Asian Journal of Soil Science and Plant Nutrition

Volume 10, Issue 2, Page 445-454, 2024; Article no.AJSSPN.117039
ISSN: 2456-9682

Impacts on Various Management Practices on Crops Yield and Soil Biology in Maize-Wheat Cropping System

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Authors' contributions

This work was carried out in collaboration among all authors. Author AK conducted the study, performed the statistical analysis and wrote the protocol. Author MS designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Author KK designed the study, Authors RS and SNK managed the analyses of the study. Author RK managed the literature searches. Author SP wrote and edited the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ajsspn/2024/v10i2301

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/117039

Original Research Article

Received: 07/03/2024
Accepted: 09/05/2024
Published: 13/05/2024

ABSTRACT

Aims: Integrated approaches that consider the synergies and trade-offs among tillage, residue, and nitrogen management are essential for optimizing agricultural sustainability to highlight the complex interplay between agronomic, environmental, and biological factors. We intended to

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Cite as: *Kumar, A., Bandyopadhyay, K. K., Prasad, S., Kumar, S. N., Singh, R., Kaur, R., & Shrivastava, M. (2024). Impacts on Various Management Practices on Crops Yield and Soil Biology in Maize-Wheat Cropping System. Asian Journal of Soil Science and Plant Nutrition, 10(2), 445–454. https://doi.org/10.9734/ajsspn/2024/v10i2301*

evaluate the impact of tillage, residue, and nitrogen management on crop growth and soil biological properties under a maize-wheat cropping system in an inceptisol.
Study Design: Split-split plot design.
Place and Duration of Study: ICAR-IARI research farm, New Delhi, since 2014.
Methodology: We collected soil samples at the anthesis stage of wheat crop and silking stage of maize crop at 0-5, 5-15, and 15-30 cm soil depth. Soil properties, namely soil organic carbon, dehydrogenase, acid, and alkaline phosphatase, soil microbial biomass carbon, soil microbial biomass phosphorus, and glomalin content by using standard procedures.
Results: We observed that the soil organic carbon, enzyme activities, microbial biomass carbon and phosphorus, and glomalin content were significantly ($P<0.05$) higher under no-tillage and residue treatment at 0-5 and 5-15 cm soil depth. Enzyme activity and microbial biomass carbon (MBC) were significantly higher by application of 100 and 150% RDN, respectively, at 0-5 and 5-15 cm soil depth. The effect of nitrogen treatment on biomass yield was significant ($P<0.05$) and found to be higher at 150% Recommended dose of Nitrogen (RDN). The biomass yield of maize was 15.3% and 44.5%, and wheat was 7.8% and 20.4%, significantly increased by applying 150% RDN over the 100% and 50% RDN respectively.
Conclusion: Farmers can successfully adopt NT with 5 t ha^{-1} crop residue mulch with 150% RDN to attain better soil health and higher biomass yield under the maize-wheat cropping system.

Keywords: Conventional tillage; crop residue; enzyme activity; glomalin content; no-tillage; soil health.

ABBREVIATIONS

CT : Conventional Tillage
NT : No-Tillage
R+ : With Residues
R0 : No Residues
LSD : Least Significant Difference
SOC : Soil Organic Carbon
MBC : Microbial Biomass Carbon
MBP : Microbial Biomass Phosphorus
DHA : Dehydrogenase
ACP : Acid Phosphatase
ALP : Alkaline Phosphatase

1. INTRODUCTION

The major problem of the present day is to meet the need for food for the fast-growing global population in a sustainable manner. Hence, the agriculture system should be not only high-yielding but also sustainable. However, faulty agriculture practices, like excessive tillage and ridiculous use of agrochemicals, diminish the physical, chemical, and biological properties of soil [1, 2]. Intensive soil cultivation alters the soil structure, aggregate stability, and porosity, reduces soil organic matter, and disturbs soil microbial activity [3]. Due to the widespread deterioration of resources, the idea of conservation agriculture (CA) has gradually emerged as an option to ensure soil health and agriculture sustainability. It revolves around three fundamental principles: minimizing soil disturbance, permanent soil cover, and crop diversification. The CA emphasizes promoting sustainable and eco-friendly farming practices while ensuring food security for future generations [4,5].

