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Effect of Tillage and Weed Control Methods in Maize (*Zea mays*) -Wheat (*Triticum aestivum*) Cropping System

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Abstract

An experiment was conducted to find out the effect of tillage and weed control methods on weed dynamics and productivity of maize (*Zea mays* L.) -wheat (*Triticum aestivum* L.) cropping system. The treatments comprised of combinations of tillage sequences in main plots and weed control methods in sub plots. The results revealed that zero tillage in rainy and winter season is as good as conventional tillage method in reducing weed dry matter and producing maize and system yield, while, conventional tillage in rainy and winter seasons (CT-CT) and conventional tillage in rainy and zero tillage in winter (CT-ZT) reduced weed density as well as weed dry weight in wheat crop consequently, higher wheat grain yield was recorded compared to rest of the tillage sequences. Integrated weed management performed in maize and wheat (IWM-IWM) sequence recorded 51.78% and 61.96% higher maize grain yield and net return of maize, 18.40% and 17.23% higher wheat grain yield and net return of wheat, 31.78% and 34.96% higher system yield and net return respectively, compared to weedy check. Zero tillage with or without residue recorded improved soil pH, organic carbon, CO_2 and dehydrogenase activity. IWM in both the crops recorded higher yields, while significantly higher B:C ratio was under recommended herbicide i.e. atrazine 1.0 kg ha^{-1} pre emergence in maize and 2,4-D 0.5 kg ha^{-1} post emergence in wheat (RH-RH). IWM-IWM improved soil CO_2 and dehydrogenase activity than RH-RH sequences from their initial values.

Keywords: Productivity, tillage, weed dynamic

1. Introduction

Maize-wheat is the third most important cropping systems after rice-wheat and rice-rice that contributes about 3% in the national food basket (Anonymous, 2013). Among different maize based cropping systems, maize-wheat ranks first having 1.8 mha area mainly concentrated in rainfed ecologies (Ghosh et al., 2015). The productivity of this system is declining after 1990's. 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. Weeds, being hardier in nature compete with maize plants for nutrients, water, sunlight and space during entire vegetative and early reproductive stages of maize; they transpire a lot of valuable conserved moisture and absorb large quantities of nutrients from the soil and their relative density plays a significant role in reducing the yield of crop (Kumar et al., 2015). Farmers plant wheat late because of multiple tillage operations (6–12). They believed that tillage was necessary for good germination, weed control, proper aeration and moisture conservation (Chauhan, 2000). Furthermore, intensive ploughing results to a decrease in soil organic matter due to acceleration of the oxidation and breakdown of organic matter and ultimately degradation of soil properties (Gathala et al., 2011). It also leads to compaction and eventually soil loss through wind and water erosion (Holland, 2004). Benefits of conservation tillage, especially zero-tillage (ZT) systems that leave crop residues on the soil surface are the stabilization of soil moisture and temperature, an improvement of aggregate stability and an increase in soil organic matter (Hajabbasi and Hemmat, 2000), higher water infiltration rates (Tullberg, 2010; Singh et al., 2011), and a reduction in weed population in some studies (Malik et al., 2004). However, negative effects of long-term ZT farming includes and increased weed competition (Mishra and Singh, 2012).The weeds are the major problem in the productivity of this system. They cause important yield losses worldwide with an average of 12.8% despite weed control applications and 29.2% in the case of no weed control (Oerke and Steiner, 1996) and, under very severe infestations the losses may go up to 80%. The study of the weed dynamic in maize-wheat cropping system helps the researchers and farmers to formulate the strategies for the control of weeds. The present study was, therefore, undertaken with the objectives to evaluate the effect of tillage/planting management techniques and their interaction on weed dynamics and productivity of maize-wheat cropping system.

