Soil Environ. 35(2): 194-206, 2016
www.se.org.pk
Online ISSN: 2075-1141
Print ISSN: 2074-9546

Recovering soil health of eroded lands through fertilizers and crop rotation

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Abstract

Soil health is important for the sustainable development of terrestrial ecosystem. The soil health and fertility of eroded lands can be restored and improved through integration of farm yard manure (FYM) with mineral fertilizers as well as incorporating legumes in the cropping system. This study was undertaken to assess the effects of integrated use of fertilizers and inclusion of a legume in crop rotation on soil microbial attributes on eroded land within a three years long field experiments at three locations in north western Pakistan. Three locations were Thana, Kabal and Matta; two croppings were wheat-mungbean and wheat-maize; and three fertilizer treatments were farmer's practice (N at 60 and P_2O_5 at 45 kg ha^{-1}), recommended mineral fertilizers (N at 120, P_2O_5 at 90, K_2O at 60 and Zn at 5 kg ha^{-1}), and recommended mineral fertilizers + FYM (N at 120, P_2O_5 at 90, K_2O at 60, Zn at 5 kg ha^{-1} + 20 t FYM ha^{-1}). Soil microbiological properties were measured after 5 cycles of cropping (3 winter and 2 summer) in 2013. The effect of fertilizer treatments on soil microbiological properties was significant at all the three sites, while the effect of cropping system was variable. The interactive effects were also variable. Soil receiving organic fertilizer (FYM) along with mineral NPK showed over 120% improvement in microbial biomass C and over 50% improvement in N fertility of eroded lands. Similarly, inclusion of legume in crop rotation improved soil microbial biomass C and N fertility by 31%. Regression analysis revealed that soil microbiological properties were determining factor for increased yield of wheat crop. Thus integration of FYM with mineral fertilizers and incorporation of a legume in crop rotation helps improve soil health and N fertility of eroded lands.

Keywords: Soil health, FYM, mineral fertilizers, crop rotation, microbial biomass

Introduction

Soil health is important for the sustainable development of terrestrial ecosystem. The soil health of eroded lands can be improved and fertility restored through integrated use of organic and mineral fertilizers and inclusion of legumes in the cropping system. The sustainability of any agriculture system depends on to optimize the inputs and output balance of nutrients and restoring soil fertility (Shah *et al*., 2010b; Muhammad *et al*., 2010). One way of achieving this objective is to ensure the return of nutrients that are removed from the soil. This can be achieved by cropping legumes as rotation crops, or adding mixed chemical and organic source of nutrients to replenish the nutrients deficiency (Shah *et al*., 2010b).

Increasing nutrient inputs into terrestrial ecosystems affect not only plant growth but also affect activity and composition of soil microorganisms. Nutrients are added to soils from several sources to replenish soil fertility for sustainable crop production. These sources include different forms of organic and mineral fertilizers or atmosphere. Atmospheric pool is exploited mainly through legumes which are capable of fixing large amount of nitrogen. Although all sources of nutrients increases soil fertility and crop growth, they have different effects on soil microbial composition and activities which have tremendous influence on soil health. Several long-term studies have shown that fertilization led to changes in the composition of soil microbial community (Peacock *et al*., 2001, Böhme *et al*., 2005, Hartmann *et al*., 2006, Langer and Klimanek, 2006, Zhong *et al*., 2010, Hu *et al*., 2011; Kirchmann *et al*., 2013). Organic fertilizers have shown substantial increases in soil fertility, microbial activity and crop growth (Groffman *et al*., 1987; Bullock, 1992, Lin *et al*., 2010; Černý *et al*., 2003; Shah *et al*., 2010; Šimon and Czakó, 2014; Luo *et al*., 2015). The application of manure which contains mineralizable and readily hydrolyzable C results in higher microbial biomass, microbial activity and microbial population (Hasebe *et al*., 1985; McGill *et al*., 1986; Ocio *et al*., 1991; Collins *et al*., 1992; Goyal *et al*., 1992; Chakraborty *et al*., 2010; Lin *et al*., 2010; Verde *et al*., 2014; Luo *et al*., 2015). The long term, fertilization of agricultural soil results in increased microbial biomass C, which is likely caused by associated increases in organic C due to higher crop productivity (Geisseler and Scow, 2014).

