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Zero-tillage in Mung Bean-Wheat Cropping System: Impact on Soil Properties and Crop Productivity

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ABSTRACT

Background: Inclusion of legume crops in efficient cropping system is important to maintain soil bio-physical property for sustainable production systems. Conservation agriculture (CA) practices have been demonstrated to be successful in cereal based systems. But the information on zero-tillage as CA practice in legume based systems is lacking, which may further help in conservation of soil resources on sustainable basis. Hence study on impact of zero-tillage on soil biological and physico-chemical properties was undertaken at CCS Haryana Agricultural University, Regional Research Station, Bawal (Rewari), India during 2019-20 and 2020-21.

Methods: The soil of experimental site was loamy sand in texture and low in organic carbon, N and P, while medium in K. The treatments included nine tillage combinations for crop establishment under mung bean [*Vigna radiata* (L.) Wilczek]-wheat (*Triticum aestivum* L.) cropping system (MWCS) *viz.*, Zero-tillage mung bean (ZTM) *fb* zero-tillage wheat (ZTW), ZTM *fb* reduced tillage wheat (RTW), ZTM *fb* conventional tillage wheat (CTW), reduced tillage mung bean (RTM) *fb* ZTW, RTM *fb* RTW, RTM *fb* CTW, Conventional tillage mung bean (CTM) *fb* ZTW, CTM *fb* RTW, CTM *fb* CTW. The experiment was laid out in randomized block design with three replications.

Result: After two years, there was no change in soil texture and EC of the soil due to different crop establishment methods, while the bulk density of upper soil layer (0-15 cm) decreased marginally under system-based ZT method. The Infiltration rate increased with decrease in the frequency of tillage in both the crops. Organic carbon in upper layer increased while pH decreased marginally under ZTM-ZTW as compared to CTM-CTW. Available N and P showed increasing trend with decrease in number of tillage operations after two years of MWCS. Tillage practices had no significant effect on available K. The grain yield of wheat was not influenced by tillage during 2019-20, but in 2020-21 it was significantly higher under ZT wheat sown after ZTM (5025 kg ha^{-1}) than RTW (4622-4722 kg ha^{-1}) and CTW (4593-4641 kg ha^{-1}), irrespective of tillage practices in mung bean. The seed, stover and biological yields of mung bean were similar under all crop establishment methods in MWCS. This indicated sustainability of zero-tillage methods of establishment in MWCS.

Key words: Mung bean, Soil properties, Wheat, Yield, Zero-tillage.

INTRODUCTION

Mung bean (*Vigna radiata* L.)-Wheat (*Triticum aestivum* L.) is an important pulse-based cropping system followed widely in arid and semi-arid regions. Mung bean in India alone accounts for about 65% of its world acreage and 54% of the production. It has high nutritive value, thus has an advantage over the other pulses. Its seeds contain 24.2% protein, 1.3%, 60.4% carbohydrates, 11.8 ppm calcium and 34.0 ppm phosphorus (Imran *et al*., 2015). During 2018-19, the total area covered under mung bean in India was 47.55 lakh hectares with a total production of 24.55 lakh tons and productivity of 516 kg ha^{-1}. Rajasthan had the highest area (51.86%) and production (49.77%), while Madhya Pradesh has the maximum productivity (1235 kg ha^{-1}) against the national yield average of 516 kg ha^{-1}. The area, production and productivity of mung bean in Haryana was 19,100 ha, 12,490 tons and 654 kg ha^{-1}, respectively, during 2018-19 (DES, 2019).

The adoption of conservation agriculture (CA) leads to improvement in economy of farm (in terms of reduction in fuel, saving of time, water and energy; and proper seed and fertilizer placement as well as integrated weed management), yield improvement, increased soil stability (reduced wind and water erosion), better nutrient use efficiency and proper water utilization. Cropping sequence and crop rotations involving legumes and pulses help in minimizing the speed of insect-pestpopulation build-up, through life cycle disruption, biological nitrogen fixation, control of off-site pollution and enhancing biodiversity

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(Kassam and Friedrich, 2009). Under CA, we need to follow and encourage zero-tillage (ZT) along with maintaining soil cover and suitable crop rotations preferably involving pulses/legumes.

