Soil & Environ. 29(1): 53 - 60, 2010
www.se.org.pk
Online ISSN: 2075-1141
Print ISSN : 2074-9546

Impact of cropping patterns and fertilizer treatments on the organic fertility of slightly eroded Pirsabak soil series in NWFP, Pakistan

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Abstract

This study was undertaken as a part of soil fertility management of eroded soils in NWFP, Pakistan. The study was started in summer 2006 and continued for four consecutive crop seasons till winter 2007, in District Swabi, NWFP, Pakistan. Soil fertility status of the experimental site was determined before the start of the experiment. The experiment was laid out in a factorial split plot design using two factors viz cropping patterns and fertilizer treatments. The cropping patterns included maize-wheat-maize rotation, maize-lentil-maize rotation and maize-wheat+lentil intercrop-maize rotation and these were kept in main plots whereas the fertilizer treatments included control, 50% NP, 100% NPK and 20 t ha^{-1} farmyard manure integrated with 50% N and 100% PK as mineral fertilizers which were placed in sub plots. Fertilizers were applied for four seasons continuously. At the end of winter 2007, soil samples from two depths (0-20 cm and 20-40 cm) were collected from each plot and analyzed for microbial biomass carbon (MBC) at day 3, day 6 and day 10 incubation periods, total nitrogen (TN), microbial biomass nitrogen (MBN), and mineralizable nitrogen (MN). Results showed significant improvement in organic fertility of soil with fertilizer addition and cropping patterns. Combined application of organic and inorganic fertilizers (20 t ha^{-1} farmyard manure integrated with 50 % N and 100 % PK) showed 55, 25, 18 and 61 % increase in total N, MBN, MN, and MBC after 10 days incubation period over the control, respectively, in the surface soil whilst 100% NPK showed 44, 15, 6 and 45 % improvement over the control treatment for the same parameters in surface soil. Data further showed 43, 23, 19 and 60 % increase in the corresponding microbial parameters in combined organic and inorganic fertilizer treatment over the control treatment in sub soil whilst 100% NPK showed 39, 20, 10 and 54 % increase in TN, MBN, MN and MBC over the control in sub soil. The cropping patterns having cereal-legume rotation also improved organic soil fertility and showed 27 and 13% more total N and MBC after 10 days incubation period over the cereal-cereal rotation respectively and the improvement in MBN and MN in cereal-legume rotation over cereal-cereal rotation was non significant in surface soil. In the sub-surface soil cereal-legume rotation improved TN, MBN, MN and MBC by 9, 6, 8 and 28 % over the cereal-cereal rotation. It was concluded that there is sufficient potential to improve soil organic fertility in Pirsabak soil series, the restoration of which on sustained basis would require at least 50% N from the organic sources. Moreover legumes must be included in the traditional cereal-cereal cropping pattern to further improve the N input and organic fertility of these soils.

Keywords: Cropping patterns, farmyard manure, legumes, microbial biomass carbon, microbial biomass nitrogen, eroded soil

Introduction

Over two-thirds of world's 1.3 billion impoverished people live in rural areas and rely on agriculture for a significant part of their livelihoods. Increasing human population and changes in dietary habits are causing an increased demand for food and fiber. In such areas livestock play an important role in both sustainability and intensification of agricultural productivity (Reddy *et al*., 2003). However, due to the shortage of energy sources in such areas, the byproducts of livestock (dung, urine and straw bedding etc) are used to meet the household energy demand whilst the crop demand for nutrient are met from only chemical fertilizers. Use of chemical fertilizers result in a steady decline in soil organic fertility and loss of soil productivity. The same is true in Pakistan, where the main attention has been focused on maximizing yield using nitrogenous chemical fertilizers. This has resulted in a steady decline in soil organic matter. The decline in soil organic matter has changed the natural balance of nutrient cycling in soil. According to Yoo *et al*. (1974), imbalanced use of chemical fertilizers, along with being an economic loss to the farmers, may bring about deterioration in the soil environment. Chemical fertilizers applied to soils can provide crops with specific nutrient elements, but not with

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all the essential elements they need. On very poor soils, the successes of fertility rehabilitation schemes require recovery of soil organic matter and mineral nutrient cycling in the soil. Soil fertility and crop productivity of such soils might be ameliorated by employing soil organic matter enhancing management practices, such as use of FYM (Banning *et al*., 2008).