Soil biotic properties are affected by tillage and nitrogen (N) fertilization, but it is unclear how a combination of tillage, N fertilization and residue retention impacts soil biotic properties. Microbial biomass and enzyme activity are two biologically active SOC components regarded as key markers for assessing short-term changes in soil quality brought through different soil and crop management practices [6,7]. These are involved in various soil processes, such as organic matter decomposition, nutrient transformation, and pollutant degradation, which are critical for nutrient availability, carbon cycling, and maintaining a sustainable environment. Therefore, studying soil enzyme activity provides vital information for sustainably understanding and managing soil ecosystems. According to several investigations, Conservation agriculture (CA) significantly changes the soil organic carbon (SOC), microbial biomass carbon (MBC), enzyme activity, and glomalin content, which improves soil health [8, 9]. However, the literature has limited evidence on the impact of different tillage and residue management practices under the maize-wheat cropping system. It is hypothesized that no-tillage and crop residue management practices might improve soil physical, chemical, and biological properties over conventional tillage in maize-wheat cropping systems. Therefore, the long-term effects of CA on soil health must be thoroughly studied.

Thus, we aimed to evaluate the impact of different tillage and residue management practices on soil health under a maize-wheat cropping system.

2. METHODOLOGY

A field experiment was established on the maize-wheat cropping system (since 2014) at the farm of ICAR-IARI research farm, New Delhi (28°35 N latitude, 77°12 E longitude, and 228.16 m AMSL). The climatic condition is sub-tropical and semi-arid, with 652 mm annual rainfall. The field experiment was laid out using a split-split plot design, with two main plot tillage (depth 0-15 cm, thrice) combinations (CT and NT), two levels of residue mulch (wheat residue in maize crop and vice versa) [residue at the rate of 5 Mg ha^{-1} (M+) and no residue (M0)] as the subplot, and three levels of nitrogen [50 (N1), 100 (N2), and 150% (N3) of the recommended nitrogen dose] as the sub-sub plot. Recommended doses of wheat and maize were considered, 120 kg N, 60 kg P_2O_5 and 60 kg K_2O. Three replications of the treatments were done. Single super phosphate (SSP) and muriate of potash (MOP) fertilizers were administered uniformly to all treatments at sowing time for both crops. The sub-sub plot measured 4.5 × 5 m^2. The soil was sandy loam in texture with an initial soil pH was 7.8, $KMnO_4$ -oxidizable N 152 kg ha^{-1}, 0.5 M $NaHCO_3$-extractable P 12.8 Kg ha^{-1} and neutral 1 N NH_4OAc-extractable K 283 kg ha^{-1}. Soil samplesl were collected randomly at the flowering stage of both maize and wheat crops at 0-5, 5-15, and 15-30 cm soil depth with the help of a soil core sampler from each plot. In maize soil samples were collected at silking stage and wheat crop soil samples were collected at anthesis stage. Overall 216 soil samples were collected in both maize and wheat crops. Half of the soil sample was kept in a refrigerator for analysis of soil biological properties, and half of the soil sample was dried in the shade, processed, and passed through a 2-mm sieve for analysis of chemical properties. Soil properties were analyzed for SOC [10], dehydrogenase [11], acid and alkaline phosphatase [12], soil microbial biomass carbon [13], soil microbial biomass phosphorus [14], glomalin assay [15] and biomass yield was recorded by using standard procedures. Data were recorded by using the analysis of variance (ANOVA) technique, performed to determine the significant differences (P <0.05) among different treatments. The analysis of variance (ANOVA) approach was used to statistically examine all of the data using the split-split plot design Using SAS (Statistical Analysis System) software [16]. F-test was employed to determine the significance of the treatment effects and the significant difference between the means was calculated by least significant difference (LSD) values (p≤0.05)

3. RESULTS AND DISCUSSION

3.1 Biomass Yield

The biomass yield of maize and wheat crops was numerically increased under NT and mulch conditions. However, it was not significantly influenced, and this may be due to the favourable environment yet not achieved by the soil under NT and mulch conditions because the experiment was only five years old. Similar findings have been reported by [17, 18]. Furthermore, under nitrogen management practices, the biomass yield of maize and wheat crops significantly increases with increasing the RDN. The biomass yield of maize and wheat significantly (P≤0.05) increased by applying 150% RDN over 100 and 50% RDN (Table 1). The biomass yield increase with increases in the level of nitrogen has been reported by several authors [19, 20].

