Himachal Journal of Agricultural Research 47(2): 187-197 (2021)

Conservation agriculture and weed management effects on growth indices and yield attributes of maize-wheat cropping system

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Manuscript received:26.04.2021; Accepted: 05.06.2021

Abstract

A field experiment was carried out for two years from 2018 to 2020 in maize-wheat cropping system to evaluate the effect of conservation agriculture (ZT, zero tillage; crop rotation and intensification; residue management) on growth indices and yield attributes with fifteen treatment combinations of five tillage *viz.* CT-CT, CT-ZT, ZT-ZT, ZT-ZTR & ZTR-ZTR applied in maize and wheat crops in sequence(CT- conventional tillage; ZT- zero tillage; ZTR- zero tillage + residue) and three weed management treatments viz. H (recommended herbicide in maize) - H (recommended herbicide in wheat), IWM-IWM & HW-HW; (H-herbicide; IWM- integrated weed management; HW- hand weeding). Significant differences in growth and yield attributes were observed under tillage and weed management treatments in maize-wheat cropping system. Conservation agriculture (CA-ZT+R) based production system had taller plants, better unit area efficiency and yield components of maize and wheat crops. The zero tillage in maize and wheat in combination with residue incorporation (ZT-ZTR) resulted in shortest plants, lower plant population and minimum unit area efficiency in maize crop. ZT-ZT in wheat resulted in lower wheat height, unit area efficiency, effective tillers and 1000-grain weight. Weed management treatments significantly affected plant height, unit area efficiency and yield attributes of maize and wheat crops. H-H resulted in taller plants, better unit area efficiency and yield attributes i.e. plant population in maize and effective tillers, length of ear and total number of grains spike^{-1} in wheat crop. ZTR+H-ZTR+H (Conservation tillage combined with herbicide application in maize and wheat) was found to be comparatively superior to other combinations in terms of growth and yield attributes in maize-wheat cropping system.

Key words: Conservation agriculture, conventional tillage, zero tillage, residue, harvest index, yield attributes.

Maize based cropping system ranks first and has 1.8 m ha area concentrated in rainfed conditions (Ghosh *et al*. 2015) which contributes about 3% of the total food grain production of India (Jat *et al.* 2011). Global aggregated tillage system on total cropland includes only 9.74% of conservation agriculture whereas, 41.10% of conventional annual tillage (Porwollik *et al*. 2019). The low productivity of maize in India as compared to world productivity can be attributed to several limiting factors and all but the most important amongst these has been the poor weed management which poses a major threat to crop productivity (Upasani *et al*. 2017). Tillage is most important agro-technical operation performed in order to achieve optimum soil conditions for better crop growth and development (Yadav *et al*. 2017). In an intensive crop production system, soil health deterioration is a continuous phenomenon in rainfed and irrigated ecosystems. Adoption of conservation production systems can have beneficial effects on soil chemical, physical and biological properties that help to reduce soil erosion, enhance sustainability and productivity (Locke *et al*. 2002) because of reduction in production costs, minimum soil degradation and improved soil quality (Verhulst *et al*. 2010; Kassam *et al*. 2014). The benefits of conservation agriculture are more apparent under rainfed conditions where it helps to retain soil moisture, thereby increasing crop yield

(Pittelkow *et al*. 2014).

In North Western Himalayas, maize-wheat cropping system is the most predominant (Suresha *et al*. 2015) and covers around 85% of the food share (Bharti 2013). Almost 80 percent of the cultivated area of the state of Himachal Pradesh lacks irrigation facilities resulting in lower productivity (Ramesh *et al*. 2016). Therefore, boosting the viability of maize-wheat cropping sequence holds key to transform the agricultural scenario in Himachal Pradesh (Bharti, 2013). Although, there is massive growth of maize-wheat cropping system, reports of stagnation in the productivity in future have raised doubts about its sustainability (Suresha *et al*. 2015). The resource-conserving technologies should form an important component of the regional strategy for food security, rural development, enhanced profitability, improved environmental quality, and sustainability of natural resources. Tillage is an important input to ease soil-related constraints to crop production through short and long-term effects on sustainability which has effects on soil processes, populations (soil macro and micro-flora and fauna), and crop growth (Chopart *et al*. 2008).

Zero/low till conservation farming strategies are aimed to achieve better resource conservation (Mishra and Singh 2012) as compared to intensive tillage practices which consume more energy. Hence, efficient technologies are advised to ensure environmental safety and global food security (Rana *et al*. 2019; Hammad *et al*. 2020). Therefore, an experiment was undertaken to evaluate the performance of various tillage practices in relation to weed management techniques on growth and yield attributes on maize-wheat cropping system.