2. Materials and Methods

The present investigation was conducted in agronomical farm of Birsa Agricultural University, Ranchi during 2013–14, 2014–15 and 2015–16. The experimental soil was low in available nitrogen (167 kg ha^{-1}) and medium in phosphorus (19 kg ha^{-1}) and potash (187 kg ha^{-1}) and the pH was 6.2. The treatments comprised of five different tillage sequences in main plots i.e. conventional tillage both in rainy and winter seasons (CT-CT), conventional tillage in rainy and zero tillage in winter seasons (CT-ZT), zero tillage both in rainy and winter seasons (ZT-ZT), zero tillage in rainy and zero tillage along with crop residue in winter season (ZT-ZT+R) and zero tillage along with crop residue in rainy and winter seasons (ZT+R-ZT+R). Weed control methods in sub plots were namely recommended herbicide i.e. atrazine 1.0 kg ha^{-1} pre emergence in maize and 2,4-D 0.5 kg ha^{-1} post emergence in wheat (RH-RH), integrated weed management containing intercropping with black gram+pre emergence application of pendimethalin 1.0 kg ha^{-1} followed by (*fb*) manual weeding at 30 days after sowing (DAS) in maize and application of 2,4-D 0.5 kg ha^{-1} post emergence in wheat *fb* hand weeding at 40 DAS (IWM-IWM), and weedy check in rainy and winter seasons (WC-WC). The treatments were under fixed location during the years. Maize variety ‘Suwan composite’ and wheat ‘K9107’ were sown under irrigated conditions. The recommended dose of N, P_2O_5 and K_2O for maize and wheat was 120:60:40 kg ha^{-1}. Entire phosphorus and potassium were applied at the time of sowing to both the crops. In maize, nitrogen was applied in three equal splits at sowing, knee height and tasseling stages whereas in wheat, half nitrogen at the time of sowing and remaining nitrogen was applied in two equal splits at tillering and panicle initiation stages.

The observations on weed dynamics was focused on weed density and dry matter accumulation by weeds at 30 and 60 DAS. The weed densities were counted within quadrate of size 0.5×0.5 m^2 and were converted to per m^2. The weed samples taken for recording observation on weed density at 30 and 60 DAS were sun dried to remove any excess moisture present on the surface of weeds then oven dried at 60 °C±5 °C. After complete oven drying the dry weight was recorded in g m^{-2} on electronic balance. Data on weed density and dry matter of weeds were subjected to square root transformation *i.e.* (X+0.5) prior to statistical analysis for test of significance. The treatment effects were compared using transformed means.

The analysis of variance method (Gomez and Gomez, 1984) was followed for statistical analysis of the various data.

3. Results and Discussion

3.1. Study on weeds

Maize: Tillage methods did not influence grassy, broad leaved and sedges as well as total weed density. The dominance of weeds under conventional and zero tillage may be because of different reasons. As under conventional tillage weed seeds which remained buried within soil might have transported up on the soil surface by soil disturbance while under zero tillage weed seeds which remained on soil surface germinated and grew resulting similar effect on weed density and dry matter at 30 and 60 DAS as that of conventional tillage. Matloob et al. (2015) have also observed grassy weeds were much higher under zero while broad-leaved weeds, especially *Trianthemum portulacastrum* dominated under continuous tillage system. Thus, the density and biomass of weeds was considerably similar under both the tillage systems (Table 1).

Among weed control methods, integrated weed management (IWM) performed in both the season recorded significantly reduced weed density as well as weed dry matter of all categories of weeds. Similar results were also observed by Bali et al. (2016). The decrease of grassy, broad leaved, sedges, and total weed density was to the tune of 53.33, 70.37, 70.76 and 63.23% compared to weedy check at 30 DAS, while at 60 DAS it was to the extent of 52.84, 57.27, 63.98 and 57.57%, respectively compared to weedy check. Whereas, this treatment decreased weed dry matter to the tune of 52.24 and 64.89% compared to weedy check at 30 and 60 DAS respectively. Verma et al. (2015) have also suggested that for getting effective control of composite weed flora, a logical combination of several weed control methods is likely to prove the most effective approach.

Wheat: Continuous conventional tillage (CT-CT) similar to conventional tillage performed in rainy and zero tillage in winter season (CT-ZT) recorded significantly reduced weed density of all categories of weeds as well as dry matter of weeds at 30 and 60 DAS compared to other tillage sequences. Reduction in weed density and weed dry matter under conventional tillage in wheat crop has also been reported by Ramesh et al. (2014); Han et al. (2013) (Table 2).