3.2 Soil Organic Carbon

Soil sampling at various depth will give the interactive effect of tillage and residue retention at the different depths. Different tillage and residue management practices significantly (P<0.05) influenced the soil organic carbon (SOC) at 0-5 and 5-15 cm soil layer but not at 15-30 cm soil layer, while under nitrogen treatment, SOC was non-significant irrespective of soil depth of both maize and wheat crop. However, among tillage treatment the SOC was found higher under NT than the CT across the soil depth. The SOC in the surface layer (0-5 cm) was higher for maize and wheat crops, under NT over CT. Furthermore, the SOC in the soil surface layer of maize and wheat crops was found to be higher under the mulch condition than the no mulch condition. Thus, both tillage and crop residue management significantly (P<0.05) influenced SOC in the surface layer of soil (Table 1). This may be due to the regular retention of previous crop residue [21] and less incorporation of crop residue in the soil by NT, which leads to an uneven distribution of soil organic matter and a decrease in the rate of organic matter decomposition and carbon mineralization across the soil profile. Therefore, more SOC was found at the upper layer of soil (0-5 cm) [22]. The SOC was found to be higher but not significant in the surface layer of soil by application of 150% over the 50% and 100% application of the recommended dose of nitrogen (RDN). This may be due to the sufficiency of nutrients provided by nitrogen fertilizer, which increases the shoot and root biomass and, hence, SOC [3].

3.3 Biological Activities

The dehydrogenase enzyme activity is commonly used as an indicator of microbial activity in soils, and the activities of alkaline and acid phosphatases play important role in the phosphors cycle and solubilize the organic phosphorus and remobilize remobilization phosphate to help the plant cope with P-stressed conditions [23]. The dehydrogenase (DHA), acid phosphatase (ACP), and alkaline phosphatase (ALP) activity was significantly ($P<0.05$) influenced by different tillage, residue, and nitrogen management practices at 0-5 and 5-15 cm of soil depth but not at the 15-30 cm of soil depth of both maize and wheat crops. However, the enzyme activity was found to be higher under NT over CT across the soil depth (Figs 1, 2, 3). This may be due to minimal soil disturbance, better soil aeration, and more soil organic carbon content, which provide a favourable environment for soil microbes and enzymes [24,25]. Furthermore, The DHA, ACP, and ALP activity in the soil surface layer of maize and wheat crops were found higher under mulch conditions than no mulch conditions (Fig 1, 2, 3). This may be due to increasing organic matter content and nutrient availability by incorporating crop residue on the soil surface. Therefore, this stimulates microbial activity and subsequently enhances soil enzyme production [26]. Enzyme activity is also affected due to the development of plant growth and modification of soil climatic conditions (temperature and moisture) by applying crop residue [27]. Thus, the SOC represents a source of soil enzymes [28]. The trends of changing enzyme activity in the surface layer were found to be 100>150>50% RDN application of both maize and wheat crops (Fig 1, 2, 3). Under nitrogen management practices, the enzyme activity was improved by 100 over the 50 and 150% doses of nitrogen application, which may be due to the toxic effect of nitrogen application. Choudhary and Behera [3] reported that enzyme activity improved with 60 kg ha^{-1} of nitrogen over 120 and 180 kg ha-1 nitrogen in conservation agriculture under maize and wheat cropping systems due to the toxic effect of higher nitrogen application dose.

