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Impact of tillage practices on physico-chemical and microbiological properties of soil in wheat-pearl-millet cropping system

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Abstract
The impact of two tillage systems: zero-tillage (ZT) and conventional tillage (CT) with cropping pattern *i.e.* conventional tillage wheat-conventional tillage pearl millet (CTW-CTPM), conventional tillage wheat-zero tillage pearl millet (CTW-ZTPM), zero tillage wheat-conventional tillage pearl millet (ZTW-CTPM) and zero tillage wheat-zero tillage pearl millet (ZTW-ZTPM) on physico-chemical and microbiological properties of sandy textured soil was evaluated at CCSHAU, Regional Research Station at Bawal, Rewari, Haryana. After harvesting of wheat in 2017, triplicate soil samples from undisturbed and disturbed soil were obtained from two different depths (0-15 cm and 15-30 cm), for determination of bulk density (BD), soil organic carbon (SOC), microbial biomass carbon and nitrogen, viable counts of microbes and nutrient release pattern. The bulk density decreased with depth from 0-15 to 15-30 cm under ZT and *vice-versa* under CT. Values of physico-chemical and microbiological properties were relatively higher under ZTW-ZTPM system at surface layer. SOC was higher at surface layer under ZTW-ZTPM (0.29%) as compared to CTW-CTPM (0.26%) and the respective values at subsurface layer were 0.25 and 0.23%. Thus zero tillage system promoted better physico-chemical and microbiological quality of the soil when compared to the conventional tillage system.

Keywords: Microbiological properties, Nutrient release pattern, Physico-chemical properties, Soil, Tillage systems

Introduction

Tillage systems influence physico-chemical and microbiological properties of soil and have major impact on soil productivity and sustainability. Conventional tillage practices can adversely affect the productivity of the soil over the long term due to soil erosion and loss of organic matter. Sustainable soil management can be practiced through conservation tillage (including no-tillage), high crop residue return, and crop rotation (Hobbs *et al.,* 2008). In conservation tillage system at least 30% of crop residues are left in the field *i.e.* an important conservation practice for soil erosion reductions. The advantages of conservation tillage practices over conventional tillage include reducing cultivation cost; allowing crop residues to act as an insulator and reducing soil temperature fluctuation; building up soil organic matter and conserving soil moisture, improve soil quality and crop productivity (Schwab and Murdock, 2005). Reducing the intensity of soil tillage decreases the manpower and energy required for crop production (Osunbitan *et al.,* 2005) and offers long-term benefits from improved soil structure, reduced fuel consumption, bio diversity, stability of ecosystem and energy use efficiency (Iqbal *et al.,* 2005).

Soil management practices uses traditional plowing to prepare the land that may reduce soil organic matter (SOM) and microbial activity (Dick, 1984). Agricultural practices toward lesser soil degradation are needed to improve soil quality and agricultural sustainability. No-tillage, planting with minimal soil disturbance combined with crop rotations protects the soil against degradation toward sustainability. Conventional tillage system alters soil structure exposing more organic matter to microbial attack while no-tillage practices stimulate the formation and stabilization of macro-aggregates, which represent an important mechanism for protection and maintenance of SOM besides other effects as more stable temperature and changes in the distribution of organic matter and nutrients in the soil (Dick, 1984). The SOM decomposition is mediated by microorganisms, which have their activity stimulated on tropical soils where temperature is higher than temperate climate. Crop rotations that have diverse crop sequences also can be important for maintaining and improve soil quality. Crop rotations change the soil habitat due to their difference in extract nutrients, depth of roots, amount of residue, which remain in soil and difference in their components. Rotations of crops can promote biodiversity and biological activity of the soil over monoculture. Soil management as no-tillage and crop rotations are important practices, which can reduce soil erosion, conserve organic matter and water and stimulate microbial activity (Doran, 1980; Dick, 1984).