The sowing of crops with zero-tillage is very helpful in temperature moderation. Increase in soil temperature in root zone of wheat crop during late January and early February by 0.7-1.7°C, may facilitate better crop growth by better uptake of nutrient. Whereas lower the temperature (2.1-3.8°C) under ZT in first week of April might help in uniform crop maturity by safeguarding the crop from terminal heat (Punia *et al*., 2016). Studies by Yadav *et al*. (2002) also indicated that the soil temperature in root zone (0-10 cm) increased by about 1°C in February (first week) and decreased by about 3°C in April (first week) in 2000-01 in wheat under CT-ZT as compared to CT-CT rice-wheat system at permanent sites in Haryana continue since 1997-98.

During the first 4 years of tillage, Rhoton (2000) reported that soils under no tillage contained higher organic matter content than soil under reduced and conventionaltillage, with estimated 10% loss of initial soil organic matter content with plough tillage. ZT increased organic carbon significantly to a depth of 10, 15 and 25 cm, in sandy loam, loam and clay loam soil, respectively, indicating its build-up to deeper depths with increase in fineness of soil texture. Infiltration rate increased in ZT as compared to CT; however, significant increase was observed in clay loam (28%) soil (Barzegar *et al*., 2004; Singh *et al*., 2014). Stanek-Tarkowska *et al.* (2018) found that soil organic carbon (OC) content, soil water content and bulk density in the 0-5 and 5-10 cm layers were significantly higher under reduced tillage (RT) than conventional tillage (CT) but did not differ significantly in deeper layers. However, Punia *et al.* (2016) did not find any variation in bulk density of soil after 5 years of ZT-ZT conditions in rice-wheat system.

Soil microbes are the workhorses of the soil. They break down crop residues and release nitrogen, phosphorus, potassium *and* other nutrients back to the soil. Measures of soil biology are critical for the assessment of soil quality under different agricultural management practices. Tillage, by modifying soil microclimate, exerts the most important control on soil microbial communities.

Keeping in view of the above concerns and lack of information in legume based systems; an experiment was planned with the objective to assess the impact of CA particularly tillage practices on soil properties in mung bean-wheat cropping system (MWCS).

MATERIALS AND METHODS

A field experiment was conducted during 2019-20 and 2020-21 on mung bean-wheat cropping system at Regional Research Station, Bawal, Rewari, Haryana, India, situated at 28.1°N latitude and 76.5°E longitude at an elevation of 266 meter above mean sea level with sub-tropical climatic conditions. Soil of the experimental field was categorized as loamy sand in texture, with low in OC, N and P, while medium in K (Table 1). The experimental site has semi-arid climate with hot sunny days along with dry winds during summer and severe cold days during winter. Mean maximum temperature reaches as high as 48°C and mean minimum temperature as low as 2°C. Sometimes minimum temperature touches the freezing point also. South-west monsoon season *i.e*., from July to September contributes around 80% of the total annual rainfall. Western disturbances also cause significant amount of rainfall during winter months. The total rainfall was 428 mm during *kharif* 2019, while it was 227 mm during *kharif* 2020. The rainfall during *rabi* season was 101 mm 2019-20 and 68 mm in 2020-21. The experiment was laid out in randomized block design with nine tillage treatment combinations *viz*., Zero tillage mung bean (ZTM) *fb* zero tillage wheat (ZTW), ZTM *fb* reduced tillage wheat (RTW), ZTM *fb* conventional tillage wheat (CTW), Reduced tillage mung bean (RTM) *fb* ZTW, RTM *fb* RTW, RTM *fb* CTW, Conventional tillage mung bean (CTM) *fb* ZTW, CTM *fb* RTW, CTM *fb* CTW with three replications. The varieties used were ‘MH 421’ (mung bean) and ‘WH 1105’ (wheat) and. Both the crops were raised as per recommended package of practices of the State Agriculture University.