3.4 Microbial Biomass

The present study, under microbial biomass, investigates MBC and microbial biomass phosphorus (MBP). Different tillage and residue treatments significantly ($P<0.05$) influenced the MBC and MBP. However, under nitrogen management practices, only MBC was found significant at 0-5 and 5-15 cm of soil depth of both maize and wheat crops. However, among tillage treatment MBC and MBP were found higher under NT than the CT across the soil depth. This may be due to more SOC, greater availability of food to sustain the microbial biomass and better soil aeration by retaining crop residue and decomposition of crop roots. Dixit et al. [25] have reported the same finding for MBC under different tillage and residue management practices.

Table 1. Biomass yield of wheat and maize crop as influenced by different tillage, residue and nitrogen management practices under maize-wheat cropping system

Treatment	Biomass yield (t ha^{-1})	
	Maize	Wheat
Effect of tillage		
CT (Conservation Tillage)	15.2	14.2
NT (No tillage)	16.2	14.3
LSD (P=0.05)	NS	NS
Effect of residue		
R0 (No residue)	14.7	14.1
R+ (With residue)	16.6	14.4
LSD (P=0.05)	NS	NS
Effect of Nitrogen		
N50% (50% of RDN)	12.7	12.9
N100% (100% of RDN)	15.1	14.4
N150% (150% of RDN)	18.4	15.5
LSD (P≤0.05)	3.2	2.4

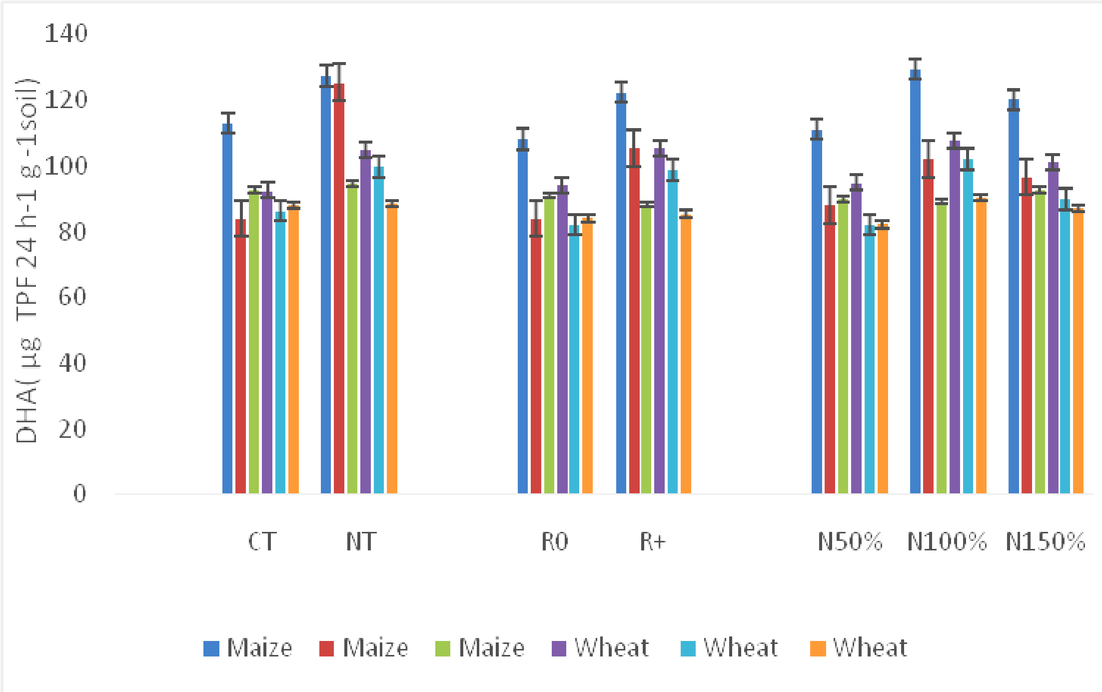

Fig. 1. Effect of different tillage, residue and nitrogen management practices on dehydrogenase activity under maize-wheat cropping system

Note: DHA- Dehydrogenase Activity; Error bars indicate the LSD value ($p < 0.05$). For treatment description, refer to Table 1