Among weed control methods, integrated weed management (IWM) performed in both the season similar to recommended herbicide recorded significantly reduced weed density as well as weed dry matter of all categories of weeds. Total weed density at 30 and 60 DAS was decreased to the tune of 74.29 and 78.75% whereas, weed dry matter 13.07 and 74.03%

Table 1: Effect of tillage and weed control methods on weed density and total dry weight of weed at different stages in maize (Pooled data of 2013, 2014 and 2015)

Treatments	Weed density (no. m^{-2})								Total weed dry weight (g m^{-2})	
	30 DAS				60 DAS					
	Grassy	Broad leaved	Sedges	Total	Grassy	Broad leaved	Sedges	Total	30 DAS	60 DAS
Tillage methods										
CT-CT	9.45 (107.67)	9.28 (104)	7.44 (70.67)	15.75 (286)	10.26 (124.33)	10.94 (137.67)	8.75 (97.67)	17.68 (360)	6.96 (51.67)	8.07 (69.96)
CT-ZT	8.54 (86.67)	9.01 (98.67)	7.36 (69.67)	14.98 (259)	10.44 (128)	10.30 (121)	8.69 (94.33)	17.34 (343)	7.02 (51.63)	8.56 (78.7)
ZT-ZT	9.32 (102.67)	8.95 (89.67)	8.65 (91)	15.85 (278.33)	9.94 (121.67)	10.80 (133)	9.22 (100.67)	17.50 (355.33)	7.22 (55.37)	8.07 (74.69)
ZT-ZT+R	9.23 (99)	9.86 (110.67)	9.29 (108.33)	16.52 (314)	10.67 (133)	10.35 (126)	9.14 (103.67)	17.58 (362.67)	7.06 (53.23)	8.26 (77.37)
ZT+R-ZT+R	8.85 (94.33)	9.97 (114)	9.09 (105)	15.95 (297)	11.42 (152.33)	10.59 (127.67)	9.23 (104)	18.30 (384.67)	7.04 (52.8)	8.61 (85.03)
SEm±	0.95	0.93	0.67	1.01	0.55	0.85	0.50	0.62	0.32	0.35
CD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed control										
R H–RH	8.03 (77)	7.81 (70.33)	7.04 (60.67)	13.21 (195.33)	8.52 (82)	8.98 (90.67)	7.66 (72.33)	14.73 (245)	5.96 (36.21)	7.06 (22.02)
IWM–IWM	7.63 (67)	7.56 (66.67)	6.67 (58.33)	13.00 (190.67)	9.14 (98.67)	8.87 (91.67)	7.33 (68)	14.87 (258.67)	6.03 (36.85)	6.75 (48.24)
WC–WC	11.58 (150)	12.88 (173.33)	11.39 (147.67)	21.22 (474.33)	13.97 (215)	13.95 (204.67)	12.02 (160.33)	23.43 (580.33)	9.18 (85.75)	11.13 (103.37)
SEm ±	0.71	0.67	0.50	0.72	0.45	0.62	0.49	0.60	0.32	0.37
CD (P=0.05)	2.80	2.64	1.97	2.81	1.77	2.43	1.93	2.36	1.25	1.46
Interaction										
SEm±	0.87	0.93	0.90	0.87	0.72	0.93	0.72	0.74	0.39	0.40
CD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	1.17	NS

*Figures in parentheses are original values

Table 2: Effect of tillage and weed control methods on weed density and total dry weight of weed at different stages in wheat (Pooled data of 2013–14, 2014–15 and 2015–16)

Treatments	Weed density (no. m^{-2})						Total weed dry weight (g m^{-2})	
	30 DAS			60 DAS			30 DAS	60 DAS
	Grassy	Broad leaved	Total	Grassy	Broad leaved	Total		
Tillage methods								
CT-CT	2.88 (11.03)	4.02 (21.21)	4.92 (32.25)	3.56 (20.27)	5.04 (28.88)	6.36 (49.14)	2.82 (8.21)	2.55 (6.94)
CT-ZT	3.06 (12.47)	4.34 (24.95)	5.30 (37.43)	3.93 (23.74)	5.58 (34.76)	7.03 (58.5)	3.23 (10.93)	2.68 (7.73)

Continue...