Materials and Methods

The present study was conducted during *kharif* 2018 to *rabi* 2019-20 at Palampur in a long-term experiment started in 2013. The experimental site was at $32^0 6^'$ N latitude, 76°32 E longitude, and 1290 m altitude. Site falls in the sub-temperate mid-hill zone of Himachal Pradesh. The region is endowed with mild summers and cool winters. The soil of the test site was silty clay loam in texture, acidic in reaction, high in OC and phosphorus, and medium in available N and K. The experiment included five tillage treatments *viz*. conventional tillage both in maize and wheat (CT-CT), conventional tillage in maize followed by zero tillage in wheat (CT-ZT), zero tillage in maize during *kharif* season and zero tillage in wheat during *rabi* season (ZT-ZT), zero tillage in maize and zero tillage incorporated with residue in wheat (ZT-ZTR) and zero tillage incorporated with residue in both maize and wheat (ZTR-ZTR); and three weed management treatments *viz*. herbicides in both maize and wheat (H-H), integrated weed management in both maize and wheat (IWM-IWM) (Herbicide + mechanical + intercrop) and two hand weeding in both maize and wheat (HW-HW). Intercropping of soybean in maize was done in an additive series, whereas, sarson was intercropped in wheat in replacement series. Recommened herbicides atrazine *fb* 2, 4-D and isoproturon *fb* 2, 4-D was applied in maize and wheat, respectively. Tillage and weed management treatments were arranged in horizontally and vertically strip, respectively, under strip plot design with three replications.

Experiment field was ploughed to a fine tilth during May. Except for zero tillage treatment, the plots were prepared with the help of a power tiller which carried rotary. During seed bed preparation, the crop stubble and weeds were removed to facilitate the planting operation. The left-over weeds were removed, and the plots were levelled to have uniform sowing and germination thereof. CT was performed using ploughing once, harrowing twice, and leveling. All the recommended package of practices was followed for raising the maize and wheat crops except for the tillage and weed control treatments.

The seeds of maize variety 'Kanchan 51 hybrid' were sown in rows 60 cm apart in the first week of June and harvested at the end of September each year. The sowing was done with hand plough by the kera method. A common dose of 120 kg N, 60 kg P_2O_5, and 40 kg K_2O ha^{-1} was supplied through urea (46% N), IFFCO (12:32:16), and MOP (60% K_2O), respectively. One-third of nitrogen and whole of P_2O_5 and K_2O were applied at the time of sowing. Remaining two-third of nitrogen was applied in two equal splits, one at knee-high and the other at the tasseling stage. Basal dose of fertilizers was placed below the seed in the open furrows made by hand-driven plough. Two splits of nitrogen were given by placing fertilizer by the sides of maize rows avoiding direct contact with plants. Intercrop of soybean grown in additive series was not given any additional fertilizer dose. Wheat crop variety 'HPW 349' was sown during the first fortnight of November at a spacing of 22.5 cm using a seed rate of 120 kg ha^{-1}. The crop was fertilized with 120 kg N, 60 kg P_2O_5, and 30 kg K_2O ha^{-1}. Half N and whole P_2O_5 and K_2O were applied at the time of sowing. The remaining nitrogen was top-dressed in two equal splits at tillering and earing stage. The crop was harvested by the mid of May each year.

The data on various growth parameters were recorded at different stages to see tillage and weed management effects. In maize crop various yield attributes were recorded as mean of 5 observations within each sub-plot. Data on cob length (cm), number of cobs per plant, dry weight of cob with husk (g), dry weight of cob without husk (g), number of grains cob^{-1} and 1000-grain weight (g) during *kharif* 2018 and 2019 have been presented in this paper. In wheat crop data on effective tillers per square metre (No.), length of ear (cm), grains $spike^{-1}$ and 1000-grain weight (g) were recorded.

Dry matter efficiency (DME): It is calculated by knowing seed yield and total dry matter production over crop growth period. It is expressed as % day^{-1}.

DME = Grain yield (kg ha^{-1}) ÷ TDMP (kg ha^{-1}) × 100 ÷ Duration of crop (days)

Where - TDMP is total dry matter production.

Unit area efficiency (UAE): It is estimated as the quantum of seed/grain yield produced over a unit land area for a specified crop growth period. It is expressed as kg m^{-2} day^{-1}.

UAE = Grain yield (kg ha^{-1}) ÷ Land area (ha) × 1 ÷ Duration of crop (days)

Harvest index (%): Harvest index was calculated using the formula given by Hay (1995).