Crop establishment methods

For conventional tillage treatments, each plot was prepared with two harrowing + two ploughing followed by planking as preparatory tillage. Whereas for reduced tillage, one harrowing followed by planking was done. In zero-tillage treatment, no tillage operations were carried out for both the crops and were sown directly in moist soil one week after applying pre-seeding herbicide glyphosate @ 1.0%+0.1% Triton X-100 (a non-ionic surfactant) to knock-down the pre-emerged weeds. Zero-till seed-cum-fertilizer drill was used for sowing across conventional, reduced and zero tillage plots keeping row to row distance of 20 cm. Seed rate of 20 kg ha^{-1} for mung bean and 100 kg ha^{-1} for wheat was used for sowing.

Physical and chemical propertiesof soil

The soil were sampled from five different placesin the experimental site at 0-15 cm depth before sowing. Samples were mixed thoroughly and conglomerate sample was made. Physical and chemical properties of soil samples were recorded at the initiation of experiment (from composite sample) and also at the termination of the experiment from treatment wise plots.

The mechanical analysis the soil samples wasdone by International Pipette method. Bulk density of soil (0-15 cm) was determined by the core sampler method and Infiltration rate was measured with double ring infiltrometer. The sample was also analysed for N, P, K, OC, pH and electrical conductivity (EC).

Biological properties of soil

Soil samples was taken at initiation and termination of experiment and analysed for microbial population and nematode count. Sampling was done as explained in above section.

Microbial count

Ten-fold dilution was prepared from 1 g soil sample. Appropriate inoculum volume (0.1 ml) was pipetted onto the centre of the surface of suitable medium (Table 2). The sample was spread evenly over the surface of agar using the sterile glass spreader, by carefully rotating the petri-dish underneath at the same time. The plates were incubated at 30°C for 1-2 days. Colony forming unit (CFU) per g soil was calculated as per the formula:

$$\text{CFU/ml} = \frac{\text{Number of colonies} \times \text{Dilution factor}}{\text{Inculum volume}}$$

Nematodes count

For extraction of nematodes from the soil, Cobb's Sieving and Decanting technique combined with modified Baermann's funnel technique was followed by using a series of 20, 60, 300 mesh sieves. Each soil sample was thoroughly mixed and 200 cc of soil was drawn for processing. The representative soil sample was placed in a steel pan and soaked in 1 litre of water. The soil lumps were broken to enable them to go into a suspension. The suspension was stirred well and allowed to stand for 10-15 seconds for the heavy soil particles to settle at the bottom of the pan. This muddy suspension was then poured through 20 mesh sieves to catch stones and other coarse materials and the suspension was collected in a second pan that was again allowed to settle for about 15-30 seconds. The whole aliquot obtained from 300 mesh was then passed through a 350-mesh sieve. Catch on sieve was collected in a beaker, with water. The contents of beaker were then poured gently over a double layered tissue paper placed over an aluminium mesh support. This assembly was then placed a petri dish containing water. After 48 hrs, the nematode suspension was collected and examined under a stereoscopic binocular microscope for identification regarding the number of free living and plant parasitic nematodes.

Statistical analysis

Data collected during the study were statistically analyzed by using the technique of analysis of variance (ANOVA) described by (Cochran and Cox, 1959). To judge the significant difference between means of two treatments, the critical difference (CD) was worked out using following formula:

$$CD = (\sqrt{2EMS/r}) \times t \text{ value at } 5\%$$

Where,
CD = Critical difference.
EMS = Error mean sum of square.
r = Number of replications.
t = Value of t-distribution at 5% level of error degree of freedom.

The results were tested for treatment means by applying 'F' test of significance on the basis of null hypothesis. The 'OPSTAT' (Sheoran *et al*., 1998) software of CCS Haryana Agricultural University, Hisar, India was used for statistical analysis.