The present experiment site has been characterized as slightly eroded being suffered from the effects of past soil erosion. The imbalanced use of fertilizers and the traditional cereal-cereal cropping system has not been able to restore the natural fertility of these soils. To increase the crop production and farm income on sustainable basis, these lands require careful handling and land management on scientific lines. Application of organic and mineral fertilizers in integrated form not only enhance crop production but also offers a chance to the farming system for restoring soil fertility on sustained basis. Moreover, inclusion of legumes in crop rotations protect the fragile soil surface and may even counteract erosive forces by restoring the organic matter content and organic fertility of these soils. This would also help to restore the natural fertility of these soils. This study was carried out for two years to investigate for adopting cost effective soil fertility improvement and crop productivity restoration measures on the slightly eroded Pirsabak soil series in District Swabi, NWFP, Pakistan.

Material and Methods

The experiment was conducted on farmer's field for two years to investigate the cost effective fertility restoration measures on the slightly eroded Pirsabak soil series in District Swabi, NWFP, Pakistan. The experiment was started in summer 2006 and was continued for four seasons continuously till winter 2007. Pre-sowing soil fertility characteristics are given in Table 1.

Two factorial split plot design was used where cropping patterns were kept in main plots and fertilizer treatments in sub plots. Fertilizer treatments included T1 (control), T2 (50 % NP also called farmer's practice), T3 (100 % NPK) and T4 (20 t ha^{-1} farmyard manure integrated with 50 % N and 100 % PK as mineral fertilizers). Cropping patterns included C1 (maize-wheat-maize rotation), C2 (maize-lentil-maize rotation) and C3 (maize-wheat + lentil intercrop-maize rotation). Well rotten FYM was obtained from NWFP Agricultural University Dairy Farm well before each season application and applied one month before field cultivation.

In case of 100 % NPK, the fertilizer N was applied in two splits. Soil was cultivated each season with respective crop rotation in each cropping pattern from summer 2006 to winter 2007. At the end of the experiment, soil samples from 0-20 cm and 20-40 cm depth were collected from each treatment plot and were analyzed for soil microbial properties.

Microbial biomass C and N were determined by the method described by Jenkinson and Powlson (1976). Twenty gram soil sample was fumigated with chloroform to kill all microbes and then inoculated with 1g fresh un-fumigated soil. This was then incubated for 3, 6 and 10 days in the presence of NaOH in a vial suspended inside the flask to trap the evolved CO_2. Twenty gram of the same soil sample was taken in another beaker without chloroform fumigation and incubated for the same time in the presence of NaOH to trap the CO_2 evolved. Microbial biomass C was determined by using the equation; Biomass C = (Fc-Ufc)/Kc Where Fc = CO_2 produced from fumigated soil, Ufc = CO_2 produced from un-fumigated soil, Kc = 0.45 (Jenkinson and Ladd, 1981).

The amount of soil microbial biomass N was calculated by using the following equation; Biomass N = (Fn-Ufn)/Kn Where Fn = NH_4-N mineralized during 10 days from fumigated soil, Ufn = NH_4-N mineralized during 10 days from un-fumigated soil, Kn = 0.54 (Jenkinson, 1988). Mineralizable N estimated as the difference of mineral N determined at day 0 before incubation and at day 10 after incubation by using Kjeldhal distillation procedure. Total N in soil was determined by the Kjeldhal method of Bremner (1996). Organic matter in soil samples was determined by the Walkely-Black procedure (Nelson and Sommers, 1996). The data was statistically analyzed using RCB split-plot design (Gomez and Gomez, 1984). The treatment means were compared using least significance difference (LSD) test of significance at 5 and 1 % level of significance according to Steel and Torrie (1980).