Harvest Index (HI) = Economic yield ÷ Biological yield ×100

Results and Discussion

Weed flora

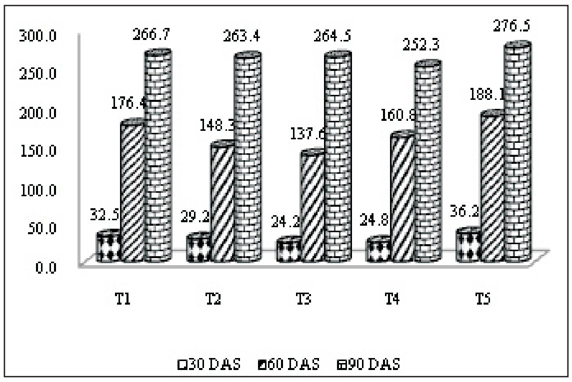
Experimental field was monitored during crop growth phases to look for the occurrence of different weed species at monthly intervals after emergence particular stage from *kharif* 2018 to *rabi* 2019-20. *Ageratum conyzoides, Commelina benghalensis, Echinochloa colona, Digitaria sanguinalis, Cyperus* sp., *Panicum dichotomiflorum and Bidens pilosa* were the major weeds during *kharif* season. Occurrence of *Parthenium hysterophorus* and *Bidens pilosa* was seen only during *kharif* 2018 which were otherwise not present during *kharif* 2019, whereas, occurrence of *Polygonum alatum* was seen only during *kharif* 2019. *Avena ludoviciana, Daucus carota, Lolium temulentum, Poa annua, Vicia sativa* and *Phalaris minor* were the major weeds during *rabi* 2018-19 and 2019-20. *Cornopous didymus* making up lowest share during both the years.

Plant height (cm)

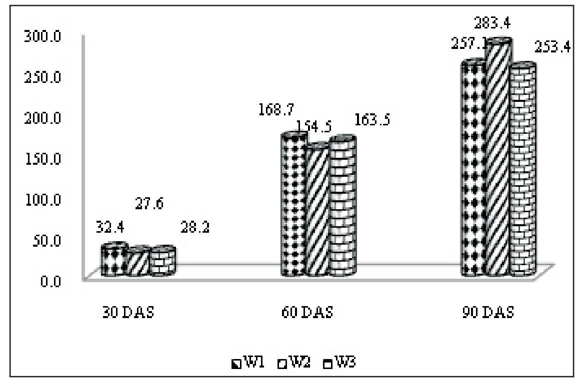
Data pertaining to effect of tillage and weed control treatments on plant height at monthly interval of pooled data of both the crops during 2018-19 and 2019-20 have been presented in Fig 1. From the Figure it was inferred that plant height of maize increased up to 90 DAS in all the treatments during both the years.

Among tillage treatments, ZTR-ZTR resulted in taller plants during 30, 60 and 90 DAS. Significant difference in plant height was observed with zero tillage combine with incorporation of wheat straw mulch as compared with conventional tillage. Taller plants in the conservation tillage with straw mulch might be because of good soil physical conditions and more water conservation (Pervez *et al*. 2009). The lowest plant height at 60 DAS (137.6 and 134.8 cm) was recorded in ZT-ZT during 2018 and 2019. In weed management treatments, IWM-IWM resulted in taller plants (283.4 cm) followed by H-H (257.1 cm) during *kharif* 2018, whereas, during *kharif* 2019, H-H had taller plants (230.3 cm) than HW-HW and IWM-IWM.

In wheat crop, effect of tillage and weed management methods on plant height beginning at 30 days interval up to harvest of crop has been presented in Fig. 2. It is clear from the figure that height of wheat crop increased up to 150 DAS and thereafter decreased. During the starting months, plant height increased slowly which could be due to lower temperature thereafter it increased significantly up to 150 DAS. The tallest plants at 150 DAS were noted under conventional tillage in maize followed by conventional tillage in wheat (CT-CT) followed by ZTR-ZTR during both the years. Meena



(a)



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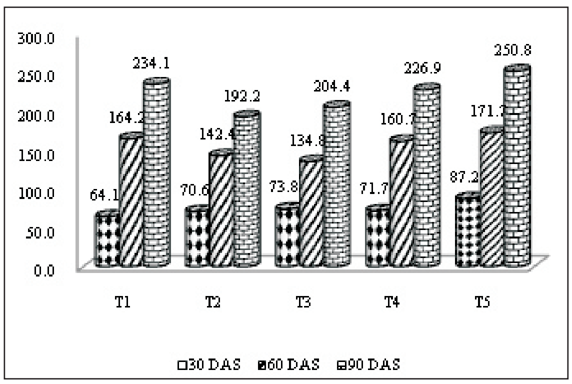