Carbon (C) and nitrogen (N) are two of the most important elements which affect the productivity and quality of the soil (Franzluebbers, 2002). Most of the photosynthesized organic carbon from atmospheric CO_2 to the plant body is eventually decomposed and converted from organic substrate into inorganic products (CO_2 and aerobic mineralizing water). In this process, the microbial community uses carbon as a substratum to increase its number and biomass, so any synthesized biologically compound is destroyed by the inhabitants of the soil (Moran and Hodson 1989; Hanisch *et al.,* 1996). Soil microorganisms such as bacteria, fungi, and protozoa are the dominant organisms that are responsible for the decomposition of organic matter and the subsequent mineralization of C and N. Indirectly, soil fauna also influences the cycles C and N (Carney and Matson, 2005). The mineralization of added organic materials and the rapid oxidation of substrates are influenced by many factors. This will likely depend on the interaction of physical, chemical and biological processes that are influenced by local environmental conditions (Bismarck *et al.,* 2006). Soils have an enormous diversity of microorganisms, among which bacteria, archaea and fungi play a pivotal role in the functioning of the ecosystem, such as regulating decomposition of organic matter and soil C dynamics, and mediating nutrient cycling (Singh *et al.,* 2010; Wagg *et al*., 2014). As microbial habitats the soil environment has been reported to have significant impacts on the structure and diversity of microbial communities (Richter *et al.,* 2018). Keeping in view the above facts the present study was undertaken to ascertain the physico-chemical and microbiological status of soils under different tillage systems and analyze the nutrient release pattern of soils under different tillage systems.

Materials and Methods

***Study site and soil sampling*:** The study site was located at CCSHAU, Regional Research Station, Bawal, Rewari, Haryana. The soil texture was sandy and no-tilled and conventionally tilled plots were established in 2014. The soil samples were collected during 2017 after wheat harvest at 0-15 and 15-30 cm soil depth from five random spots/tillage plots. Soil samples were sieved through 2 mm sieve and stored at 4±1°C. For determination of microbial biomass and microbial activities, the soil was moistened to 60 per cent water holding capacity (WHC) and incubated at 30^0 C for 10 days to permit uniform rewetting and allow microbial activity to equilibrate after the initial disturbances. Sub-samples were air-dried and ground for chemical analysis.

Characterization of soil physical and chemical properties: The textural class of the soil was determined from the relative proportion of sand, silt and clay fractions in the sample using textural triangle proposed by International Society of Soil Sciences (ISSS). Bulk density of oven dried soil samples was determined by volume-mass relationship by packing the soil material through tapping in a cylinder of known volume and from the measured weight of the soil in the cylinder. The organic carbon content in different soil samples was determined by the method of Kalembassa and Jenkinson (1973).

Viable counts of bacteria, fungi, *Actinomycetes, Azotobacter* and phosphorous solubilizing bacteria in different soil samples were determined by serial dilution making and plating on respective media. Ten-gram soil was suspended in 90 ml sterilized distilled water and kept on rotary shaker for 30 minutes so that microorganisms adhered with soil particles or present in aggregates get separated and suspended uniformly into water. Serial dilutions were made in 9 ml water blanks and 0.1 ml of appropriate dilution was spread on specific media in triplicate. The plates were incubated at 28±2 ^{0}C for about 4 to 5 days and the colonies of microorganisms appearing on plates were counted.

Nutrient release pattern: Carbon mineralization was determined by measuring CO_2 evolution from soil after incubation for four weeks by the method described by Pramer and Schmidt (1964) with slight modification. For determination of mineralizable nitrogen, soil was incubated for 30 days after adjusting 60% water holding capacity at 30 ^{0}C. Initial level of inorganic N was measured at the start of incubation by steam distillation (Keeney and Nelson (1982) after extracting 10 g of soil with 100 ml of 2 M KCl. After 30 days of incubation, samples were extracted with 2 M KCl and inorganic N (NH_4^+ plus NO_3^-) in the extract was measured by steam distillation. The N mineralization was obtained by subtracting initial inorganic N values from those obtained after 30 days.