Results

Microbial biomass carbon (MBC)

Results (Table 2) showed that soil microbial biomass carbon (MBC) was significantly improved with fertilizers addition. The maximum MBC was recorded in the treatment (T4) receiving mixed application of farmyard manure (20 t ha^{-1}) and mineral fertilizers (50% N and 100% PK) at all incubation intervals and in both depths (252.5, 216.6 and 143.1 µg g^{-1} in surface soil and 157.5, 146.0 µg g^{-1} and 117.7 µg g^{-1} in sub-surface soil at 3, 6 and 10 day incubation interval, respectively). T4 was followed by T3 (100 % NPK) whist the control plot had the lowest MBC amongst the fertilizer treatments at all incubation intervals (Table 2). The cumulative MBC content during the 10 days incubation period showed 27, 45 and 61 % increase in surface (0-20 cm) and 45, 54 and 60 % increase in the sub-surface (20-40 cm) soil in the 50 % NP, 100 % NPK and combined use of FYM (20 t ha^{-1}) with 50 % N and 100 % PK from mineral fertiizers treated plots, respectively, over the control. Data in Table 2 further showed that MBC in all the fertilizer treatments was maximum during day 3 incubation interval in both soil depths and it showed a gradual decrease with increasing the incubation time. Therefore MBC at different incubation intervals was found in the following order; day 3 > day 6 > day 10.

pattern effect on MBC in sub-surface (20-40 cm) soil was significant (P<0.05) at day 10 incubation interval while it was non-significant at day 3 and day 6 incubation interval. Again C_2 (cereal-legume rotation) produced significantly higher MBC over C_1 (cereal-cereal rotation). In sub-surface soil, cereal-legume intercrop also recorded significantly higher MBC over cereal-cereal rotation. However, the cumulative MBC content at the 10 days incubation period showed that the cropping pattern effect on the MBC in the surface and sub-surface soil was non significant. It was also noted (Table 3) that all the cropping patterns recorded maximum MBC at day 3 incubation interval in both soil depths which gradually decreased at day 6 and day 10 incubation intervals.

Table 1. Physico-chemical properties of the experimental site before sowing

Property	Unit	Mean Values (0-20 cm)	Mean Values (20-40 cm)
Clay	%	26.1	28.0
Silt	%	59.4	59.8
Sand	%	14.5	12.2
Textural Class	…….	Silt Loam	Silt Loam
pH (1:5)	……	8.0	8.1
EC. (1:5)	dS m^{-1}	0.22	0.16
Organic matter	g kg^{-1}	9.0	6.2
Lime ($CaCO_3$)	%	6.2	7.5
Total N	g kg^{-1}	0.40	0.22
Mineral N.	mg kg^{-1}	15.5	12.5
AB-DTPA extractable P	mg kg^{-1}	0.95	0.25
AB-DTPA extractable K	mg kg^{-1}	88	76

Table 2. Effect of fertilizer treatments on soil organic fertility

Parameter	T1	T2	T3	T4	LSD (<0.05)	T1	T2	T3	T4	LSD (<0.05)
	0 - 20 cm					20 - 40 cm				
MBC (μg g^{-1})										
day 3	110.9 c	144.6 bc	183.3 b	252.5 a	47.1	74.7 c	120.1 b	144.9 ab	157.5 a	36.5
day 6	84.3 c	109.8 bc	148.3 b	216.6 a	52.7	53.2 b	109.7 b	131.8 b	146.0 a	41.9
day 10	43.3 d	072.2 c	102.3 b	143.1 a	22.7	39.6c	73.6 b	87.1 b	117.7 a	18.9
TN (g kg^{-1})	00.6 d	000.8 c	1.2 b	1.4 a	0.1	0.58 c	0.80 b	0.96 a	1.03 a	0.12
BN (mg kg^{-1})	39.1 c	047.6 ab	45.2 bc	54.4 a	8.1	34.6 b	41.5 ab	44.4 ab	45.6 a	10.0
MN (mg kg^{-1})	41.7 b	044.1 b	44.5 b	50.7 a	3.4	37.4 c	41.0 bc	41.6 b	46.4 a	3.7