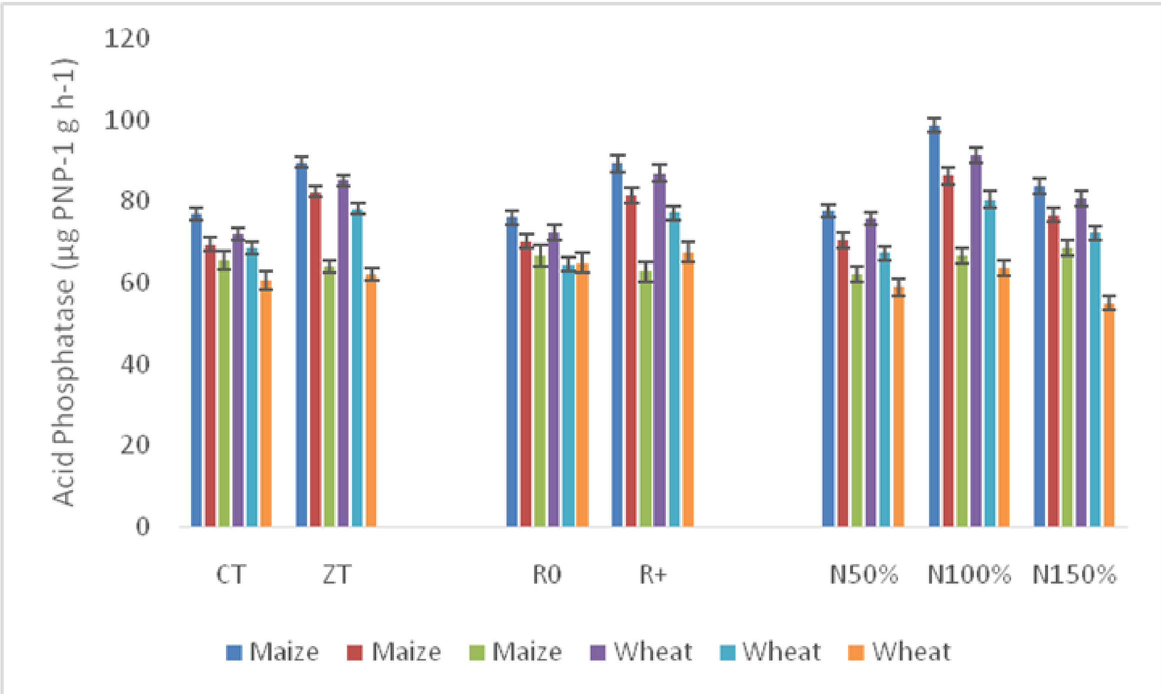

Fig. 2. Effect of different tillage, residue, and nitrogen management practices on acid phosphatase activity under maize-wheat cropping system

Note: ACP- Acid Phosphatase Activity; Error bars indicate the LSD value ($p < 0.05$). For treatment description, refer to Table 1