The effects of mineral fertilizers on microbiological properties have, however, shown inconsistent pattern. The application of mineral fertilizer either increased (Biederbeck *et al*., 1984; Kanazawa *et al*., 1988; Goyal *et al*., 1992), reduced (McGill *et al*., 1986; Omay *et al*., 1997) or had no or only marginal affected microbial community in soil (Campbell

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et al., 1991; Chakraborty *et al*., 2010; Luo *et al*., 2015). Černý *et al*. (2008) observed that the effects of mineral nitrogen fertilizers on the microbial biomass C and N were non-significant in rotation experiments but significant in experiments with continuous cultivation of maize over the eight years. Changhui *et al* (2014) reported that P addition significantly increased mineralization and the metabolic quotient (**q**CO_2) but there was no effect on microbial respiration, microbial biomass C (MBC) and microbial biomass N (MBN) during the growing seasons. However, N addition significantly increased mineralization, MBN, microbial respiration and **q**CO_2, decreased the ratio of MBC/MBN, and had no effect on soil MBC during the growing season in saline-alkaline grassland soil. Other studies have also found no or only small effects of mineral fertilization on soil microbial community composition (Esperschütz *et al*., 2007, Ogilvie *et al*., 2008 and Börjesson *et al*., 2012).

Integrated use of organic and mineral fertilizers have shown different effects on microbial communities. Combined application of organic and mineral fertilizers increased microbial biomass and activity both in the short- and long-terms. Chang *et al*. (2014) examined the long-term (12 years) effects of different kinds of organic fertilizers in combination with inorganic nitrogen (N) fertilizer on chemical and biological properties of soils in a field experiment and found that peat application led to the highest increase in soil organic carbon (SOC) content compared to compost and green manure; however, compost-treated soil had higher microbial population and higher microbial and enzyme activities, but the effects of both green manure and chemical N fertilizer on soil properties were similar. Juan *et al* (2008) reported that various soil microbial properties such as microbial biomass C&N as well as urease activity in treatments receiving both organic and mineral fertilizers compared to no fertilizer treatment in a 15-year long-term fertilizer experiment. Crop rotation with legumes is believed to improve microbiological as well as chemical properties of soil physical and chemical properties and increase nutrients availability (Wilson *et al*., 1982; Power, 1990; Aref & Wander, 1998; Shah *et al*., 2003; Shah *et al*., 2011). Inclusion of legumes in crop rotation have shown reduced C:N ratio in soil and increased mineralization which resulted in greater availability of plant nutrients (Karlen *et al*., 1994; Shah *et al*., 2010, Shah *et al*., 2011; Jannoura *et al*., 2014). Soil microbial community plays an important role in regulating nutrients availability in terrestrial ecosystems. Generally speaking, information on the impact of mineral fertilizers alone or in combination with farm yard manure (FYM) on soil microbial biomass is very limited particularly on marginal eroded lands whose soil fertility and crop productivity is very poor, and hence research is needed in this respect. We have assessed the influence of inorganic fertilizers alone and in combination with FYM under cereal- and legume-based crop rotations on microbial biomass-C and -N and microbial activity within a 3 years long field experiments established on eroded lands in the upper Swat Valley of Khyber Pakhtunkhwa, Pakistan. The results obtained are reported in this paper.

Materials and Methods

Experimental sites

This study was conducted within a three years long field experiments established at three locations on eroded fields in the upper Valley of the Swat River arising from Hindukash, Pakistan. The geo- and vernacular-positions, elevation, type of soil, taxonomic class and other important characetristics of soils of the experimental sites are given in Table 1.

