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TILLAGE AND RESIDUE IMPACTS ON MICROBIAL BIOMASS AND SOIL C AND N DYNAMICS UNDER DIFFERENT CROPPING SYSTEMS

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Abstract

This study was aimed to investigate the impacts of tillage and residue management on soil microbial biomass-C (MBC) and –N (MBN), mineralizable N (MN), soil organic carbon (SOC), and total nitrogen (TN) in wheat (*Triticum aestivum*)-fallow, wheat-maize (*Zea mays* L.) and wheat-mungbean (*Vigna radiata*) sequences three year after establishment of the experiment. No-tillage increased SOC (16.20%), TN (17.07%), MBC (10.44%) and MBN (16.87%) over the tillage treatment. Crop residue return also increased microbial biomass and accumulation of C and N in soil over the residue removed treatment. Cropping intensity promoted microbial biomass and C and N dynamics over the system containing the fallow cycles. Among cropping systems, the legume-based system (wheat-mungbean) produced greatest SOC and TN in soil than cereal-cereal (wheat-maize) system and increased MBC and MBN in similar pattern. These results demonstrated that no-tillage, residue return and cropping intensity promoted the accumulation of soil organic matter that had beneficial impacts on soil fertility through enhancement of soil microbial biomass and supply of mineralizable nutrients particularly in the rain-fed farming system.

Introduction

No-tillage, residue return and cropping intensity may enhance soil organic matter and microbial biomass and alter C and N dynamics. Cropping intensity tends to increase SOC and microbial biomass through greatest return of crop residues (Sherrod *et al*., 2003; Stromberger *et al*., 2007). Crop residues have been reported to increase soil organic fertility (Shah *et al*., 2003a; Shafi *et al*., 2007; Bakht *et al*., 2009) which can improve microbial activity and nutrient supply (Shah *et al*., 2003b). Biederbeck *et al*., (2005) reported that soil microbial communities, microbial biomass and activities were improved significantly by increasing cropping intensity and even more by using legumes as green manure in fallow-wheat system. The labile attributes were however more sensitive indicators of changes in soil quality than total organic C or N.

Tillage promotes SOM decomposition through crop residue incorporation into soil, physical breakdown of residues, and disruption of SOM protected within aggregates (Paustian *et al*., 2000; Six *et al*., 2000). It is now established that tillage accelerates organic matter degradation resulting in minimal accumulation of organic matter. Accumulation of organic matter in soil is of great practical significance in all farming systems in general and in rain-fed farming in particular. Organic matter accumulation in soil helps to improve water retention which is of great concern in rain-fed farming. Impacts of tillage on SOM have been well documented, but results vary due to soil type, cropping system, residue management and climatic conditions. Kushwaha *et al*., (2000) found that microbial biomass-C and –N were high in minimum tillage residue retained treatment and low in conventional tillage residue removed treatment. Reducing tillage from conventional to zero tillage in the residue retained treatment increased the levels of MB-C by 36-82 and MB-N by 29-104 %.

However, such information for rain-fed environment are limited. This study was conducted within a rain-fed field experiment established in 2004 to assess the impacts of tillage, crop residue and cropping sequences on microbial biomass and soil organic fertility (SOC, total N, mineralizable N) after three years of their imposition in a rain-fed field experiment in Peshawar valley of North West Frontier Province (NWFP) Pakistan.

Materials and Methods

A field experiment involving tillage, residue and cropping sequences treatments was initiated in 2004 at Livestock Research and Development Farm Surizai, Peshawar (NWFP), Pakistan. The soil (surface 0-15 cm soil) of the experimental site was loam in texture, alkaline in reaction, non-saline, calcareous in nature, and low in N, P and soil organic matter (Table 1). The experimental design was a split-split plot within a randomized complete block. Tillage treatment served as the main plot, residue management was the split plot, and cropping sequences were the split-split plot. Tillage regimes included conventional tillage (CT) and no-tillage (NT), residues treatments included residues return (+residue) and residue removed (-residue) while cropping systems included wheat-fallow (WF), wheat-corn (WC) and wheat-mungbean (WM). Wheat and corn received recommended levels of N, P and K fertilizers in each year. Soil samples (0-15 cm) were collected from plots about one month after the harvest of summer crops and just before planting of wheat in November 2007. The surface stones and liters were removed before sampling. Soil sampling was done at optimum moisture level in the soil. The soil samples were broken down by hand and allowed to air dry at room temperature just sufficient for the moist soil to pass through <2 mm sieve. The samples were either run immediately for microbial studies or kept cool to avoid unnecessary changes in soil before the microbial studies.