MBC: Microbial biomass C, TN: Total N, BN: Biomass N, MN: Mineralizable N
Control (T1), 50 % NP (T2), 100 % NPK (T3), 20 t FYM + 50 % N + 100 % PK (T4)
Means followed by the same letters are not significantly different at the P<0.05 level
*Data has been pooled from 3 cropping patterns and 3 repeats at each treatment application

Cropping patterns significantly affected microbial biomass carbon at day 3 in surface soil whilst at day 6 and day 10 incubation periods, it was non significant. Cropping patterns having legumes in crop rotation (C2) showed significantly higher (23 %) MBC over the cereal-cereal rotation at day 3 incubation period in surface soil. Cropping

Table 3. Effect of cropping patterns on microbiological properties of surface soil (0-20 cm)

Parameters	Maize-Wheat-Maize	Maize-Lentil-Maize	Maize-Intercrop-Maize	LSD (<0.05)	Maize-Wheat-Maize	Maize-Lentil-Maize	Maize-Intercrop -Maize	LSD (<0.05)
	0 - 20 cm				20 - 40 cm			
MBC (μg g^{-1})								
Day 3	153.8 b	199.0 a	165.6 ab	33.5	114.4	136.6	121.9	ns
Day 6	147.5	145.1	126.6	ns	104.9	133.9	91.7	ns
Day 10	78.7	91.2	100.8	ns	53.5 c	110.3 a	74.7 b	16.8
TN (g kg^{-1})	0.9 b	1.2 a	0.9 b	2.5	0.8	0.9	0.8	ns
BN (mg kg^{-1})	47.0	49.4	43.1	ns	39.4	42.6	42.6	ns
MN (mg kg^{-1})	44.7	46.4	44.7	ns	40.0	43.4	41.4	ns

MBC: Microbial biomass C, TN: Total N, BN: Biomass N, MN: Mineralizable N
Means followed by the same letters are not significantly different at the P<0.05 level
*Data has been pooled from 4 fertilizer treatments and 3 repeats at each cropping patterns

Total nitrogen

Results revealed that fertilizer treatments significantly (P<0.01) increased total N content in both the surface (0-20 cm) and sub surface (20-40 cm) soil. The highest total N was recorded in T4 which was treated with mixed application of farmyard manure (20 t ha^{-1}) and mineral fertilizers (50% N and 100% PK). Thus the total N content affected by fertilizer treatments were in the order T1<T2<T3<T4 in both the surface and sub-surface soil and their percent increase over the control treatment was 20, 44 and 55 % in the surface soil and 27, 39 and 43 % in the sub-surface soil in T2, T3 and T4, respectively (Table 2).

Results further revealed that cropping pattern significantly affected total N in surface soil (0-20 cm) whilst its effect in the sub-surface soil (20-40 cm) was non-significant. The maximum total N was recorded in cereal-legume rotation (C2) in both the surface and sub-surface soil (Table 3) which was 27 and 10 % higher, respectively, over the cereal-cereal rotation. The increase in total N in cereal-legume intercrop over cereal-cereal rotation was non-significant in both depths. It was further noted that the interaction between fertilizer treatments and cropping pattern was significant (P<0.05) in surface soil and non-significant in the sub-surface soil.

Microbial biomass nitrogen (MBN)

Data analysis regarding microbial biomass nitrogen (MBN) revealed that fertilizer treatment significantly (P<0.05) increased microbial biomass nitrogen (MBN) in both the surface and sub-surface soils. Mixed application of farmyard manure (20 t ha^{-1}) and mineral fertilizers (50 % N and 100 % PK) in T4 recorded the maximum MBN in both the surface and sub-surface soil. Microbial biomass nitrogen (MBN) also showed improvement with addition of mineral fertilizers (Table 2). Thus with fertilizer treatments, MBN increase over the control treatment was 18, 14 and 28 % in T2, T3 and T4, respectively, in the surface soil and 17, 22 and 24 % in T2, T3 and T4, respectively, in the sub-surface soil.

Data analysis further revealed that cropping pattern effect on MBN was non significant both in surface (0-20 cm) and sub-surface (20-40 cm) soil. Cereal-legume rotation showed a non-significant increase of 5 and 7 % over the cereal-cereal rotation in surface and sub-surface soil, respectively (Table 3).

