive phase and being more yield attributes and more vigorous as well as under a wide range of climate partly because it has a large number of primary and secondary branches. It shows better environment adoption and substantial resistance to pests and diseases during both years. However, lower yield were recorded under ZT+GR (M)-ZT (Msr)-ZT+MsR (G) due to less yield attributes. The findings of Sharma *et al., (*2007) corroborate our result. Among weed management practices, higher seed and stover yields were obtained under pendimethalin *fb* HW and pendimethalin *fb* isoproturon was due to the weed managed at critical period and better early crop growth which resulted in higher production of photosynthates and greater translocation of food materials to the reproductive parts particularly number of siliquae plant^{-1} number of seeds siliqua^{-1} and ultimately high yield. Lower weed population and higher weed control efficiency also resulted in higher seed and stover yield. The lower seed yield under weedy check may be due to the high weed interference. In our experiment, during 2016-17 yield of mustard was higher than 2015-16 it may be due to favourable weather condition and uniform and better crop establishment.

Positive correlation between yield attributes (number of siliqua plant^{-1}, length of siliqua, number of seeds siliqua^{-1}, 1000 seed weight) and seed and stover yield of mustard, negative correlation between yield attributes of mustard and total dry weight of weeds (Table 6), seed and stover yield of mustard and total dry weight of weeds (Table 7) and confirms the beneficial effect of yield attributes as well as seed and stover yield and detrimental effect of weed competition on yield attributes and yield of mustard

This 2-year study suggested that application of pre- and post-emergence herbicides is an effective strategy to control weeds under different tillage, residue and weed managements in gobhi mustard under sub-tropical conditions. The lowest population of *Medicago sativa*, *Sonchus arvensis*, *Cichorium intybus* and *Physalis minima* were found in zero tilled mustard with maize residue ZT+GR (M)-ZT+MR (Msr)-ZT+MsR (G) conditions over the years. The higher seed yield and net returns of gobhi mustard were recorded in CT compared to ZT practices due to transplanted crops. The application of pendimethalin 0.75 kg ha^{-1} as pre-emergence followed by hand weeding at 25 DAT recorded the lowest weed density and biomass. The other treatment i.e. pendimethalin 0.75 kg ha^{-1} as pre-emergence followed by isoproturon 1.0 kg ha^{-1} as post-emergence application was found comparable in gobhi mustard productivity however, this treatment was more economic in terms of net B:C ratio. We conclude that gobhi mustard could be grown successfully with zero-tillage transplanted following herbicide based weed control strategy in the clayey soils of Central India.

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