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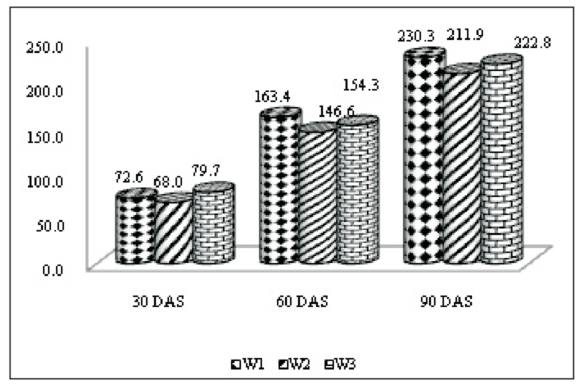

(d)

Fig. 1 Effect of tillage (a, c) and weed management treatments (b, d) on progressive plant height of maize crop during 2018 and 2019, respectively

et al. (2018) reported that conservation tillage treatments had significantly highest plant height compared to ZT without residue incorporation. Among weed management treatments, H-H resulted in taller plants i.e. 107.3 and 101.0 cm during 2018 and 2019, respectively, followed by HW-HW (104.3 and 100.3 cm) during 2018 and 2019.

Dry matter efficiency (% day^{-1})

Data pertaining to dry matter efficiency in maize and wheat crop during 2018-19 and 2019-20 have been given in Table 1. Dry matter efficiency was significantly ($p < 0.05$) affected by tillage practices during 2018 in maize and wheat crop which otherwise was not influenced during 2019 in maize and wheat crops. Significantly higher dry matter efficiency in maize crop during *kharif* 2018 was recorded under CT-CT which remained statistically at par with ZT-ZTR and ZTR-ZTR. However, ZT-ZT resulted in higher dry matter efficiency followed by CT-ZT which remained statistically at par with ZTR-ZTR and CT-CT during *rabi* 2019-20. Weed management treatments could not significantly affect dry matter efficiency (% day^{-1}) in maize during 2018, whereas in wheat crop during 2019-20. IWM-IWM resulted in higher dry matter efficiency followed by H-H which remained statistically at par with HW-HW during *kharif* 2019. However, during *rabi* 2019-20, IWM-IWM resulted in higher dry matter efficiency followed by HW-HW which remained statistically at par with H-H.

Unit area efficiency (kg m^{-2} day^{-1})

Unit area efficiency is a great physiological characteristic of a crop plant which identifies its yield (Yavas and Unay 2016). Unit area efficiency was significantly ($p < 0.05$) influenced by tillage and weed management treatments in both maize and wheat crop during 2018-19 and 2019-20 (Table 1). During *kharif* 2018, higher unit area efficiency was recorded compared to *kharif* 2019 which resulted in higher yield attributes and yield of maize crop. However, in wheat crop, higher unit efficiency was observed during *rabi* 2019-20 as compared to the *rabi* 2018-19 which resulted in higher crop productivity. ZTR-ZTR