Treatments	Weed density (no. m^{-2})						Total weed dry weight ($g\ m^{-2}$)	
	30 DAS			60D AS			30 DAS	60 DAS
	Grassy	Broad leaved	Total	Grassy	Broad leaved	Total		
ZT-ZT	4.01 (20.69)	5.03 (32.85)	6.42 (53.54)	4.68 (29.96)	7.01 (55.01)	8.62 (84.97)	3.58 (14.11)	3.30 (12.71)
ZT-ZT+R	3.86 (18.5)	4.91 (31.43)	6.26 (49.93)	4.60 (28.99)	6.70 (48.95)	8.31 (77.94)	3.72 (14.6)	3.12 (10.99)
ZT+R-ZT+R	3.86 (20.22)	5.05 (32.99)	6.39 (53.21)	4.44 (28.26)	6.75 (48.03)	8.30 (76.28)	5.42 (45.67)	3.18 (10.91)
SEm±	0.20	0.18	0.16	0.18	0.36	0.34	0.28	0.17
CD (p=0.05)	0.64	0.59	0.52	0.6	1.18	1.09	0.92	0.56
Weed control								
R H–RH	2.86 (11.26)	4.12 (23.18)	4.98 (34.44)	3.58 (20.65)	5.33 (30.41)	6.64 (51.07)	3.76 (15.4)	2.56 (6.8)
IWM–IWM	2.46 (7.6)	3.94 (20.27)	4.59 (27.86)	3.33 (17.97)	4.69 (23.22)	5.93 (41.19)	3.52 (12.58)	2.31 (5.09)
WC–WC	5.28 (30.89)	5.95 (42.61)	8.00 (73.51)	5.82 (40.11)	8.63 (75.73)	10.60 (115.84)	3.98 (28.14)	4.02 (17.68)
SEm ±	0.11	0.2	0.08	0.08	0.1	0.09	0.01	0.01
CD (p=0.05)	0.42	0.8	0.3	0.3	0.38	0.36	0.03	0.04
Interaction								
SEm±	0.29	0.37	0.31	0.38	0.46	0.49	0.31	0.28
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

*Figures in parentheses are original values

compared to weedy check.

3.2. *Yield and economics*

Maize : Pooled dataof three years revealed that all the tillage methodsrecorded similarly in producing maize grain yield consequently net return and B:C ratio. However, B:C ratio was maximum under zero tillage compared to conventional tillage owing to saving in tillage operations thus reduced cost of cultivation. Similar was the findings of Marwat et al. (2011).

Integrated weed management (IWM) performed in maize recorded 51.78% and 61.96% higher grain yield and net return of maize compared to weedy check (WC-WC), due to crop received clear environment during critical period of crop weed competition and the condition was more favorable for its growth and development. Significantly lower yield under weedy check was also recorded by Pandit et al. (2016). However, maximum B:C ratio was recorded under application of recommended herbicide i.e. atrazine 1.0 kg ha^{-1} this may be due to application of herbicide is less labour intensive, resulting less costlier. The results are in agreement to the findings of Mahmoud et al. (2012) (Table 3).

Wheat: Pooled data revealedthatconventional tillage in rainy and winter seasons (CT-CT) and conventional tillage in rainy and zero tillage in winter (CT-ZT) recorded higher wheat grain yield compared to rest of the tillage sequences.

Among weed control methods integrated weed management performed in maize and wheat (IWM-IWM) sequence similar to recommended herbicide sequences (RH-RH) recorded 18.40 and 17.23% higher pooled grain yield and net return of wheat, compared to weedy check. Bali et al. (2016) emphasized judicious combinations of cultural and chemical methods of weed control as integrated weed management system is a desired practice that aims at reducing the dosage of herbicide to be applied with mechanical weeding, which will help in managing weeds in a best way for realizing to sustain and boost the production (Table 4).

3.3. *System productivity and profitability*

Different tillage sequence performed during rainy and winter seasons did not affect system yield as well as economics, although conventional tillage performed during rainy and winter seasons recorded maximum system pooled yield and

Table 3: Effect of tillage and weed control methods on yield and economics of maize