RESULTS AND DISCUSSION

Crop productivity

The grain yield of wheat was not significantly influenced by different methods of tillage in MWCS during 2019-20. During 2020-21, grain yield of ZTW sown after ZTM (5025 kg ha^{-1}) was higher than RTW (4622-4722 kg ha^{-1}) and CTW (4593-4641 kg ha^{-1}), irrespective of tillage practices in mung bean (Table 3). In sequence with RTM, ZTW was superior to CTW but similar to RTW; whereas in sequence with CTM, all methods of wheat establishment were similar. Hussain *et al.* (2020) in Pakistan have also reported 12% higher grain yield,

Table 1: Physico-chemical analysis of the soil of experimental field atstart of the experiment.

Parameter	Value
Physico-hydrological properties	
Soil texture	Loamy sand
Sand (%)	80.8
Silt (%)	10.4
Clay (%)	8.8
Bulk density (g cm^{-3})	1.43
Infiltration rate (mm h^{-1})	24.3
Chemical properties	
pH (1:2)	8.19
Organic carbon (%)	0.19
Available N (kg ha^{-1})	104.5
Available P (kg ha^{-1})	9.80
Available K (kg ha^{-1})	176.4

Table 2: Growth media used for quantification of different microorganisms.

Growth media	Target group	Incubation time	Reference
Nutrient Agar	Bacteria	1-2 days	Atlas (2010)
Rose Bengal Agar	Fungi	4-6 days	Martin (1950)
Kenknight and Munaier's	Actinomycetes	4-6 days	Atlas (2010)
Pikovaskaya's medium	Phosphate solubilizers	3-5 days	Pikovskaya (1948)
Aleksandrov medium	K solubilizer	3-5 days	Hu *et al.* (2006)
Cellulose degraders	Cellulose degraders	2-3 days	Hendricks *et al.* (1995)

biological yield and HI of wheat when it was planted by zero tillage as compared to traditional farmers' practice in wheat (winter)-mung bean (summer) cropping sequence.

The seed and stover yields of mung bean were similar under all crop establishment methods in MWCS. Numerical differences were more pronounced during second year, with highest grain yield under ZTM-ZTW (785 kg ha^{-1}). Stori *et al.* (2018) and Sapre *et al.* (2019) also reported similar effect of ZT on these yield attributes.

Soil properties

Physical properties

Soil physical parameters *viz*., soil texture, bulk density and infiltration rate measured at the start of experiment and after two years of experiments on mung bean-wheat cropping system revealed that there was no change intexture and bulk density of soil with different tillage treatments applied for establishment of both the crops under MWCS after two year of experimentation;however, lowest value of bulk density was under ZTM-ZTW (1.41 g cc^{-1}) and highest under CTM-CTW (1.43 g cc^{-1}) (Table 4).

Tillage treatments influenced the soil water intake *i.e.*, infiltration rate (IR) increased in the order of ZT>RT>CT. The maximum mean value of IR was obtained in case of ZTM-ZTW (2.67 cm hr^{-1}) and minimum in CTM-CTW (2.36 cm hr^{-1}). It is evident from the data in Table 4 that the IR increased with decrease in the frequencies of tillage practice in both the crops under MWCS.

Table 3: Effect of tillage practices on seed and straw yield in mung bean and wheat under mung bean-wheat cropping system.

Treatment	Mung bean				Wheat			
	Seed yield (kg ha^{-1})		Stover yield (kg ha^{-1})		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})	
	2019	2020	2019	2020	2019-20	2020-21	2019-20	2020-21
ZTM-ZTW	926	785	2.091	1.866	5.367	5.025	7.607	7.211
ZTM-RTW	925	783	2.078	1.829	5.241	4.622	7.268	6.820
ZTM-CTW	925	780	2.069	1.826	5.191	4.593	7.264	6.829
RTM-ZTW	915	778	2.072	1.879	5.346	4.959	7.463	7.116
RTM-RTW	919	757	2.062	1.869	5.232	4.698	7.268	6.669
RTM-CTW	917	754	2.075	1.886	5.178	4.641	7.236	6.640
CTM-ZTW	911	775	2.023	1.800	5.329	4.822	7.440	7.213
CTM-RTW	913	756	2.058	1.836	5.196	4.722	7.175	6.582
CTM-CTW	915	753	2.024	1.834	5.157	4.625	7.160	6.565
SEm ±	32	37	59	37	155	89	114	539
CD ($P\leq0.05$)	NS	NS	NS	NS	NS	270	NS	NS

ZTM- Zero-tillage mung bean, ZTW- Zero-tillage wheat, RTM- Reduced tillage mung bean, RTW- Reduced tillage wheat, CTM- Conventional tillage mung bean, CTW- Conventional tillage wheat, NS- Non-significant.