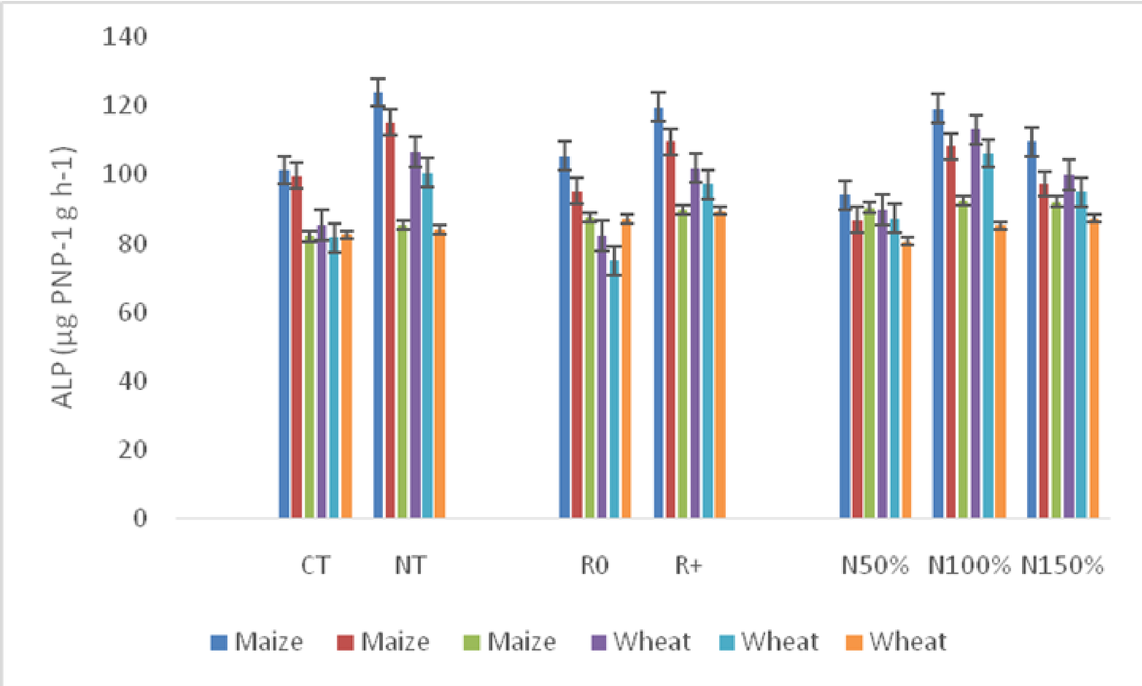

Fig. 3. Effect of different tillage, residue and nitrogen management practices on alkaline phosphatase activity under maize-wheat cropping system

Note: ALP- Alkaline Phosphatase Activity; Error bars indicate the LSD value ($p < 0.05$). For treatment description, refer to Table 1

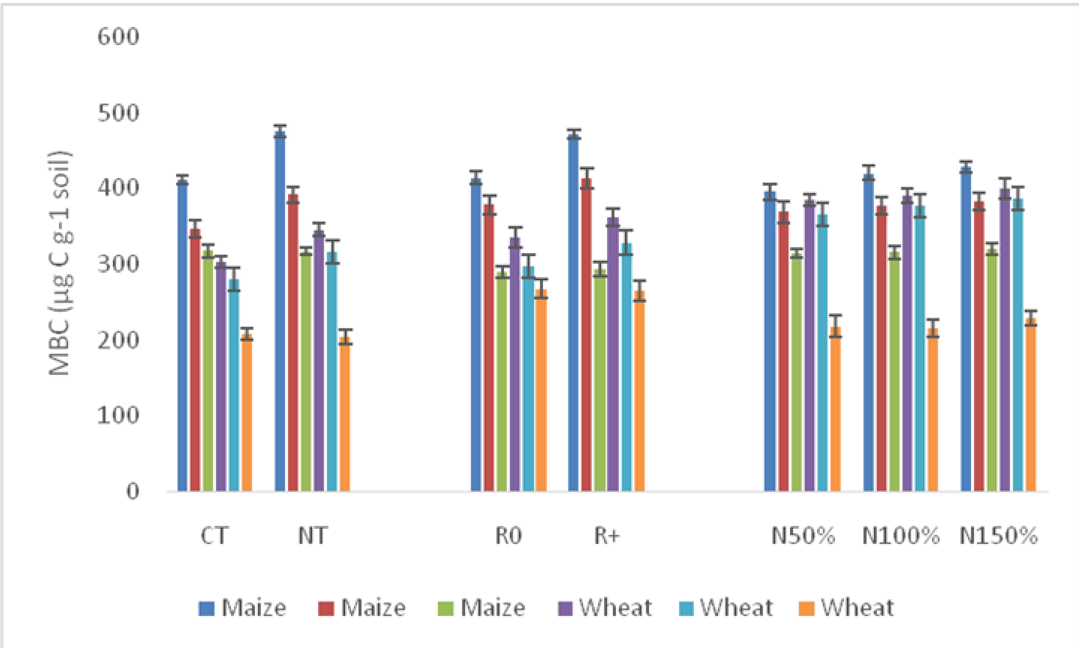

Fig. 4. Effect of different tillage, residue and nitrogen management practices on soil microbial biomass carbon (MBC) under maize-wheat cropping system

Note: MBC- Microbial Biomass Carbon; Error bars indicate the LSD value ($p < 0.05$). For treatment description, refer to Table 1