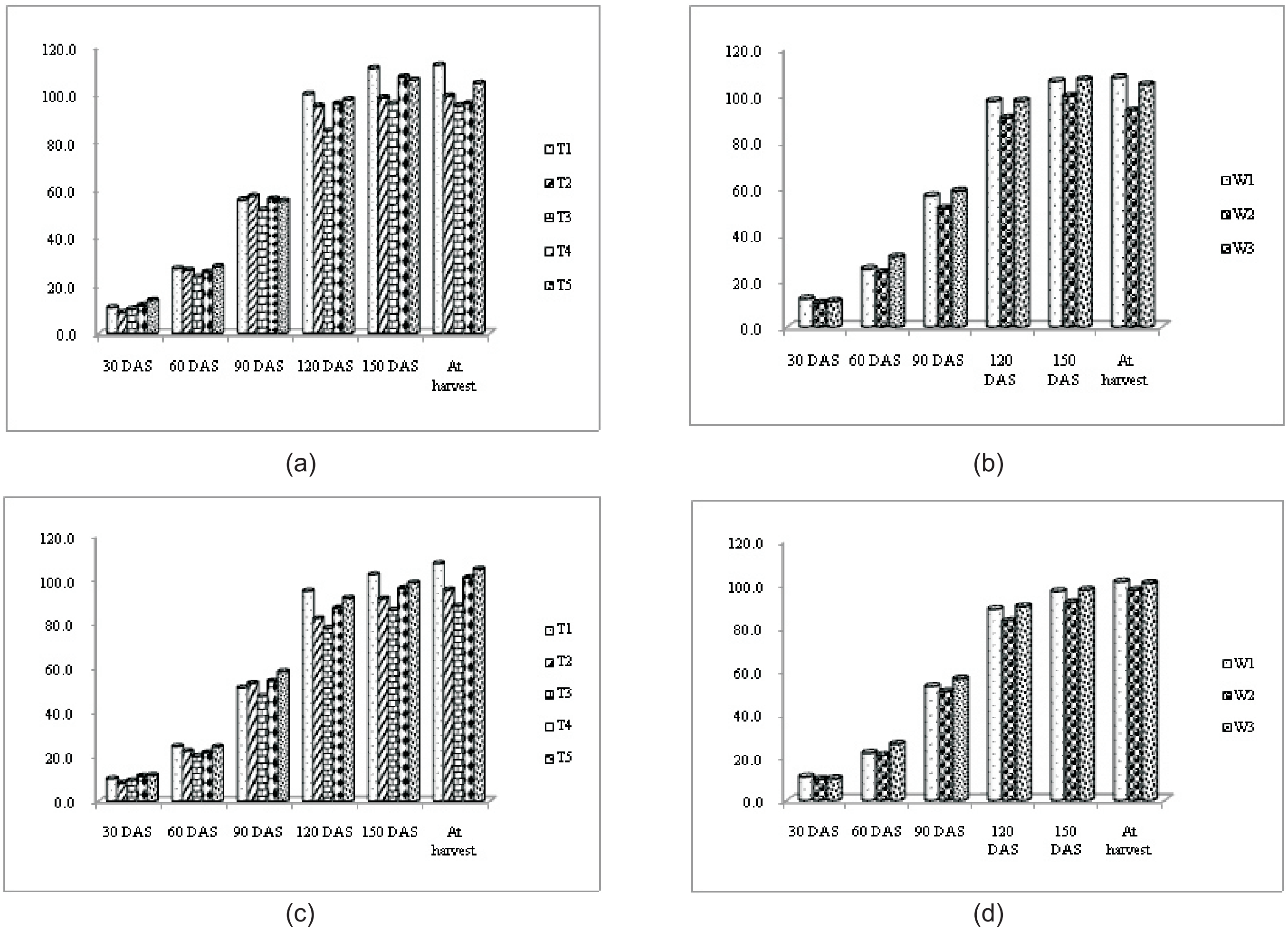

Fig. 2 Effect of tillage (a, c) and weed management treatments (b, d) on progressive plant height of wheat crop during 2018-19 and 2019-20, respectively

resulted in highest unit area efficiency during both the years in maize and wheat crop. In maize during 2018, ZTR-ZTR remained statistically at par with CT-CT which remained at par with CT-ZT. Lowest unit area efficiency was recorded in ZT-ZTR and ZT-ZT during 2018 and 2019, respectively.

Among weed management treatments, IWM-IWM (intercrop + herbicide + hand weeding) had maximum unit area efficiency which was statistically similar to H-H during *kharif* 2018 and 2019 followed by HW-HW. Lowest unit area efficiency (kg m^{-2} day^{-1}) among weed management treatments was recorded in HW-HW during both the experimental years.

In wheat crop, ZTR-ZTR resulted in highest unit area efficiency among all the tillage treatments during *rabi* 2018-19 and 2019-20 which remained statistically similar with CT-ZT and CT- CT during 2018-19. However, during rabi 2019-20, CT-ZT remained statistically at par with ZTR-ZTR. CT-ZT remained statistically at par with CT-CT and ZT-ZTR. Lowest unit area efficiency was seen in ZT-ZT during both the experimental years. Among weed management treatments, HW-HW and H-H have maximum unit area efficiency during *rabi* 2018-19 and 2019-20, respectively. HW-HW remained statistically similar to H-H during first year, whereas, H-H resulted in highest unit area efficiency which remained statistically similar HW-HW followed by IWM-IWM (intercrop + herbicide + hand weeding) during the second year of experiment (Table 1).