Soil analysis for microbiological properties

Microbial Biomass (C and N): Microbial biomass-C (MBC) and –N (MBN) were estimated by using chloroform fumigation incubation method as described in Horwath & Paul (1994). Soil samples were fumigated with chloroform to the extent to kill all microbes present in the soil sample. The fumigated samples were inoculated with 1.0 g of unfumigated same soil sample. Both fumigated and unfumigated soil samples were incubated in the presence of NaOH solution. The amount of CO_2 evolved was measured by titrating the NaOH solution against standard HCl solution. The amount of mineral N was also measured both in fumigated and unfumigated samples. The amount of MBC and MBN were calculated as follows:

Calculation of biomass C: The amount of CO_2-C produced from fumigated and unfumigated samples were used to calculate soil microbial biomass C using the following expression:

$$\text{Biomass C} = (F_c - U_{fc})/k_c$$

where

F_c = CO_2 flush from fumigated soil

U_{fc} = CO_2 produced from unfumigated soil

K_c = 0.45 (Jenkinson & Ladd, 1981)

Table 1. Some characteristics of soil (0-15 cm) of the experimental site before the establishment of field experiment.

Soil property	Value
Soil pH (1:5 soil/water)	7.94
EC (1:5 soil/water) (dSm^{-1})	1.34
Soil organic matter (g kg^{-1} soil)	7.82
Total N (g kg^{-1} soil)	0.35
Total mineral N (ug g^{-1} soil)	11.25
AB-DTPA extractable P (ug g^{-1} soil)	4.03
AB-DTPA extractable K (ug g^{-1} soil)	80.84
Sand (%)	32
Silt (%)	30
Clay (%)	38
Textural class	Loam

Calculation of biomass N: Microbial biomass N was calculated from the amount of mineral N produced in fumigated and un-fumigated samples using the following equation:

$N = (F_n - U_{fn})/k_n$

Fn = The flush of NH_4 –N from fumigated soil

U_{fn} = The NH_4 –N mineralized during 10 days from unfumigated soil

K_n = 0.54 (Jenkinson, 1988).

Other soil properties: Soil organic carbon (SOC) was determined by the Walkley-Black procedure using $K_2Cr_2O_7$ as an oxidizing agent (Nelson & Sommers, 1996). Total N (TN) was determined by the Kjeldhal method described by Bremner (1996). Mineralizable N was determined by analyzing soil samples for mineral N before (day 0) and after incubation (10 days) at 25^{o}C (Abbasi *et al*., 2003). The amount of mineralizable N was calculated by difference. The soil mineral N (NH_4-N + NO_3-N) was determined by the steam distillation method described by Mulvaney (1996).

Statistical analysis: Data were analysed using CoStat (CoHort Software, 1996). Correlation coefficients (r) were calculated and ANOVAs were used for treatment comparisons at $p<0.05$, with separation of means by LSD.

Results and Discussion

Soil organic carbon (SOC) and total N (TN) concentrations: The results showed that SOC and TN were greater in the NT than in the CT treatment (Table 2). Averaged across residue treatments and cropping sequences, SOC was 9.48 g kg^{-1} soil in the CT and 11.01 g in NT treatment. Similarly, TN was 0.34 g kg^{-1} soil in the CT and 0.40 g in NT treatment. Although SOC and TN were not impacted significantly by tillage, SOC and TN tended to be highest in NT than in CT treatment. Soil organic C under NT was 16.2% higher than CT regime. Similarly, the increase in TN under NT was 17.07% higher than CT regime.

Table 2. Soil organic C (SOC) and total N (TN) as influenced by tillage, crop residues and cropping sequences.