Table 4: Effect of different tillage methods on soil physical properties in mung bean-wheat cropping systemafter two years of experimentation.

Treatment	Soil texture			Infiltration rate	Bulk density
	Sand (%)	Silt (%)	Clay (%)	(cm hr^{-1})	(g cc^{-1})
Initial values at the initiation of experiment (1 week before sowing of mung bean in 2019)					
-	80.8	10.4	8.8	2.43	1.43
Final values at termination of experiment (one day after wheat harvest during 2020-21)					
ZTM-ZTW	80.8	10.4	8.8	2.67	1.41
ZTM-RTW	80.8	10.4	8.8	2.63	1.42
ZTM-CTW	80.8	10.4	8.8	2.55	1.43
RTM-ZTW	80.8	10.4	8.8	2.64	1.42
RTM-RTW	80.8	10.4	8.8	2.58	1.43
RTM-CTW	80.8	10.4	8.8	2.41	1.43
CTM-ZTW	80.8	10.4	8.8	2.46	1.42
CTM-RTW	80.8	10.4	8.8	2.37	1.43
CTM-CTW	80.8	10.4	8.8	2.36	1.43
SEm ±	-	-	-	-	0.003
CD ($P\leq0.05$)	-	-	-	-	NS

ZTM- Zero-tillage mung bean, ZTW- Zero-tillage wheat, RTM- Reduced tillage mung bean, RTW- Reduced tillage wheat, CTM- Conventional tillage mung bean, CTW- Conventional tillage wheat, NS- Non-significant.

Annual ploughings affect soil compaction by maintaining a fairly loose structure or increasing soil porosity (Dam *et al*., 2005). CT adoption results in higher BD compared to minimum tillage (Oliveira*et al*., 2020). However, variations in bulk density due to tillage practices are frequently overshadowed by short-term alterations in organic matter content in soil (Heuscher *et al*., 2005), soil water content and rooting pattern (Strudley *et al*., 2008).

Chemical properties

The effect of tillage practices on pH and EC remained non-significant (Table 5). However, after two years, the pH decreased slightly under the treatment ZTW-ZTM (8.12), while it increased under treatment CTM-CTW (8.23), from the initial pH value (8.19) at start of the experiment. ZT helped in marginally reducing the pH of the soil. The sowing of both crops under zero tillage resulted in significantly higher organic carbon (0.22%) as compared to CTM-CTW (0.19%) under MWCS. The effects of RT on OC were not pronounced as compared to CT.

After two years of experimentation on MWCS, available nitrogen showed increasing trend with decrease in number of tillage operations, with maximum available N under ZTM-ZTW (113.3 kg ha^{-1}) and the lowest under CTM-CTW (104.9 kg ha^{-1}). However, ZT in wheat had more effect on available N than ZT in mung bean. The maximum increase was recorded where both crops were grown with ZT practice followed by either crop grown in zero tillage and both crops grown on reduced tillage.Tillage practices did not affect available phosphorus and potassium significantly after two years of experimentation, but numerical differences were there. The maximum available P and K were recorded after ZTM-ZTW (11.23 and 179.3 kg ha^{-1}, respectively) and minimum under CTM-CTW (10.40 and 176.6 kg ha^{-1}, respectively), as compared to initial value of 9.8 kg ha^{-1} and 176.4 kg ha^{-1}, respectively (Table 5).