Mineralizable nitrogen (MN)

Results further revealed that fertilizer treatments significantly (P<0.01) increased the mineralizable N both in surface and sub-surface soil (Table II). Again T4 (mixed application of farmyard manure and mineral fertilizers) recorded the maximum mineralizable N in both the surface and sub surface soils. Mineral fertilizers alone also showed increase in mineralizable N in both soil depths. Thus the percent increase in fertilizer treatments over the control treatment was 5, 6 and 17 % in T2, T3 and T4, respectively in the surface soil and 9, 10 and 20 % in T2, T3 and T4, respectively in the sub-surface soil (Table 2).

The cropping pattern effect on mineralizable N was statistically non-significant in both depths. Yet C_2 (cereal-legume rotation) recorded the maximum mineralizable N amongst the cropping patterns which was 4 and 8 % increase in mineralizable N over the C_1 (cereal-cereal rotation).

Discussion

Fertilizer significantly increased soil microbial biomass C in both the surface and sub-surface soil as compared to the control treatment whereas the mixed application of farmyard manure and mineral fertilizers recorded the maximum increase in soil microbial biomass C. These results are supported by Vineela *et al*. (2008). Rabary *et al*. (2008) also reported higher microbial biomass and soil respiration from the plots receiving combined use of farmyard manure and mineral fertilizers. The increase of soil microbial biomass C with each increment of mineral fertilizes might be explained by the increased above and below ground plant biomass that increased soil organic matter and provided energy source for soil microbes to flourish as compared to the control plot (Goyal *et al*., 2006). Furthermore, addition of mineral fertilizers increased the rooting depth that caused an increase of soil organic C with depth (Lorenz and Lal, 2005) and hence soil microbial biomass C increased in sub-surface soil of the fertilized plots as compared to the sub-surface soil of the control plot. Moreover, the surface application of N fertilizer might have acted as a starter dose to increase the microbial processes in fertilized plots as compared to the control plot. Simek *et al*. (1999) also found that the addition of organic manure and the smallest amounts of inorganic fertilizers led to significant increases in the microbial biomass of the soils as compared to the unfertilized one. Results further showed that with increasing soil depth, soil microbial biomass C decreased. This might be due to the reduced aeration and increased soil compaction (data not shown) that might have reduced soil microbes to flourish deep into the soil. It was also noted from the data that with the increased incubation period, soil microbial biomass C showed a decreasing trend. This might be attributed to the decreasing content of the decomposable microbial cells previously killed by the fumigation (Jenkinson and Powlson, 1976).

Cropping patterns effect at day 3 incubation interval was significant in the surface soil where the cereal-legume rotation recorded significantly higher content of microbial biomass C. Since the legumes provide easily metabolizable N rich leguminous organic matter (Giller, 2001) which is easily attacked by micro-organisms (Warman and Cooper, 2000) thereby increasing microbial activity in legume plots at the initial days of incubation and resulted more soil microbial biomass C in cereal-legume rotation as compared to cereal-cereal rotation (Collins *et al*., 1992). As the easily metabolizable N rich organic matter got exhausted, the effect of cropping pattern became non-significant with increased period of incubation. In the sub-surface soil with low level of energy source (soil organic matter), microbial processes took time to establish and were non significant at day 3 and day 6 incubation intervals but became significant at day 10 incubation interval. A number of scientists like Kirchner *et al*. (1993), Campbell *et al*. (1997), Martyniuk and Wagner (1978) supported higher microbial parameters in legume based cropping pattern while the others like Campbell *et al*. (1991), Shah and Khan (2003) argued that higher microbial parameters in legume based cropping pattern might be due to the greater amount of organic C, the legume return to the soil.