Yield attributes

Maize

The effect of tillage and weed management treatments on different yield contributing characters

Table 1. **Effect of tillage and weed management on dry matter efficiency and unit area efficiency of maize and wheat crop during 2018-19 and 2019-20**

Treatment (Maize – wheat)	Dry matter efficiency (% day^{-1})				Unit area efficiency (kg m^{-2} day^{-1})			
	Maize		Wheat		Maize		Wheat	
	2018	2019	2018-19	2019-20	2018	2019	2018-19	2019-20
Tillage								
CT-CT	0.254	0.198	0.176	0.188	65.83	59.72	27.07	33.16
CT-ZT	0.245	0.199	0.182	0.195	63.87	58.01	27.62	35.95
ZT-ZT	0.245	0.205	0.203	0.180	62.60	55.40	23.49	28.70
ZT-ZTR	0.254	0.202	0.178	0.185	61.44	55.95	24.34	31.10
ZTR-ZTR	0.249	0.187	0.166	0.186	67.90	61.84	28.33	37.20
SEm±	0.002	0.005	0.006	0.013	0.92	0.87	0.99	1.65
LSD (P=0.05)	0.007	NS	0.020	NS	2.99	2.82	3.23	5.39
Weed management								
H-H	0.249	0.192	0.168	0.188	66.03	60.54	30.29	39.21
IWM-IWM	0.250	0.223	0.196	0.177	66.83	60.54	13.50	23.39
HW-HW	0.249	0.179	0.179	0.195	60.11	53.47	34.72	37.07
SEm±	0.002	0.003	0.005	0.007	1.27	0.93	1.36	1.16
LSD (P=0.05)	NS	0.013	0.021	NS	4.98	3.65	5.33	4.57

CT, conventional tillage; ZT, zero tillage; R, residues; H, herbicide; IWM-IWM, integrated weed management; HW, hand weeding; figures with same sign as superscript in a same factor mean statistically at par with each other

i.e. plant population (no. m^{-2}) at 90 DAS, number of cobs per plant, cob length, dry weight of cob with husk, dry weight of cob without husk and grains per cob have been presented in Table 2. A cursory glance at the data revealed that tillage methods in maize significantly ($p < 0.05$) influenced the effective plant population (no. m^{-2}) at 90 DAS during both years, number of cobs per plant during *kharif* 2018, length of maize cob, dry weight of cob without husk and grains per cob during both the years. Conservation tillage in combination with residue incorporation in maize and wheat crop (ZTR-ZTR) resulted in significantly ($p < 0.05$) more plant population at 90 DAS during both the years which remained at par with CT-CT during 2018 and CT-CT and CT-ZT during 2019. ZTR-ZTR resulted in greatest number of cobs per plant during 2018 which remained statistically similar to CT-CT and CT-ZT. Minimum number of cobs per plant was recorded in ZT-ZT during both the years. Larger maize cob was obtained from ZTR-ZTR during both the years which remained at par with CT-CT during 2018 and with CT-ZT and CT-CT during 2019. The smallest maize cob was obtained in ZT-ZT during both the years (Table 2).

Conservation tillage in combination with residue incorporation in maize and wheat crop (ZTR-ZTR) resulted in highest dry weight of cob without husk, which remained statistically at par with CT-CT during both the years. However, CT-ZT remained statistically at par with ZT-ZT and ZT-ZTR. Maximum grains per cob were recorded in ZTR-ZTR which remained statistically at par with CT-CT during both the years and CT-ZT during 2019. Jat *et al*. (2018) reported that permanent bed resulted in significantly higher cob length, cob weight and grains cob^{-1} compared to conventional tillage. Higher yield contributing characters of maize crop with zero tillage in combination with residue incorporation might be due to improved soil health (Jat *et al*. 2013; Parihar *et al*. 2016, Singh et al. 2016), lesser weed population (Chauhan *et al*. 2007) and better water regimes (Ram *et al*. 2010).

Table 2. Effect of tillage and weed management on yield attributed of maize crop

Treatment (Maize – wheat)	Plant population (no. m^{-2})		Number of cobs $plant^{-1}$		Cob length		Dry weight of cob without husk		Grains cob^{-1}	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Tillage										
CT-CT	7.5	7.2	1.7	1.8	21.1	21.1	60.1	51.1	273.1	265.8
CT-ZT	6.9	6.6	1.6	1.7	20.6	21.3	51.6	44.7	266.6	267.6
ZT-ZT	6.5	6.4	1.5	1.6	20.5	20.2	49.0	39.6	251.1	249.5
ZT-ZTR	5.9	5.7	1.4	1.6	20.7	20.3	50.2	41.3	245.4	241.3
ZTR-ZTR	7.7	7.6	1.9	2.0	21.5	21.4	62.1	54.4	279.4	270.2
SEm±	0.2	0.2	0.1	0.1	0.2	0.2	1.9	2.3	3.9	4.8
LSD (P=0.05)	0.7	0.8	0.3	NS	0.6	0.8	6.1	7.5	12.6	15.5
Weed management										
H-H	7.1	7.0	1.7	2.0	20.9	20.5	54.1	46.3	261.1	269.6
IWM-IWM	6.6	6.4	1.8	1.6	21.2	22.0	58.8	49.2	268.4	254.6
HW-HW	6.9	6.8	1.5	1.6	20.6	20.1	50.9	43.1	259.9	252.4
SEm±	0.3	0.3	0.1	0.1	0.1	0.4	1.8	2.5	2.7	4.4
LSD (P=0.05)	NS	NS	NS	0.2	0.4	1.4	NS	NS	NS	NS