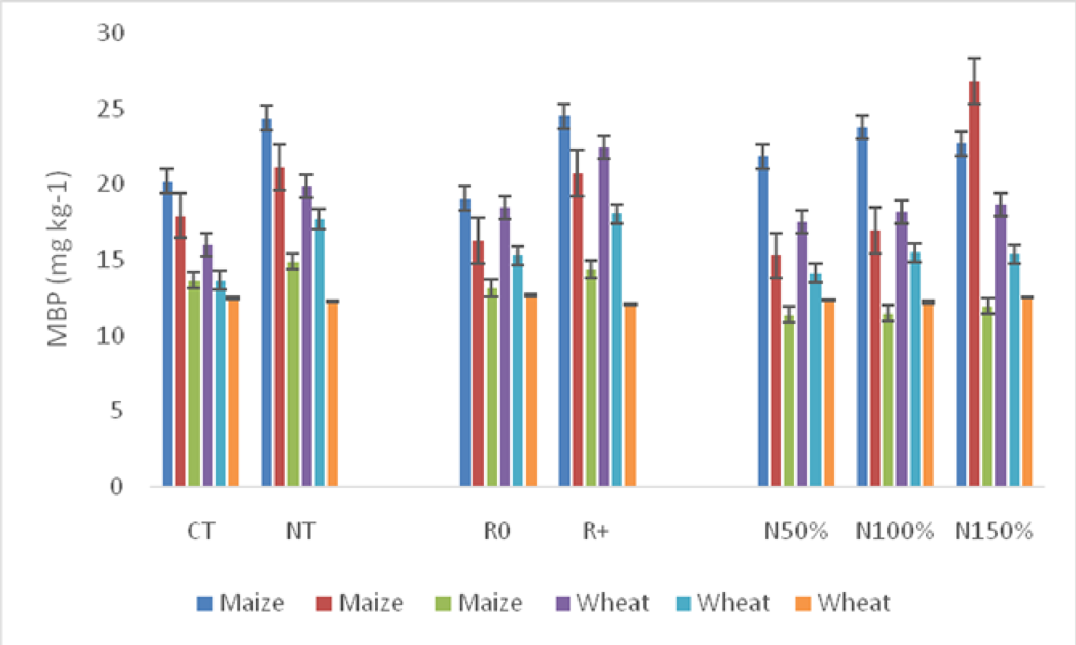

Fig. 5. Effect of different tillage, residue and nitrogen management practices on soil microbial biomass phosphorus (MBP) under maize-wheat cropping system

Note: MBP- Microbial Biomass Phosphorus; Error bars indicate the LSD value ($p < 0.05$). For treatment description, refer to Table 1