Soil total N content showed significant increase with increasing fertilizer dose applied to the soil and the highest total N was found in the plots treated with farmyard manure combined with 50% N and 100% PK in both depths. These results are in line with those of Yang *et al*. (2007) who reported that application of high amounts of FYM resulted in C, N and S accumulation in bulk soil. Simek *et al*. (1999) also reported that soil N content for all fertilized plots was greater as compared to the control. Laboratory analysis of farmyard manure for four seasons showed total N content of 10.6 g kg^{-1} on the average. Lupwayi *et al*. (2000) reported that along with other nutrient elements, manure contains on average 18.3 g N. Addition of farmyard manure continuously for four seasons increased the total N content by 42% in the surface soil (0-20 cm) at the experimental site. An increase in total N content in sub-soil was also noted on similar pattern. The findings of Purakayastha *et al*. (2008) also indicated 31% increase in total N content with the combined use of NPK and farmyard manure in 0-15 cm soil layer. The increase in total N with mineral fertilizers alone as compared to the control plot might be due to more crop productivity that returned more plant parts to the soil as compared to the control plot (Goyal *et al*., 2006).

With the inclusion of legumes in crop rotation, the crop biomass that is left back in the field contain nitrogen rich residues (Ussiri *et al*., 2006) due to the biologically fixed N in the legume root nodules (Giller, 2001; Wartianen *et al*., 2008) which increased the total N content in soil as compared to the crop rotation containing sole cereals. Similar results were also reported by Shafi *et al*. (2006) who attributed the increase in total N in soil to the carry over effect both from fertilizer application in organic and inorganic form and from the cropping pattern effect including legumes in rotation. Research conducted by a number of scientists supported the role of legumes in crop production. Upon his research findings, Bhattacharyya *et al*. (2008) concluded the legume-cereal rotation as one of the profitable cropping systems.

Results revealed that fertilizer application increased microbial biomass N, and mineralizable N in both the surface and sub-surface soils. Again, the maximum microbial biomass N and mineralizable N were recorded in mixed application of farmyard manure and mineral fertilizers in both soil depths. These findings confirmed the findings of Shresta *et al*. (2009) who reported increased biomass content with manure application. The addition of organic and inorganic fertilizers in integrated form increased soil organic matter content that provide source of carbon and other nutrients for microbes (Courtney and

Mullen, 2008) and altered the biochemical properties of soil by increasing potentially mineralizable N and microbial biomass C and N (Monaco *et al*., 2008). Goyal *et al*. (2006) also revealed that the amount of soil organic matter and mineralizable C and N were higher in plots receiving organic treatments.

It was also noted that cereal-legume rotation had highest microbial biomass N and mineralizable N as compared to cereal-cereal rotation and cereal-legume intercrop. This might be attributed to more N_2 fixation and N released from organic matter decomposition and subsequently incorporated into microbial biomass. These findings are in line with Jensen (1994) who reported a sharp decrease in ^{15}N during organic matter decomposition which was incorporated into microbial biomass. The nodulated roots and above ground residues, after the crop harvest, represent a valuable source of N (Giller, 2001) and soil organic matter (Campbell *et al*. (1991) the decomposition of which provide a meaningful contribution to the N economy of soil (Glasener *et al*., 2002). Rego and Seeling (1996) reported an increase in mineralizable N in a rotation with pegeonpea intercrop along with increase in total N in surface (0-15 cm depth). Higher biomass N in surface soil at the experimental site (Pirsabak series) might be due to more legume biomass produced which might have fixed more N_2 from the atmosphere. This might also be due to greater organic C content returned to the soil by legumes crop in rotation (Campbell *et al*., 1991; Shah and Khan, 2003). Legume based cropping pattern generally supports higher contents of soil microbial parameters including microbial activity, microbial biomass carbon and N and microbial number (Collins *et al*., 1992; Kirchner *et al*., 1993; Campbell *et al*., 1997).

Conclusion

The study concluded that mixed application of farmyard manure and mineral fertilizers improved the organic fertility of the slightly eroded Pirsabak soil series. Mineral fertilizers alone also showed improvement in soil organic fertility as compared to the control plot. The cereal-legume crop rotation also showed improvement in organic soil fertility of the eroded soils. A strategy of the combined use of fertilizers both from the organic and inorganic sources and cropping patterns including legumes in crop rotation must be adopted for several crop seasons continuously in order to improve the soil fertility on sustained basis.

Acknowledgement

The authors are thankful to the Higher Education Commission of Pakistan for financial support to carry out the research project.

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