Treatments	Yield (kg ha^{-1})								Cost of cultivation (₹ ha^{-1})	Net return (₹ ha^{-1})			
	Grain				Straw								
	2013	2014	2015	Pooled	2013	2014	2015	Pooled		2013	2014	2015	Pooled
Tillage methods													
CT-CT	2415	1677	2714	2269	4076	2082	4464	3541	18990	25387	10329	30648	22121
CT-ZT	2043	1872	2902	2272	3501	3438	4774	3904	18990	18657	15966	34088	22904
ZT-ZT	1842	2694	2615	2384	3072	4048	3795	3638	14690	19084	33816	32125	28342
ZT-ZT+R	2245	2839	1074	2053	3730	4362	4415	4169	14690	26445	36619	10250	24438
ZT+R-ZT+R	2104	3133	1506	2248	3539	5221	4588	4449	14690	23948	42747	17076	27924
SEm±	102	251	378	244	184	144	434	303		1506	3976	6220	3901
CD (p=0.05)	334	818	1232	NS	602	471	NS	NS		4911	12964	20283	NS
Weed control													
R H–RH	2364	2672	2202	2413	4045	3996	4524	4188	14558	28992	33514	27520	30009
IWM–IWM	2609	3098	3042	2916	4499	5232	5387	5039	20914	27219	36020	35490	32910
WC–WC	1417	1559	1242	1406	2207	2262	3311	2593	13758	11911	14151	11494	12519
SEm±	58	134	63	85	128	133	241	196		745	2126	789	1220
CD (p=0.05)	226	526	248	334	501	522	947	769		2924	8346	3095	4789
Interaction													
SEm±	225	363	405	331	318	218	380	330		3724	5691	6357	5257
CD (p=0.05)	NS	NS	1214	992	NS	654	1138	989		NS	NS	19057	15760

Table 3: Continue...

Treatments	B:C ratio			
	2013	2014	2015	Pooled
Tillage methods				
CT-CT	2.34	1.54	2.61	2.16
CT-ZT	1.98	1.84	2.80	2.21
ZT-ZT	2.30	3.30	3.19	2.93
ZT-ZT+R	2.80	3.49	1.70	2.66
ZT+R-ZT+R	2.63	3.91	2.16	2.90
SEm±	0.08	0.23	0.40	0.24
CD (p=0.05)	0.27	0.77	NS	NS
Weed control				
R H–RH	2.99	3.30	2.89	3.06
IWM–IWM	2.30	2.72	2.70	2.57
WC–WC	1.87	2.03	1.84	1.91
SEm ±	0.03	0.12	0.11	0.09
CD (P=0.05)	0.12	0.47	0.45	0.34
Interaction				
SEm±	0.24	0.30	0.36	0.30
CD (p=0.05)	NS	0.89	1.08	0.90

B:C ratio was calculated on the basis of gross return. Price of maize grain- ₹ 15/kg, straw-₹ 2/kg, wheat grain -₹ 13/kg, straw-₹3/kg

net return (Table 5).

Among weed control methods integrated weed management performed in maize and wheat (IWM-IWM) sequence similar to recommended herbicide sequences (RH-RH) recorded 31.78% and 34.96% higher system pooled yield and net return respectively, compared to weedy check. However, application of RH-RH in maize and wheat recorded maximum pooled B:C ratio that was 12.06 and 18.41% more compared to IWM-IWM and WC-WC. Khaliq et al. (2013) also reported highest net benefits were associated with the use of label herbicide dose in all tillage practices. This may be due to low cost of cultivation under recommended herbicide as compared to integrated weed management.

3.4. Soil properties

Zero tillage in rainy and zero tillage along with crop residue in winter season (ZT-ZT+R) similar to ZT+R-ZT+R recorded 5.63 pH, which was 2.31% more than initial value and 3.37% more than conventional tillage sequences. ZT+R-ZT+R also recorded 3.16% and 14.37% higher organic carbon and CO_2 respectively than initial values. ZT+R-ZT+R similar to ZT-ZT+R and CT-ZT recorded 7.76% more dehydrogenase than initial value and 26.06% more than conventional tillage sequences (CT–CT) which may be because of less soil disturbance under zero

Table 4: Effect of tillage and weed control methods on yield and economics of wheat