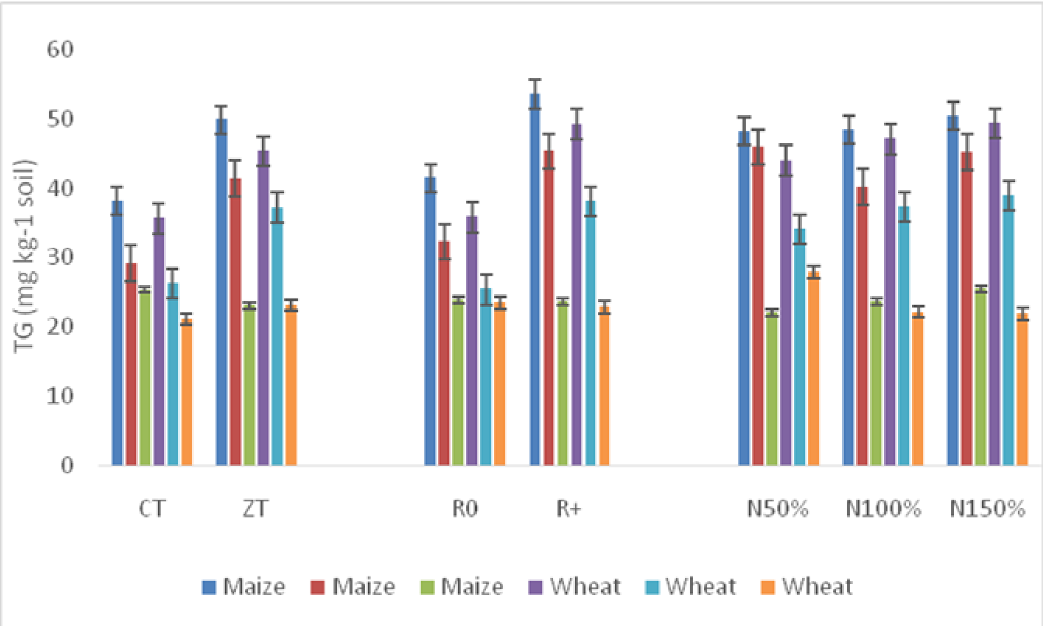

Fig. 6. Effect of different tillage, residue and nitrogen management practices on total glomalin content under maize-wheat cropping system

Note: TG- Total Glomalin Content; Error bars indicate the LSD value ($p < 0.05$). For treatment description, refer to Table 1

Choi et al. [29] and Kihara et al. [30] reported that MBP was higher under NT than CT under different tillage and cropping systems. Furthermore, among residue treatment, MBC and MBP were found to be higher under mulch conditions than the no mulch conditions across the soil depth. Bolo et al. [31] also reported similar findings. Under nitrogen management practices, the trends of MBC and MBP in the surface layer were found to be 150>100>50% RDN application of both maize and wheat crops (Fig 4, 5). However, the MBC was improved with a 150% dose of nitrogen application, and this may be due to greater biomass recorded in the 150% RDN fertilized plot than in the 50 and 100% RDN. Álvaro-Fuentes et al., 2013, also reported similar results in conservation agriculture [32]. Under nitrogen management practices, the MBP was not influenced significantly across the soil profile by the application of different doses of nitrogen for both maize and wheat crops.

3.5 Glomalin Content

Total glomalin (TG) extractable was significantly influenced by tillage and residue management practices at 0-5 and 5-15 cm soil depth but not at the 15-30 cm soil depth of both maize and wheat crops. However, among the tillage treatment, the TG was found to be higher under NT over the CT across the soil depth. This may be due to minimizing mechanical disturbance of the soil. When soil is left undisturbed, arbuscular mycorrhizal fungi (AMF) can thrive and produce more glomalin. The no-tillage system allows the fungal hyphae to grow and proliferate, leading to increased glomalin production in the soil [33]. Under CT, the macro-aggregates into micro-aggregates lead to decomposition and loss of glomalin [34]. Bhattacharya et al. [35] have also reported that glomalin protein was significantly higher under conservation agriculture over the CT. Furthermore, among the residue treatment the TG was found higher under the mulch condition than the no mulch condition across the soil depth (Fig 6). This may be due to crop residue increasing AMF diversity and enhancing functioning [36]. Soil glomalin was higher under the residue retention plot than no residue [37]. Under nitrogen management practices, the TG numerically increases with increasing the dose of nitrogen application across the soil depth but has no significant influence under both maize and wheat crops.

4. CONCLUSION

The biomass yield of maize and wheat crops was statically not significant under tillage and residue management but increased significantly with increased nitrogen application dose. Thus, the biomass yield of both crops was higher by applying 150% RDN. Furthermore, adaptation of NT with residue incorporation improves soil organic carbon, enzyme activity (dehydrogenase, acid, and alkaline phosphates), MBC, MBP, and glomalin content at 0-5 and 5-15 cm soil depth. Under nitrogen management practices, the enzymatic activity and MBC were improved by 100 and 150% application of RDN, respectively. The increase of enzymatic activity, MBC, and MBP could improve the microbial activity and nutrient mobility of the soil. Therefore, our study suggested that no-tillage with 5 t ha^{-1} crop residue retention and proper nitrogen management improved the overall soil health, which is suitable for the maize-wheat cropping system. In the real world where farmers are facing soil health deterioration due to conventional agricultural practices, this study recommend the zero tillage and residue retention practices for sustainable agriculture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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