CT, conventional tillage; ZT, zero tillage; R, residues; H, herbicide; IWM-IWM, integrated weed management; HW, hand weeding; figures with same sign as superscript in a same factor mean statistically at par with each other

Weed management treatments could not significantly influence the plant population at 90 DAS, and dry weight of cob without husk and grains per cob during both the years (Table 2). H-H had a maximum number of cobs per plant followed by IWM-IWM which was equal to HW-HW during 2019. IWM-IWM resulted in longest maize cob during both the years which remained statistically similar to H-H during 2018. However, IWM-IWM followed by H-H had more maize cob length during 2019.

Wheat

Tillage treatments gave significant variation ($p < 0.05$) in the number of effective tillers, length of ear, total number of grains $spike^{-1}$ and 1000-grain weight during rabi 2018-19 and 2019-20 (Table 3). ZTR-ZTR had a higher number of effective tillers followed by ZT-ZTR and CT-CT during 2018-19. However, during rabi 2019-20, ZTR-ZTR resulted in a maximum number of effective tillers (No. m^{-1}) which remained statistically at par with CT-CT and CT-ZT. Minimum number of effective tillers was recorded in ZT-ZT during both the years. Papu et al. (2012) and Thapa et al. (2019) also reported higher number of effective tillers in conservation production system compared to conventional tillage. ZTR-ZTR had maximum ear length during 2018-19 which remained at par with CT-ZT and CT-CT, whereas, CT-CT resulted in maximum ear length which was at par with ZTR-ZTR during *rabi* 2019-20 (Table 3). CT-ZT had highest total number of grains per spike which statistically ($p < 0.05$) remained similar with ZTR-ZTR and CT-CT during rabi 2018-19. However, ZT-ZTR had maximum total number of grains per spike which remained at par with ZT-ZTR, CT-CT and CT-ZT during rabi 2019-20. Lowest total number of grains per spike during both the years was recorded in ZT-ZT. Permanent bed with 30% maize residue had higher grains per spike (Jat *et al*. 2018). ZTR-ZTR had maximum 1000-grain weight during both the years which behaved statistically similar with CT-ZT during both years and to ZT-ZTR during *rabi* 2019-20. Zero tillage with residue mulch provided favorable soil moisture and temperature conditions for better crop growth resulting in higher yield contributing characters and yield (Verhulst *et al*. 2011; Gathala *et al*. 2011; Parihar *et al*. 2016, 2017). Thapa *et al*. (2019) also reported that highest 1000-grain weight of wheat was recorded under tillage in combination with residue incorporation as compared to removal of residue.

Weed management treatments significantly ($p < 0.05$) influenced the effective tillers, total number of grains per spike during *rabi* 2018-19, ear length during 2019-20 and 1000-grain weight during both the years (Table 3). HW-HW resulted in highest number of effective tillers followed by IWM-IWM and H-H during *rabi* 2018-19. During 2019-20, H-H behaved statistically similar for effective tillers as HW-HW

H-H had longest ear length amongst weed management treatments followed by HW-HW and IWM-IWM. HW-HW resulted in statistically similar length of ear as IWM-IWM. HW-HW resulted in maximum total number of grains per spike which remained statistically at par with H-H during *rabi* 2018-19. 1000-grain weight was significantly influenced by different weed management treatments during both the experimental years (Table 3). The HW-HW resulted in maximum 1000-grain weight followed by H-H and IWM-IWM during *rabi* 2018-19. During 2019-20, HW-HW resulted in significantly higher 1000-grain weight being statistically at par with H-H.