Statistical analysis: The significance of treatment effects was analyzed following two factorial RBD analysis, using OP Stat software at CCSHAU, Hisar.

Results and Discussion

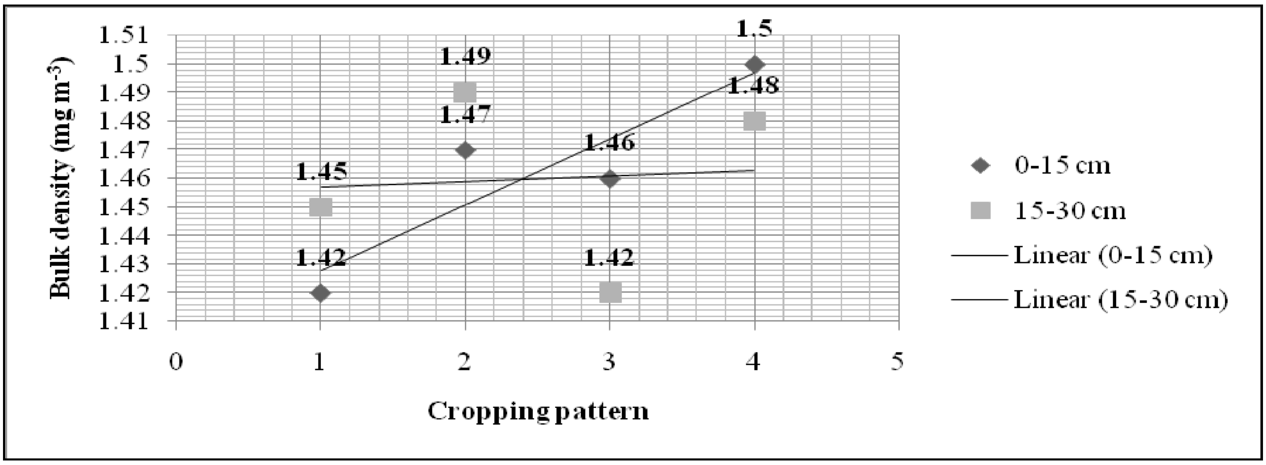
Soil texture: The data on mechanical composition of the soil samples were collected from conventional as well as adjoining conservationally cultivated plots located at Regional Research Station, Bawal (Rewari). The soils were found as sandy textural class and the contents of sand, silt and clay in soil samples in conventionally managed plots was 94, 3 and 3%, respectively, while in conservationally managed plots, the corresponding values were 92, 4 and 4%, respectively.

Bulk density: Soil physical properties changed with the intensive tillage practice but for having significant effect, tillage practice required a set period of time (Bhatt and Kukal, 2015). The physical properties had variations with the depth of the soil (Qi *et al*., 2018). One feature that was almost always changed by soil tillage was the bulk density (BD). Conventional tillage (CT) using a moldboard plow, turned a hunk of deep soil to the surface and led to the creation of large pores in the plow layer which could lead to loss of soil bulk density (Mousavibougar *et a1*., 2012). Tillage practices affected the bulk density and the data on bulk density of soil in different cropping systems revealed that the long-term zero tillage (ZT) in different cropping systems affected the soil bulk density at 0-15 cm depth (Fig 1). The bulk density decreased with depth from 0-15 to 15-30 cm under ZT and *vice-versa* under CT. Highest bulk density observed under ZTW-ZTPM in the surface layer was 1.50 mg m^{-3}, which further decreased with depth 1.48 mg m^{-3} at 15-30 cm soil layer, while under CTW-CTPM system, BD values at 0-15 cm layer was 1.42 mg m^{-3} and increased to 1.45 mg m^{-3} at 15-30 cm depth. Individually, the bulk density was significantly (P<0.05) affected but interaction of tillage and depth was non-significant.