Zero-tillage improved the amounts of available N and P in the top soil, which could be attributed to partial retention of residues and favourable conditions for increased microbial populations. Reyes *et al.* (2002) also reported noteworthy escalations of available N and P in reduced or zero-tillage practices than traditional deep ploughing. Kumar and Yadav (2005) reported a marginal decline in soil pH relative to the initial values under traditional tillage. Jat *et al*. (2018) concluded that an appreciable quantity of N and K fertilizers (up to 30% and 50%, respectively) was saved under CA-based management system in maize-wheat-mungbean copping system after 4 years of continuous cultivation.

Biological properties

Dehydrogenase activity in the soils was recorded the highest under ZTM-ZTW (90.75 µg TTP g^{-1} soil 24-hr^{-1}), while it was minimum under CTM-CTW (34.67 ìg TTP g^{-1} soil 24-hr^{-1}). The dehydrogenase activity in the soils was found significantly higher in ZTW-ZTM as compared to initial value from the field (80.0), whereas it decreased in the treatment where conventional tillage was applied to any of the crop in MWCS (Table 6).

The bacterial population at the initiation of the experiment was 1.62×10^7 g^{-1} dry soil (Table 6). It increased to 6.63×10^7 g^{-1} dry soil under the treatment of ZTM-ZTW after two years of experimentation, which was significantly higher to all other methods of crop establishment. The bacterial population under CTM-CTW remained similar to initial value of the field. Similarly, the phosphate solubilizer and N- fixer microbes also increased significantly under the system based zero-tillage treatment as compared to initial value and it remained unchanged in conventional tillage treatments

Table 5: Effect of tillage treatments on soil chemical properties in mung bean-wheat cropping systemafter two years of experimentation.

Treatment	OC (%)	EC (dS m^{-1})	pH (1:2)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Initial values at the initiation of experiment (1 day before sowing of mung bean in 2019)						
-	0.19	0.17	8.19	104.5	9.8	176.4
Final values at termination of experiment (one day after wheat harvest during 2020-21)						
ZTM-ZTW	0.22	0.18	8.12	113.3	11.0	179.3
ZTM-RTW	0.21	0.18	8.14	110.9	10.8	178.2
ZTM-CTW	0.19	0.17	8.15	107.0	10.6	177.0
RTM-ZTW	0.20	0.18	8.17	110.9	10.8	179.0
RTM-RTW	0.19	0.18	8.19	104.9	10.6	178.9
RTM-CTW	0.19	0.17	8.19	103.8	10.5	176.9
CTM-ZTW	0.21	0.17	8.17	110.3	10.8	177.2
CTM-RTW	0.19	0.16	8.20	106.3	10.5	177.0
CTM-CTW	0.19	0.16	8.23	104.9	10.4	176.6
SEm ±	0.01	0.01	0.08	1.4	0.1	8.1
CD ($P\leq0.05$)	0.02	NS	NS	4.3	NS	NS

ZTM- Zero-tillage mung bean, ZTW- Zero-tillage wheat, RTM- Reduced tillage mung bean, RTW- Reduced tillage wheat, CTM- Conventional tillage mung bean, CTW- Conventional tillage wheat, NS- Non-significant.

under MWCS. The degree to which microbial biomass increased under no-till compared to conventional tillage differed greatly, from 17% increase reported by Das *et al.* (2014) up to 98% increase reported by Balota *et al.* (2004). The population of plant parasitic nematodes per 200cc soil sample was recorded significantly less in system based zero-tillage as compared to reduced and conventional tillage in MWCS after two years of experimentation (Table 7). Maximum population of plant parasitic nematodes was recorded where CTM-CTW (369 per 200 cc soil) was followed, while minimum population was found in ZTM-ZTW (125 per 200 cc soil).

The number of saprophytic nematodes, which are beneficial nematodes and play an important role in organic matter recycling to enrich the nutritional status of the soil, were recorded more in zero-tillage system (Table 7). Significantly higher population of saprophytic nematodes were recorded in ZTM-ZTW (720 per 200 cc soil) system in

Table 6: Effect of tillage treatments on microbial counts in mung bean-wheat cropping systemafter two years of experimentation.