Harvest Index

Data pertaining to harvest index have been given in Table 4. In maize crop higher harvest index was recorded during *kharif* 2018, whereas in wheat crop it was observed high during *rabi* 2019-20. Harvest index was significantly ($p < 0.05$) affected during kharif 2018 by tillage treatments. However, it was not significantly influenced by tillage and weed management treatments in maize and wheat during 2019. ZT-ZTR and CT-CT resulted in higher harvest index than other tillage treatments which remained statistically similar with all other tillage treatments during *kharif* 2018. However, during *rabi* 2018-19, ZT-ZT resulted in higher harvest index being at par with CT-ZT. Pariyar *et al*. (2019) also reported about the higher harvest index under conservation

Table 3. Effect of tillage and weed management on yield attributes of wheat

Treatment (Maize – wheat)	Effective tillers (no. m^{-2})		Length of ear (cm)		Total number of grains spike^{-1} (No.)		1000-seed weight (g)	
	2018	2019	2018	2019	2018	2019	2018	2019
Tillage								
CT-CT	315.3	404.8	9.8	12.5	46.1	54.2	44.4	45.7
CT-ZT	307.3	352.7	10.1	11.4	47.2	52.7	46.8	48.1
ZT-ZT	249.6	259.6	9.4	10.8	44.9	48.2	44.8	45.2
ZT-ZTR	346.6	359.7	8.9	10.4	45.8	54.3	45.3	46.0
ZTR-ZTR	365.2	412.8	10.2	12.0	46.4	55.6	47.1	48.3
SEm±	6.0	6.2	0.2	0.3	0.4	1.2	0.5	0.7
LSD (P=0.05)	19.4	20.2	0.5	0.9	1.3	3.8	1.6	2.4
Weed management								
H-H	276.6	375.4	9.8	12.0	46.1	55.6	45.4	46.5
IWM-IWM	305.5	334.2	9.6	11.0	44.5	50.1	45.1	46.1
HW-HW	368.3	364.2	9.7	11.2	47.7	53.3	46.5	47.4
SEm±	3.7	6.7	0.2	0.2	0.5	1.3	0.2	0.2
LSD (P=0.05)	14.4	26.3	NS	0.7	1.9	NS	1.0	0.9

CT, conventional tillage; ZT, zero tillage; R, residues; H, herbicide; IWM-IWM, integrated weed management; HW, hand weeding; figures with same sign as superscript in a same factor mean statistically at par with each other

Table 4. Effect of tillage and weed control on harvest index and net returns (000' Rs ha^{-1}) in maize-wheat cropping system

Treatment (Maize -Wheat)	Harvest index			
	2018		2019	
	Maize	Wheat	Maize	Wheat
Tillage				
CT-CT	0.32	0.33	0.25	0.33
CT-ZT	0.31	0.34	0.25	0.34
ZT-ZT	0.31	0.38	0.25	0.32
ZT-ZTR	0.32	0.33	0.25	0.33
ZTR-ZTR	0.31	0.31	0.23	0.33
SEm±	0.00	0.01	0.01	0.02
LSD (P=0.05)	0.01	0.04	NS	NS
Weed management				
H-H	0.31	0.31	0.24	0.33
IWM-IWM	0.31	0.37	0.28	0.31
HW-HW	0.31	0.34	0.22	0.34
SEm±	0.00	0.01	0.00	0.01
LSD (P=0.05)	NS	0.04	0.02	NS

CT, conventional tillage; ZT, zero tillage; R, residues; H, herbicide; IWM-IWM, integrated weed management; HW, hand weeding; figures with same sign as superscript in a same factor mean statistically at par with each other

agriculture system compared to conventional tillage. Weed management treatments significantly affected the harvest index during *kharif* 2019 where IWM-IWM had higher harvest index followed by H-H and HW-HW. IWM-IWM resulted in higher harvest index and was similar with HW-HW during *rabi* 2018-19.

Conclusion

Results from the present study showed that conservation agriculture based maize-wheat cropping system (ZTR-ZTR) resulted in taller plants and high dry matter efficiency and unit area efficiency of maize and wheat. ZTR-ZTR had higher yield contributing characters like plant population per metre, number of cobs per plant and dry weight of cob followed by conventional tillage in maize crop. In wheat crop higher effective tillers and length of ear was higher in ZTR-ZTR followed by conventional tillage in maize and wheat crop. Total number of grains per ear was higher under CT-ZT and ZTR-ZTR. However, 1000-grain weight was maximum under ZTR-ZTR, followed by conventional tillage in maize and zero tillage in wheat (CT-ZT). Among weed management treatments, H-H resulted in higher plant height and yield contributing characters in maize-wheat cropping system. Based on the results of the present study, it is suggested to follow ZTR+H-ZTR+H among all the combinations for better growth and growth indices and yield attributes from maize-wheat cropping system.

Conflicts of Interest: The authors declare that there are no conflicts of interest in this research paper.

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