Table 1: Location, soil series, taxonomic class and other important characteristics of soil (0-30 cm) of the experimental sites

Property	Thana	Kabal	Matta
Geo-position	34^0-36′-51″ N 72^0-05′-28″ E	34^0-45′-18″ N 72^0-15′-17″ E	34^0-56′-54″ N 72^0-23′-22″ E
Elevation (m)	796	888	1175
Vernacular position	3km from Thana on Null road	7 km from Kabal on Chakdara road	10 km from Matta on Biha road
Soil series	Burhan	Missa	Buner
Taxonomic class (USDA soil classification system)	Clayey, mixed, hyperthermic, UdicHaplustepts	Coarse silty, mixed, thermic, TypicDystrudepts	Coarse silty, mixed, thermic, TypicDystrudepts
Soil pH	7.80	7.81	7.76
Soil organic matter (%)	1.21	1.07	0.82
MB-C (μg g^{-1} soil)	348	280	234
MB-N (μg g^{-1} soil)	10.2	8.2	9.3
Bactera (x10 g^{-1} soil)	2.8	1.6	1.7
Fungi (x10 g^{-1} soil)	0.32	0.30	0.27

Field experiments

Composite soil samples at 0-30 cm were collected from each experimental site before starting the experiments and analyzed for important soil characteristics (Table I). Field experiments were commenced with wheat in winter 2010, and continued for 3 years till 2012/13 on same layout at all three sites. The experiment at each location was comprised of two cropping systems viz., wheat-maize-wheat (S_1) and wheat-mungbean-wheat (S_2) and three fertilizer treatments viz., 1) farmer's practice (N at 60 and P_2O_5 at 45 ha^{-1}, 2) recommended inorganic fertilizers (N at 120, P_2O_5 at 90, K_2O at 60 and Zn at 5 kg ha^{-1}), and 3) inorganic fertilizers + FYM (N at 120, P_2O_5 at 90, K_2O at 60, Zn at 5 kg ha^{-1} + 20 t farm yard manure (FYM) ha^{-1}) arranged in a split plot design with three replications. Cropping systems were assigned to main plots and fertilizer treatments to sub-plots. Nitrogen was applied in the form of urea, phosphorus in the form of single superphosphate, potash in the form of SOP (sulfate of potash) and Zn in the form of zinc sulfate. In winter, the sites were planted to wheat in November and harvested in May each year. In summer, the same sites were planted to maize (Azam variety) or mungbean (local variety) in early July and harvested in late September or early October each year. For this study, soil samples at 0-30 cm were collected from each treatment plot of all the three experimental locations after wheat harvest in May 2013 (after 5 cycles of cropping). The soil samples were kept in cool box to avoid microbial changes during transportation to laboratory. The soil samples were analyzed for required soil microbiological properties immediately after sampling or otherwise stored in refrigerator.

Measurement of bacterial and fungal population

Both bacterial and fungal populations were determined following dilution plate technique (Wollum II, 1982), and the colonies were counted after a week.

Microbial biomass (C and N)

Microbial biomass C and N were determined by using chloroform fumigation method as outlined in Horwath & Paul (1994). The difference in CO_2 evolved between fumigated and non fumigated samples was considered as microbial biomass C, and was calculated using the following expression:

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

Where F_c= CO_2 evolved in fumigated soil; U_{fc} = CO_2 evolved in un- fumigated soil; K_c= 0.45 (Jenkinson and Ladd, 1981). The CO_2 evolution in soil samples was measured by the technique followed in Shah *et al*. (2010). Similarly, the microbial biomass N was determined from the amount of mineral N produced in fumigated and un-fumigated samples during 10 days using the following expression:

$$\text{Biomass N} = (F_n\text{-}U_{fn})/K_n$$

Where F_n= Flush of NH_4-N in fumigated sample; U_{fm} = Flush of NH_4-N in un-fumigated sample; K_n = 0.54 (Jenkinson, 1988).

Mineralizable C and N

The amount of CO_2 produced in un-fumigated soil samples during 10 days was used to calculate the amount of mineralizable C. Similarly, the amount of mineralizable N was determined by subtracting the initial mineral N level in soil at day 0 from that obtained at day 10 in the un-fumigated soil (Shah *et al*., 2010).