In present study, the sandy texture soil under wheat-pearl millet cropping pattern and soil quality indicator such as bulk density, decreased with depth from 0-15 to 15-30 cm under different cropping patterns by adoption of ZT and *vice-versa* under CT. It had also been reported that ZT increased bulk density (Lampurlanes and Cantero-Martýnez, 2003), lowered soil temperatures and decreased oxygen diffusion. Contrary to it, Jat *et al.* (2009) reported that the tilled system in 10-15 and 15-20 cm soil layers had higher bulk density and penetration resistance due to compaction caused by the repeated wet tillage in rice, while Bhatt and Kukal (2015a) under sandy loam soil after two years of investigation reported that tillage systems had non-significant effect on the bulk density of the soil profile.

Soil organic carbon: Zero-tillage (ZT) affected the chemical properties of the soil in entirely different patterns to as that of what CT did. No-tillage could also lead to improvements in soil quality by improving soil structure and enhancing soil biological activity, nutrient cycling, soil water holding capacity, water infiltration and water use efficiency (Hobbs *et al.,* 2008). Mean organic carbon content of soil upto a depth of 30 cm was observed in grassland (Singh *et al.,* 2018).

Soil organic carbon (SOC) is an important indicator of soil health as it affects almost all the physico-chemical properties. The soil organic carbon in sandy textured soils was higher in upper layer than bottom layer with the values 0.26-0.29% in surface layer and 0.23-0.25 % in subsurface layer and organic carbon was relatively higher with the adoption of ZTW-ZTPM (0.29%) at surface layer (Fig 2). Individually as well as the interaction of tillage and depth were significant (P<0.05) under wheat-pearl



1= CTW-CTPM; **2=** CTW-ZTPM; **3=** ZTW-CTPM; **4=** ZTW-ZTPM;

Fig 1. Effect of conventional and zero tillage on soil bulk density under different cropping patterns