	SOC ($g\ kg^{-1}$ soil)	**TN ($g\ kg^{-1}$ soil)**
No-tillage	5.50	0.34
Tillage	6.39	0.40
% increase over tillage	16.20 %	17.07 %
-residue	6.25	0.41
+residue	5.63	0.34
% increase over -residue	10.97 %	20.30 %
Wheat-fallow (WF)	5.24	0.28
Wheat-corn (WC)	6.33	0.34
Wheat-mung (WM)	6.25	0.49
% increase by WC over WF	20.86 %	21.43 %
% increase by WM over WF	19.20 %	75.90 %

Crop residue return did not significantly increase the SOC and TN after three years of continuous residue return to the soil (Table 2). Averaged across cropping sequences and tillage regimes, SOC was 10.78 g kg^{-1} in +residue and 9.71 g in –residue treatment. Similarly, TN was 0.41 g kg^{-1} in +residue and 0.34 g in –residue treatment. It indicates that although differences in SOC and TN between +residue and –residue were not significant, SOC and TN under NT were 10.97% and 20.30%, respectively higher than CT treatment.

Soil organic C and TN were greatest under continuous cropping (eg., WC, WM) compared with cropping containing the fallow cycles (eg., WF). Averaged across residue and tillage treatments, cropping intensity increased SOC by 20.86% and TN by 75.89% compared with WF system (Table 2). Among cropping sequences, WC and WM produced about similar amounts of SOC but different amounts of TN. WM increased TN by 75.89% whereas WC increased TN by 21.43% over the WF system.

NT generally produced greatest SOC and TN in the surface 0-15 cm soil. The accumulation of relatively greatest amount of SOC and TN in NT treatment could be due to the fact that tillage promotes SOM decomposition through crop residue incorporation into soil, physical breakdown of residues, disruption of SOM protected within aggregates and enhanced intimation of SOM with microorganisms (Paustian *et al*., 2000; Six *et al*., 2000), therefore less SOC and TN produced in the CT compared with NT treatment. Similar trends for SOC were observed in related but long-term studies (Wright *et al*., 2005; Stromberger *et al*., 2007) but opposite in other studies (Unay *et al*., 2005). The return of crop residue is likely to promote SOC and TN in soil as we observed. The accumulation of SOC and TN due to continuous application of crop residues is more in NT than in CT because of little degradation and exposure of SOM/crop residue to microorganisms. Similar results have been reported by other researchers (Stromberger *et al*., 2007).

Continuous cropping produced more SOC and TN than cropping where fallow cycle was included. Increased cropping intensity seek to conserve soil resources, including carbon through greater residue return and water through increased water use efficiency by crops (Sherrod *et al*., 2003). The greatest increases in SOM are usually observed in intensive cropping systems, where multiple crops are grown yearly (Ortega *et al*., 2002; Sherrod *et al*., 2003; Wright & Hons, 2004; Stromberger *et al*., 2007). This has practical implications as increases SOM has potential for increasing the nutrient supply to crops through changes in the mineralization and immobilization of nutrients by microbial biomass. We found that legume-based cropping system produced more SOC and TN than cropping containing a fallow cycle. Types of crop residues therefore play important role in C sequestration and organic matter cycling due to differences in C/N ratios or quality of residues (Shah *et al*., 2003b).

These results thus suggested that NT, return of crop residues and continuous cropping promotes the accumulation of soil organic matter and had beneficial impacts on soil fertility through supply of mineralizable nutrients. This is particularly important for dryland farming where high temperature does not allow the accumulation of soil organic matter.

Mineralizable N: The results showed that mineralizable N (MN) was not impacted by tillage. Differences between NT and CT for MN were not significant (Table 3). Averaged across residue treatments and cropping sequences, MN was 12.40 µg g^{-1} soil in the CT and 11.18 µg in NT treatment. However, crop residue return significantly increased the MN over the residue removed treatment (Table 3). Overall, residue increased MN by 35.45 % over the residue removed treatment. Similarly, crop rotation significantly increased MN. We observed that WC system increased MN by 78.54 % over the WF system (Table 3). The impact of legume-based rotation on microbial biomass was more substantial. Wheat-mungbean rotation increased MN by 300 % over the WF rotation. Mineralizable N was significantly related to TN (r = 0.89) and SOC (r = 0.46).