Other soil analysis

Total mineral N (NH_4-N, NO_3-N) in soil samples was determined by the steam distillation method (Mulvaney, 1996), soil pH was measured in soil: water suspension (1:10) using pH meter (Thomas, 1996) and soil organic matter was determined by the modified Walkley-Black procedure (Nelson and Sommers, 1996).

Statistical analysis

The obtained data was analyzed using analysis of variance procedure. Treatment means were compared using least significant difference (LSD) test of significance according to Steel & Torrie (1980). Combined analyses of the data were done using the method of Gomez & Gomez (1984).

Results and Discussion

Soil Respiration

Data obtained on the rate of soil respiration during two days of incubation period exhibited significant ($P<0.05$) differences among fertilizer treatments but non-significant differences among cropping systems at all the three sites (Table 2). The interactive effect was non-significant for fertilizer treatments and cropping system but was significant for cropping systems and locations ($P<0.05$).The trend of soil respiration was similar at all the sites (Table 2). Although the effect of cropping systems was statistically non-significant, soil respiration was consistently greater for wheat-mung (CS2) than for wheat-maize (CS1) cropping system at all the three sites. These results indicated that legume (mungbean) involvement in cropping system increased soil respiration by 6.8% at Thana, 16.2% at Kabal and 17.3% at Matta site compared with cereal-cereal cropping system. In case of fertilizer treatments, the rate of soil respiration was significantly greater in treatment receiving mineral NPK fertilizers at recommended rate along with FYM at 20 t ha^{-1} (T3) compared with other treatments receiving only mineral NPK fertilizers at recommended rate (T2) or as farmer's practice (T1). However, differences in soil respiration between T1 and T2 were statistically non-significant. These results showed that the rate of respiration in T3 was 48 % greater over T1 and 44 % over T2 at Thana, 61% over T1 and 37% over T2 at Matta, and 54 % over T1 and 17 % over T2 at Kabal.

Table 2: Interactive effect of cropping systems and fertilizer treatments on rate of CO_2 evolution (ug g^{-1} soil day^{-1}) at three sites

Treatment	2nd day	5th day	10th day
Cropping system (CS)		**Thana**	
Wheat-maize	77	47	26
Wheat-mung	82	48	27
Significance (*p*<0.05)	**ns**	**ns**	**ns**
Fertilizer treatments (FT)			
NPK as farmers practice[1]	69	36	19
Recommended NPK[2]	70	45	22
Recommended NPK + FYM[3]	101	62	37
Significance (LSD *p*<0.05)	**12.2**	**11.5**	**10.8**
Cropping systems		**Kabal**	
Wheat-maize	65	42	22
Wheat-mung	75	46	27
Significance (*p*<0.05)	**ns**	**ns**	**ns**
Fertilizer treatments			
NPK as farmers practice[1]	55	31	18
Recommended NPK[2]	65	39	22
Recommended NPK + FYM[3]	89	61	33
Significance (LSD *p*<0.05)	**11.9**	**10.5**	**9.3**
Cropping systems		**Matta**	
Wheat-maize	134	70	28
Wheat-mung	157	113	24
Significance (*p*<0.05)	**ns**	**ns**	**Ns**
Fertilizer treatments			
NPK as farmers practice[1]	113	90	30
Recommended NPK[2]	149	77	19
Recommended NPK + FYM[3]	174	108	29
Significance (LSD *p*<0.05)	**16.4**	**23.6**	**19.2**

1Receiving fertilizers as per farmers practice i.e. N at 60 kg and P at 45 kg P_2O_5 ha^{-1}; 2Receiving mineral NPK fertilizers at recommended rate viz., N at 120, P_2O_5 at 90, K_2O at 60 and Zn at 5 kg ha^{-1}; 3Recommended mineral NPK as above plus FYM at 20 t ha^{-1}; ns = non-significant and * = significant (p <0.05).