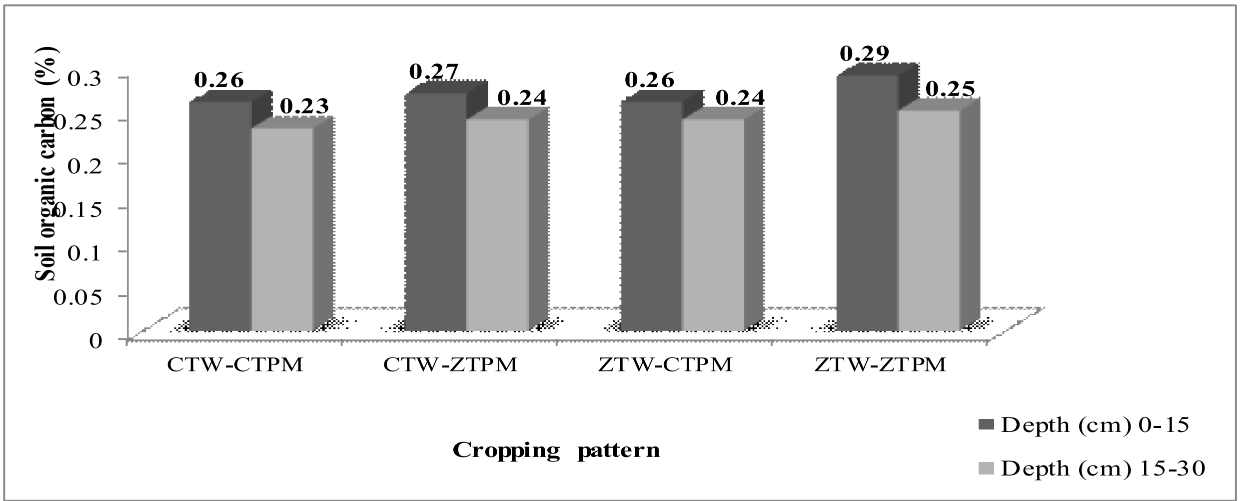


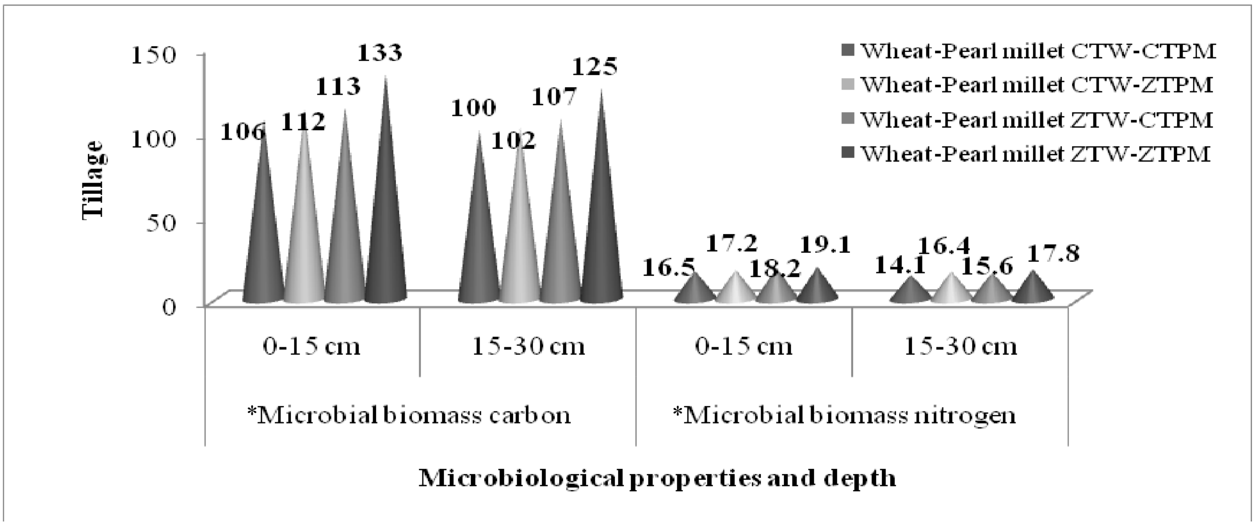
Fig 2. Effect of conventional and zero tillage on soil organic carbon under different cropping pattern

millet systems. In the present study, SOC under wheat-pearl millet cropping pattern was relatively higher in surface layer under ZT as well as CT and our findings were in agreement with those of Naresh *et al.* (2015). Song *et al.* (2019) reported that conservation tillage practices significantly influenced the total soil organic carbon (SOC) content at surface (0-15 cm) layer compared to CT due to retention of residues, minimum disturbance and accumulation of organic carbon near the soil surface layer in ZT.

***Microbiological properties**:* Soil management practices and other perturbations of soil system affect the soil microflora and microbial processes that are agriculturally and environmentally important. Various microbiological properties of soil under conventional and zero-tillage systems under wheat-pearl millet cropping pattern at RRS, Bawal (Rewari) were determined.