The lack of differences between tillage treatments for mineralizable N in soil is not understandable. We would expect more mineralization in NT because of greater accumulation of SOM but it did not happen. As expected, mineralizable N was however greatest for the residue return treatment. Crop residues normally contain large reserve of nutrients together with C as an energy source for soil microorganisms. Thus, the addition of crop residues promotes microbial activity and the breakdown of crop residues with subsequent mineralization of nutrients. We observed greater mineralizable N in soil under legume-based cropping system. Legumes normally contain more N than cereals and the C/N ratio of legume residue is lower than the cereal. Thus, this was likely a result of crop residues with lower C/N ratios in legume (mungbean) than in cereal (wheat, corn) residue (Hulugalle, 2000). Incorporation of crop residues with high C/N ratios may cause immobilization in the short-term, but long-term potential for N mineralization is enhanced (Fosu *et al*., 2007), thus increasing the potential N supply to subsequent crops.

Microbial biomass C and N: The results showed that microbial biomass-C (MBC) and –N (MBN) were greater in NT than in the CT treatment (Table 4). Averaged across residue treatments and cropping sequences, MBC were 464 µg g^{-1} soil in the CT and 420 µg in NT treatment. Similarly, MBN were 54.7 µg g^{-1} soil in the CT and 46.8 µg in NT treatment. Although the impact of NT on MBC and MBN was not significant statistically, MBC was 10.44 % and MBN 16.87 % greater in NT than in CT treatments. Crop residue return significantly increased MBC and MBN over the residue removed treatment (Table 4). Overall, residue increased MBC by 17.16 % and MBN by 23.72 %. Similarly, crop rotation significantly increased MBC and MBN (Table 4). We observed that WC system increased MBC by 11.33 % and MBN by 16.83 % over the WF system.

The impact of legume-based rotation on microbial biomass was more substantial. Wheat-mungbean rotation increased MBC by 42.20 % and MBN by 60.15 %.

Table 3. Mineralizable N as influenced by tillage, crop residues and cropping sequences.

	Mineralizable N (ug g^{-1} soil in 10 days)
No-tillage	12.40
Tillage	11.18
% increase over tillage	-9.86 %
-residue	13.57
+residue	10.02
% increase over -residue	35.45
Wheat-fallow (WF)	5.21
Wheat-corn (WC)	9.30
Wheat-mung (WM)	20.87
% increase by WC over WF	78.54 %
% increase by WM over WF	300.7 %

Table 4. Microbial biomass-C (MBC) and -N (MBN) as influenced by tillage, crop residues and cropping sequences.

	MBC (ug g^{-1} soil)	**MBN (ug g^{-1} soil)**
No-tillage	420	46.8
Tillage	464	54.7
% increase over tillage	10.44 %	16.87 %
-residue	477	56.15
+residue	407	45.38
% increase over -residue	17.16 %	23.72 %
Wheat-fallow (WF)	375	40.40
Wheat-corn (WC)	417	47.20
Wheat-mung (WM)	533	64.70
% increase by WC over WF	11.33	16.83 %
% increase by WM over WF	42.20 %	60.15 %

The possible reason for increased microbial biomass in NT treatment could be due to the fact that soil organic matter and crop residues are not subjected to rapid degradation in soil under NT system and hence gradually promote the accumulation of SOM in soil. Where there is more organic matter, there is likely to be more microbial biomass because organic matter serves as a source of energy for soil microorganisms. Significantly positive correlation between soil microbial biomass (MBC, MBN) and SOC have been reported by Wright *et al.*, 2005). We also observed that MBC was significantly related to SOC (r = 0.63) and TN (r = 0.95). Similarly, MBN was significantly related to SOC (r = 0.69) and TN (r = 0.95). Similar to our results that residue management and tillage influence SOM accumulation and microbial community dynamics in addition to C sequestration has also been reported (Shah *et al.*, 2003a). Changes in microbial biomass occur from the interactions of tillage, organic matter, soil moisture, pH, temperature, aeration and substrate availability (Feng *et al.*, 2003; Lodhi *et al.*, 2009). Microbial biomass responds quickly to changes in soil management and is often used as an indicator of soil quality (Biederbeck *et al*., 2005).

Conclusions

This study has shown that NT, residue return and cropping intensity increased SOC, TN, MBC and MBN. Microbial biomass C and MBN were significantly related to SOC and TN. Mineralizable N was also related to TN and SOC, but the relationship was much stronger with TN than SOC. Our results suggest that no-tillage is better for the accumulation of organic matter in soil in the rain-fed agriculture. Similarly, the return of crop residues and inclusion of legume in the cropping system promotes the soil organic fertility and is therefore recommended for rain-fed farming.

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