The rate of soil respiration at day 5 was significantly affected by fertilizer treatments (P<0.05) at Thana and Kabal but unaffected at Matta. However, the effect of cropping system was non-significant at all the three sites. The interactions between fertilizer treatment x cropping system x location was significant (P<0.05). At Thana, treatment receiving recommended NPK along with FYM (T3) produced significantly higher rate of soil respiration over the treatment receiving fertilizers at farmer's practice (T1) with an increase of about 72%. Although differences between treatments receiving recommended NPK plus FYM and that receiving only recommended NPK were statistically non-significant, the rate of CO_2 evolution was 37% greater in former than in later treatment. At Kabal, the rate of soil respiration at day 5 was significantly greater in the treatment receiving both recommended NPK and FYM than the other two treatments. However, differences in soil respiration between treatments receiving NPK at recommended rate or at farmers practice were statistically non-significant.

At day 10, the effect of fertilizer treatments on soil respiration was non-significant (P<0.05) for all the three locations. The effect of cropping systems was significant (P<0.05) for Thana and Kabal but non-significant for Matta. The interaction of cropping systems x fertilizers treatments x locations for soil respiration was non-significant. At Thana, the significantly highest rate of soil respiration was recorded in the treatment receiving recommended NPK plus 20 t ha^{-1} compared with the other two treatments. The same trend was observed at Kabal as at Thana. However, at Matta, differences in soil respiration at day 10 between fertilizer treatments were statistically non-significant.

With respect to temporal variation in CO_2 production, the rate of CO_2 production decreased with incubation period in soils of all the three sites (Fig 1). It indicates that the easily degradable organic materials disappeared quickly during the first few days of incubation period. Cumulative CO_2 during the first 2 days of incubation showed that the effect of fertilizer treatments was significant (P<0.05) at all the three sites (Table 3). However, the effect of cropping system was significant (P<0.05) only at Matta. The interaction between fertilizer treatments x cropping system was also significant. Among fertilizer treatments, that receiving recommended NPK along with FYM produced significantly highest cumulative CO_2 than that receiving fertilizers either at recommended rate only or at farmers practice at all the three locations. Almost the same trend in cumulative CO_2 production was observed during 5 and 10 days of incubation periods at all the three sites. The interactions between all factors were non-significant both at day 5 and 10. Like our results, Jannoura *et al* (2014) also observed that organic fertilizers increased CO_2 production in soil, whereas the cropping system had no effects on these microbial indices. However, Changhui *et al* (2014) reported that P addition significantly stimulated mineralization rate and the metabolic quotient (**q**CO_2) but there was no effect on microbial respiration. The addition of N on other hand significantly increased microbial respiration and **q**CO_2

during the growing season in saline-alkaline grassland soil. Several other researchers have also reported that addition of organic fertilizers increased microbial activity including soil respiration in different lab incubation and field experiments (Groffman *et al*., 1987; Bullock, 1992, Lin *et al*.,2010; Černý *et al*., 2003; Shah *et al*., 2010; Šimon and Czakó, 2014; Luo *et al*., 2015).

Table 3: Interactive effect of cropping systems and fertilizer treatments on cumulative CO_2 (ug g^{-1} soil) in eroded land at three farmers fields

Treatment	2nd day	5th day	10th day
Cropping system (CS)		Thana	
Wheat-maize	154	295	425
Wheat-mung	165	309	444
Significance (*p*<0.05)	**ns**	**ns**	**ns**
Fertilizer treatments (FT)			
NPK as farmers practice[1]	138	246	341
Recommended NPK[2]	140	275	385
Recommended NPK + FYM[3]	202	388	573
Significance (LSD *p*<0.05)	26.4	33.5	42.6
	Kabal		
Cropping system			
Wheat-maize	130	256	366
Wheat-mung	150	288	423
Significance (*p*<0.05)	**ns**	**ns**	*****
Fertilizer treatments			
NPK as farmers practice[1]	110	203	293
Recommended NPK[2]	130	247	357
Recommended NPK + FYM[3]	178	361	526
Significance (LSD *p*<0.05)	**37.2**	**53.6**	**59.2**
	Matta		
Cropping system			
Wheat-maize	268	478	618
Wheat-mung	314	653	773
Significance (*p*<0.05)	*****	*****	*****
Fertilizer treatments			
NPK as farmers practice[1]	226	496	646
Recommended NPK[2]	298	529	624
Recommended NPK +FYM[3]	348	672	817
Significance (LSD *p*<0.05)	**27.5**	**43.8**	**41.7**