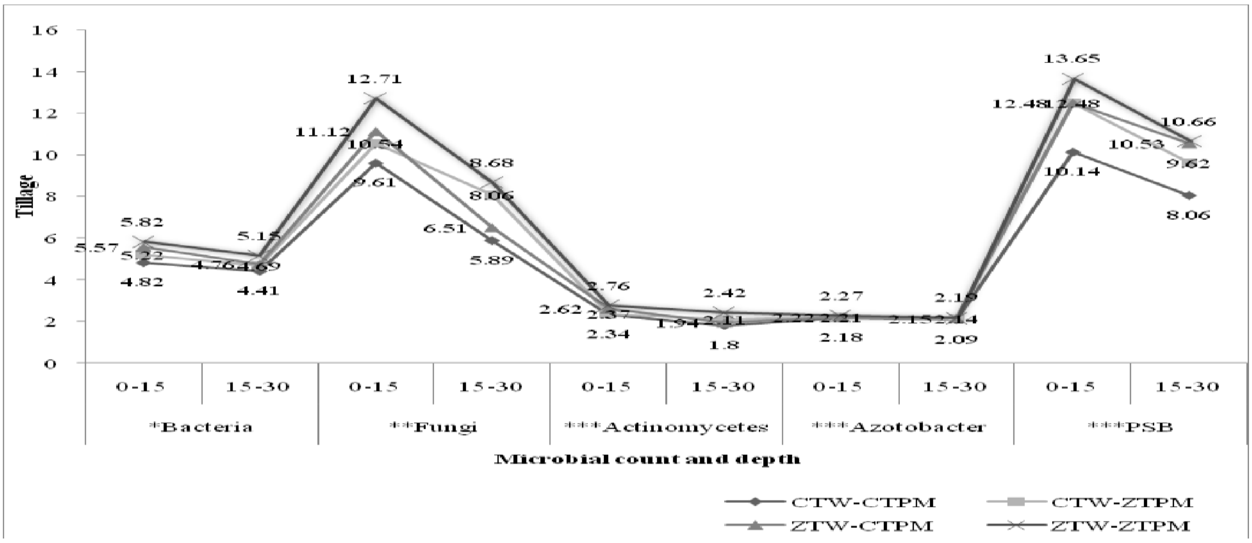
Microbial biomass carbon and nitrogen: Soil microbial biomass was shown to respond to agricultural management practices and alternation to no-tillage or increased cropping intensity increased microbial biomass in response to increased nutrient reserves and improved soil structure and water retention and soil microbial properties had a strong correlation with soil health. In the present study, microbial biomass was decreased with an increase in soil depth. Conventional tillage (summer tillage) decreased soil organic matter and soil structure which could be due to the reduction in soil microbial communities. When microbial biomass changes, one might also expect shifts in microbial community structure to occur due to the temporal increase in microbial niche, water retention or reduced physical disturbance with no-tillage. The impact of tillage practices on microbial biomass carbon and nitrogen in different soil samples indicated that under wheat-pearl millet cropping pattern, microbial biomass carbon and nitrogen was higher in 0-15 cm layer under CT as well as ZT (Fig 3). Under conventional tillage system (CTW-CTPM) microbial biomass carbon and nitrogen were observed as 106 and 16.5 mg kg^{-1} soil, respectively at surface soil and 100 and 14.1 mg kg^{-1} soil, respectively at subsurface soil. While by adoption of zero tillage practice with ZTW-ZTPM system, the corresponding values were 133 and 19.1 mg kg^{-1} soil and 125 and 17.8 mg kg^{-1} soil. Individually, the effect of tillage and depth on microbial biomass carbon and nitrogen was significant ($P<0.05$) but the interaction of tillage and depth was non-significant.

Tillage operations interrupts soil aggregates exposing organic matter to microbial degradation which finally oxidizes OM to CO_2. Balota *et al.* (2004) reported that ZT significantly increased the soil microbial biomass C (MBC) as compared to CT. Bhatt and Kukal (2015) in their two-year study on the sandy loam soil reported non-significant effect of the double zero till on soil properties. Further ZT systems improved total C by 45%, microbial biomass by 83% and MBC: total C ratio by 23% at upper 5 cm depth over CT. C and N mineralization enhanced to 74% with ZT upto 0-20 cm depth. Under ZT, the metabolic quotient (CO_2 evolved per unit of MBC) diminished by 32% averaged across soil depths. Thus tillage produced a microbial pool that was more metabolically active than under ZT systems which further oxidized the inherent soil C to CO_2. In this regard, microbial biomass could be a valuable tool for understanding changes in soil properties and in the degree of soil degradation.