Treatments	Yield (kg ha^{-1})								Cost of cultivation (₹ ha^{-1})	Net return (` ha^{-1})			
	Grain				Straw								
	2013	2014	2015	Pooled	2013	2014	2015	Pooled		2013	2014	2015	Pooled
Tillage methods													
CT-CT	4.54	4.48	3.86	4.29	5.63	7.20	7.12	6.65	24204	51706	55636	47601	51648
CT-ZT	4.08	4.06	3.64	3.93	5.61	6.97	6.87	6.48	22454	47416	51236	45716	48123
ZT-ZT	3.88	3.74	3.09	3.62	5.35	6.75	6.61	6.24	22454	44036	46416	37797	42750
ZT-ZT+R	3.96	3.94	3.20	3.70	5.19	6.69	7.31	6.40	22454	44596	48836	41299	44910
ZT+R-ZT+R	4.00	3.97	2.94	3.58	5.19	6.57	7.82	6.53	22454	45116	48866	39459	44480
SEm±	0.30	0.19	0.09	0.18	0.28	0.39	0.24	0.30		4506	3514	1424	3148
CD (*p*=0.05)	NS	0.62	0.29	0.58	NS	NS	NS	NS		NS	11458	4643	NS
Weed control													
R H–RH	4.15	4.13	3.63	3.97	5.52	7.07	7.63	6.74	22535	47975	52365	47573	49304
IWM–IWM	4.40	4.38	3.61	4.13	5.67	7.30	7.89	6.95	25382	48828	53458	45270	49185
WC–WC	3.73	3.61	2.78	3.37	5.00	6.14	5.92	5.69	20495	42995	44855	34280	40710
SEm±	0.11	0.06	0.10	0.12	0.24	0.22	0.37	0.28		1646	468	1103	1072
CD (*p*=0.05)	0.43	0.23	0.39	0.48	NS	0.88	1.44	1.10		NS	1836	4330	4208
Interaction													
SEm±	0.50	0.53	0.21	0.31	0.36	0.55	0.54	0.48		7038	7479	4359	6292
CD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS		NS	NS	13067	NS

Table 4: Contiue

Treatments	B:C ratio			
	2013	2014	2015	Pooled
Tillage methods				
CT-CT	3.14	3.30	2.98	3.14
CT-ZT	3.11	3.28	3.07	3.15
ZT-ZT	2.96	3.07	2.69	2.91
ZT-ZT+R	2.99	3.17	2.86	3.01
ZT+R-ZT+R	3.01	3.18	2.80	3.00
SEm±	0.20	0.16	0.20	0.48
CD (*p*=0.05)	NS	NS	0.65	NS
Weed control				
R H --- RH	3.13	3.32	3.11	3.19
IWM – IWM	2.92	3.11	2.78	2.94
WC – WC	3.10	3.19	2.75	3.01
SEm ±	0.08	0.03	0.04	0.05
CD (P=0.05)	NS	0.10	0.16	0.2
Interaction				
SEm±	0.31	0.33	1.21	0.62
CD (*p*=0.05)	NS	NS	3.63	1.86

B:C ratio was calculated on the basis of gross return. Price of maize grain- ₹ 15/kg, straw-₹ 2/kg, wheat grain -₹ 13/kg, straw-₹ 3/kg

tillage bringing up favorable soil environment for soil flora and fauna to survive. This also brought up similar effects under IWM-IWM and WC-WC in enhancing soil CO_2 and dehydrogenase than initial value. According to Mutiu et al. (2015) zero or minimum tillage is beneficial to soil physical improvement as process of soil physical degradation normally sets in immediately after conventional tillage. Research reports indicate that conservation tillage, particularly under minimum tillage, is better than conventional tillage in terms of soil chemical improvement. All available reports are in agreement that soils under conservation tillage are more favoured than conventional tillage in terms of soil fauna activities and biological properties improvement. Małecka et al. (2012) have also found accumulation of organic carbon at the soil surface under reduced tillage and no tillage. The concentration of organic C in reduced tillage and particularly in no tillage, had increased significantly in the top layer (0-5 cm), by 18.3% and 26.1%, respectively, in comparison with CT

Among weed control methods, WC-WC and IWM-IWM performed similar in enhancing soil CO_2 and dehydrogenase. Weedy check recorded 4.53%, 5.34% and 13.27% higher CO_2 and 0.79%, 0.31% and 7.56% higher dehydrogenase than initial value, IWM-IWM and RH-RH, respectively (Table 5).