Treatment	Dehydrogenase activity (µg TTP g^{-1} soil $24\text{-}hr^{-1}$)	Microbial count		
		Bacterial population ($\times 10^7$) g^{-1} dry soil	Phosphate solubilizer ($\times 10^6$) g^{-1} dry soil	N- fixer ($\times 10^6$) g^{-1} dry soil
Initial values at the initiation of experiment (1 week before sowing of mung bean in 2019)				
-	80.00	1.62	1.16	2.19
Final values at termination of experiment (one day after wheat harvest during 2020-21)				
ZTM-ZTW	90.75	6.63	3.07	3.97
ZTM-RTW	84.17	5.70	2.87	3.83
ZTM-CTW	73.58	4.77	2.60	3.20
RTM-ZTW	76.17	6.02	2.83	3.50
RTM-RTW	71.17	3.43	2.47	3.47
RTM-CTW	50.42	3.10	2.00	2.70
CTM-ZTW	60.42	4.23	2.17	2.83
CTM-RTW	44.00	2.80	1.43	2.03
CTM-CTW	34.67	1.83	1.17	1.80
SEm ±	2.42	0.11	0.17	0.08
CD ($P \leq 0.05$)	7.33	0.35	0.51	0.23

ZTM- Zero-tillage mung bean, ZTW- Zero-tillage wheat, RTM- Reduced tillage mung bean, RTW- Reduced tillage wheat, CTM- Conventional tillage mung bean, CTW- Conventional tillage wheat.

Table 7: Effect of tillage treatments on nematode population mung bean-wheat cropping system after two years of experimentation.

Treatment	Nematode population 200 cc^{-1} soil	
	Total parasites	Total saprophytes
Initial values at the initiation of experiment (1 week before sowing of mung bean in 2019)		
-	234	500
Final values at termination of experiment (one day after wheat harvest during 2020-21)		
ZTM-ZTW	11.2 (125)*	26.8 (720)
ZTM-RTW	11.4 (130)	23.6 (557)
ZTM-CTW	12.4 (152)	22.2 (492)
RTM-ZTW	12.3 (149)	22.5 (507)
RTM-RTW	15.7 (246)	20.6 (423)
RTM-CTW	16.2 (260)	19.1 (362)
CTM-ZTW	13.4 (179)	22.1 (487)
CTM-RTW	17.1 (290)	15.2 (231)
CTM-CTW	19.2 (369)	15.1 (228)
SEm ±	0.3	0.3
CD ($P \leq 0.05$)	0.9	1.0

*Original data given in parentheses were subjected to square root ($\sqrt{X+1}$) transformation before analysis.

ZTM- Zero- Tillage mung bean, ZTW- Zero-tillage wheat, RTM- Reduced tillage mung bean, RTW- Reduced tillage wheat, CTM- Conventional tillage mung bean, CTW- Conventional tillage wheat.

comparison to CTM-CTW (228 per 200 cc soil). The number of saprophytic nematodes deceased with increase in tillage operations for establishment of both the crops under MWCS.

The retention of partial residues could be the reason for a greater number of saprophytic nematodes due to availability of substrate *and* vice-versa (Yadav and Malik 2005). Reduction in the population of nematodes under ZT wheat was also reported by Dabur *et al*. (2002).

CONCLUSION

After two years of experimentation, the tillage methods for crop establishment in MWCS did not influence soil texture, EC and pH; while the bulk density of 0-15 cm soil decreased marginally under system-based ZT method. The infiltration rate increased with decrease in the frequencies of tillage operations in both the crops under MWCS. The soil OC of 0-15 cm layer increased, while pH decreased marginally under ZTM-ZTW. Available N and P also showed increasing trend with decrease in number of tillage operations. Tillage practices had no significant effect on available K. Bacterial population, phosphate solubilizer, N-fixer and dehydrogenase activity in soil were recorded highest under ZTM-ZTW. Population of plant parasitic nematodes in soil were less and saprophytic nematodes were more in ZT as compared to CT. The ZTM-ZTW was sustainable in terms of crop productivity and soil properties.

Conflict of interest

All authors declare that they have no conflicts of interest.

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