*mg kg^{-1} soil

Fig 3. Effect of conventional and zero tillage on soil microbial biomass carbon and nitrogen under different cropping pattern



*CFU g^{-1} soil × 10^4; **CFU g^{-1} soil × 10^3; ***CFU g^{-1} soil × 10^2

Fig 4. Effect of conventional and zero tillage on viable count of different microbial groups under different cropping pattern

Microbial count: ZT condition was realized to be better for both micro and macro soil organisms. Greater number of microorganisms was attributed to the higher infiltration rate in no-tilled soil. The microbial count was determined in different soil samples to know the change in population of bacteria, fungi, actinomycetes, *Azotobacter* and phosphate solubilizing bacteria (PSB) with different tillage practices under different cropping systems.

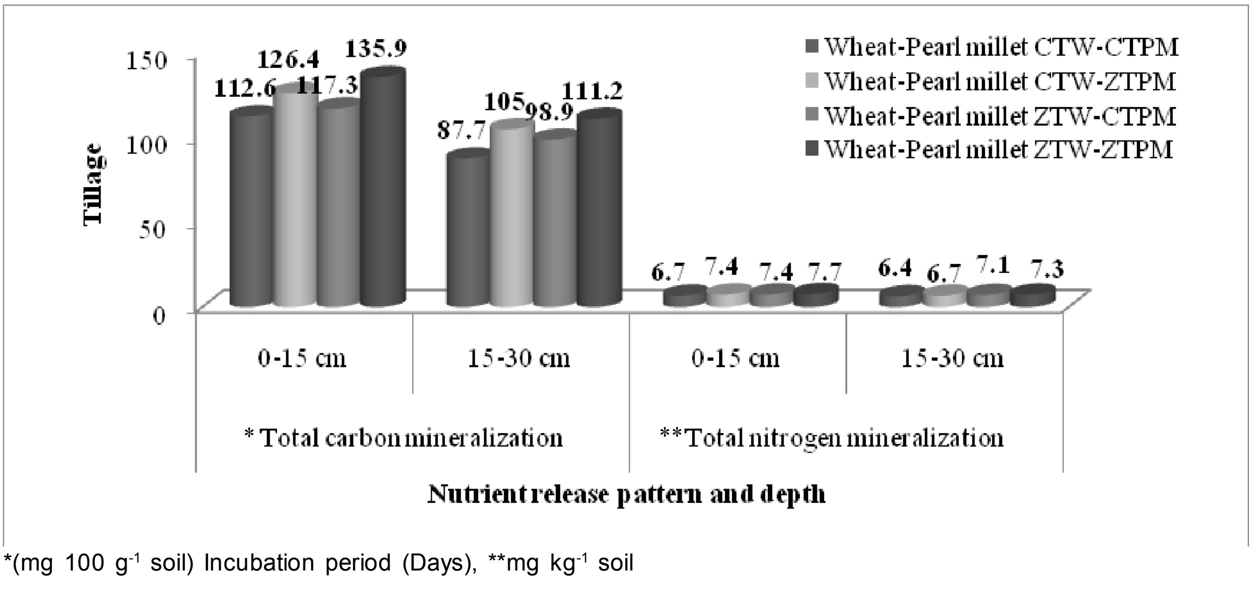
The data revealed that the bacterial count was relatively higher among all microbial groups under all systems (Fig 4). Maximum total bacteria, fungi, actinomycetes, *Azotobacter* and PSB counts were observed 5.82×10^4, 12.71×10^3, 2.76×10^2, 2.27×10^2 and 13.65×10^2 cfu g^{-1}, respectively at surface layer under ZTW-ZTPM and at subsurface layer the corresponding values were 5.15×10^4, 8.68×10^3, 2.42×10^2, 2.19×10^2 and 10.66×10^2 cfu g^{-1}. Total bacteria, fungi, actinomycetes, *Azotobacter* and PSB counts were observed 4.82×10^4, 9.61×10^3, 2.34×10^2, 2.18×10^2 and 10.14×10^2, respectively at surface layer under CTW-CTPM and at subsurface layer the corresponding values were 4.41×10^4, 5.89×10^3, 1.8×10^2, 2.09×10^2 and 8.06×10^2 cfu g^{-1}. Individually, the effect of tillage and depth was significant (P<0.05) but interaction of tillage and depth was varied under wheat-pearl millet cropping pattern.