Table 5: Effect of tillage and weed control methods on yield and economics of maize- wheat cropping system (2013-2016)

Treatments	System yield (t ha^{-1})				Cost of cultiva-tion (₹ ha)	Net return (₹ ha)				B:C ratio			
	2013-14	2014-15	2015-16	Pooled		2013-14	2014-15	2015-16	Pooled	2013-14	2014-15	2015-16	Pooled
Tillage methods													
CT-CT	8.02	7.28	8.08	7.79	43194	77096	66012	77969	73692	2.77	2.50	2.81	2.69
CT-ZT	7.17	7.24	8.06	7.49	41444	66123	67182	79522	70942	2.61	2.60	2.92	2.71
ZT-ZT	6.68	7.82	7.12	7.21	37144	63053	80161	69638	70951	2.70	3.15	2.87	2.91
ZT-ZT+R	7.21	8.17	5.89	7.09	37144	71029	85390	51261	69227	2.92	3.33	2.38	2.88
ZT+R-ZT+R	7.08	8.75	6.23	7.35	37144	69076	94086	56252	73138	2.88	3.57	2.51	2.99
SEm±	0.25	0.39	0.35	0.33		3695	5793	5245	4911	0.10	0.15	0.09	0.11
CD (p=0.05)	0.82	1.27	1.14	NS		12049	18889	17103	NS	NS	0.48	0.29	NS
Weed control													
R H–RH	7.60	8.19	7.48	7.76	37093	76956	85810	75098	79288	3.08	3.35	3.02	3.15
IWM–IWM	8.16	9.05	8.47	8.56	46296	76029	89480	80762	82090	2.64	2.94	2.74	2.77
WC–WC	5.94	6.31	5.28	5.84	34252	54841	60409	44927	53392	2.61	2.80	2.31	2.57
SEm±	0.13	0.17	0.15	0.15		1950	2504	2325	2260	0.05	0.06	0.06	0.06
CD (p=0.05)	0.51	0.66	0.59	0.59		7653	9829	9126	8871	0.19	0.24	0.24	0.24
Interaction													
SEm±	0.56	0.59	0.44	0.53		8345	8904	6580	7943	0.22	0.22	0.12	0.19
CD (p=0.05)	NS	NS	1.32	NS				19725	23811	NS	NS	0.36	0.57

B:C ratio was calculated on the basis of gross return. Price of maize grain- ₹ 15/kg, straw-₹ 2/kg, wheat grain -₹ 13/kg, straw-₹ 3/kg

Table 6: Effect of tillage and weed control methods on soil properties after harvest of wheat (2015-16)

Treatments	pH	OC g kg^{-1} soil	CO_2 mg 100 g^{-1} soil day^{-1}	Dehydrogenase (µg TPF hr^{-1} g^{-1} soil)	Azato-bacter cfu (X103)
Tillage Methods					
CT-CT	5.44	4.48	5.55	5.05	2.56
CT-ZT	5.44	4.59	5.25	6.19	3.11
ZT-ZT	5.52	4.86	5.37	6.07	2.89
ZT-ZT+R	5.63	4.83	5.93	6.78	3.22
ZT+R-ZT+R	5.62	5.06	6.89	6.83	3.89
SEm±	0.03	0.06	0.24	0.19	0.27
CD (p=0.05)	0.09	0.21	0.80	0.64	NS
Weed control					
R H --- RH	5.54	4.71	5.36	5.87	2.80
IWM – IWM	5.47	4.79	5.85	6.33	3.20
WC – WC	5.57	4.79	6.18	6.35	3.40
SEm±	0.04	0.03	0.09	0.10	0.29
CD (P=0.05)	NS	NS	0.34	0.38	NS

Continue...

Treatments	pH	OC g kg^{-1} soil	CO2 mg 100 g^{-1} soil day^{-1}	Dehydrogenase (µg TPF hr^{-1} g^{-1} soil)	Azato-bacter cfu (X103)
Interaction					
SEm±	0.06	0.09	0.44	0.61	0.35
CD (p=0.05)	NS	NS	NS	NS	NS
CV%	1.94	3.14	13.18	17.17	19.25
Initial value	5.50	4.90	5.90	6.30	3.00

3. Conclusion

Continuous zero tillage sequences with or without residue in maize wheat cropping system is more beneficial than conventional tillage. Application of recommended herbicide in maize and wheat is more profitable to farmers followed by integrated weed management sequences method for controlling weeds and attaining higher yield.

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