In the present study, the effect of tillage practices on microbial groups under wheat-pearl millet cropping patterns was studied and viable count was observed relatively higher in zero tilled soil at 0-15 cm depth compared to conventional tilled soil and bacteria were most abundant among all microbial groups under all the systems. These results were conformity with the observations of Dongre *et al.* (2017) and they attributed relatively higher bacterial, actinomycetes and fungal count at 0-15 cm depth under conservational agriculture system to submerged conditions in deeper layer. Schmidt *et al.* (2018) recorded higher total bacterial number in cover cropped plots at different depths, while zero till treatments showed higher number at surface layer compared to standard tillage because farming practices and depths favored distinctly different microbial life strategies.

Carbon and nitrogen mineralization: Basal respiration is determined as a gross flux of CO_2 from mineralization that reflects the total metabolic activity of heterotrophic soil micro-organisms and labile carbon status of soil. The carbon mineralization was estimated as amount of CO_2-C evolved from different soil samples with different tillage systems and the total nitrogen mineralization was estimated as ammoniacal and nitrate-N different soil samples with different tillage systems (Fig 5). It was observed that organic C evolved estimated as CO_2-C, continuously decreased with increasing incubation period in all the soil samples and the total C mineralization increased with zero-tillage that was more pronounced at 0-15 cm depth. However, during the entire incubation period, amount of total CO_2-C evolved varied amongst wheat-pearl millet cropping system in both tillage practices and total carbon mineralization in 28 days varied in a range of 135.9 and 111.2 mg/100 g soil at 0-15 cm and 15-30 cm depth, respectively under zero-tillage system (ZTW-ZTPM) and comparatively lower values were observed under conventional tillage system (CTW-CTPM) in a range of 112.6 and 87.7 mg/100 g soil at surface and subsurface layers, respectively.

Total nitrogen mineralized in 28 days observed in a range of 7.7 and 7.3 mg kg^{-1} soil at surface and subsurface soil, respectively in zero-tillage system (ZTW-ZTPM), while comparatively lower values were observed to a range of 6.7 and 6.4 mg kg^{-1} soil at surface and subsurface soil, respectively under conventional tillage system (CTW-CTPM). Individually, the effect of tillage and depth on total C and N mineralization was significant (P<0.05), but interaction of tillage with depth was non-significant.

In the present study, C and N mineralization was comparatively higher under ZT system than CT system at surface layer under wheat-pearl millet cropping pattern.



*(mg 100 g^{-1} soil) Incubation period (Days), **mg kg^{-1} soil

Fig 5. Effect of conventional and zero tillage on carbon and nitrogen mineralization under different cropping pattern

These results were in conformity with those of Oorts *et al.* (2006). Fang *et al.* (2015) reported that significantly increased C and N mineralization at surface layer of ZT could be due to decomposition of organic matter in surface layer. The increase in basal respiration could also be due to promotion of organic matter mineralization and increase in readily available soil carbon due to enhanced aeration as observed by Sun *et al.* (2014). Higher mineral N was reported by Jat *et al.* (2018) under zero-tillage since high C: N ratio stimulated the microbial community to degrade organic substrate. Kumar *et al.* (2018) reported that mineralizable nitrogen content increased at 0-15 cm depth under ZT as compared to conventional tillage and increased mineralizable nitrogen indicated higher accumulation of organic carbon due to retention of crop residue at surface soil.

Conclusion

Zero-tillage practice with crop residue resulted in relatively higher bulk density, soil organic carbon, microbial biomass, viable count of microbes as well as nutrient release pattern at the surface layer varied by soil depths. The ZT treatments, on an average, had best of soil physico-chemical conditions to support crop production relative to the CT treatment, and ZT should, therefore, be employed for sustainable crop production in the area.

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