[1]Receiving fertilizers as per farmers practice i.e. N at 60 kg and P at 45 kg P_2O_5 ha^{-1}; [2]Receiving mineral NPK at recommended rate viz., N at 120, P_2O_5 at 90, K_2O at 60 and Zn at 5 kg ha^{-1}; [3]Recommended mineral NPK as above plus FYM at 20 t ha^{-1};ns = non-significant and * = significant (p <0.05).

Correlation studies showed that the relationship between CO_2 evolution and days of incubation was found negative for all the three sites with an r-value of -0.85 for Thana, -0.83 for Kabal and -0.94 for Matta. Regression equations were also developed to establish relationship between CO_2 production and days of incubation, and to predict CO_2 production from days of incubation (eq. 1 to 3) for different sites as follows:

Thana CO_2 (µg g^{-1} soil day^{-1}) =

$$87.84 - 6.47 * day \quad r^2 = 0.73 \quad \textbf{eq. 1}$$

Kabal CO_2 (µg g^{-1} soil day^{-1}) =

$$77.38 - 5.52 * day \quad r^2 = 0.68 \quad \textbf{eq. 2}$$

Matta CO_2 (µg g^{-1} soil day^{-1}) =

$$171.06 - 14.74 * day \quad r^2 = 0.89 \quad \textbf{eq. 3}$$

All the three equations show that there is a constant decrease in the rate of CO_2 production with each day of incubations at all the three sites.

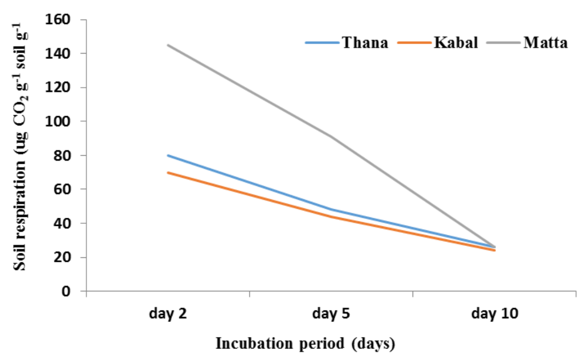

Figure 1: Rate of CO_2 evolution in soils of three locations (Thana, Kabal, Matta) during 10 days of incubation period

Mineralizable-C and -N

Data collected on the mineralizable C showed that the results were significant (P<0.01) for fertilizer treatments but non-significant (P<0.05) for cropping systems at all the three sites (Table 4). However, the interactive effects of cropping systems, fertilizer treatments and locations were non-significant. Although the effect of cropping systems was statistically non-significant, mineralizable C was consistently greater for wheat-mungbean (CS2) than for wheat-maize (CS1) cropping system at all the three sites. These results indicated that legume (mungbean) involvement in cropping system increased mineralizable C by 7.5% at Thana, 15.7% at Kabal and 25.1% at Matta site compared with cereal-cereal cropping system. With respect to the effect of fertilizer treatments, the significantly highest

Table 4: Interactive effect of cropping systems and fertilizer treatments on mineralizable-C (Min-C) & -N (Min-N), microbial biomass-C (MBC) & –N (MBN) (ug g^{-1}soil) in eroded lands at three farmers' fields

Treatment	Site	MinC	MinN	MBC	MBN
Cropping system	**Thana**				
Wheat-maize		113	22	364	11.6
Wheat-mung		122	27	473	18.0
Significance (*p*<0.05)		**ns**	**ns**	*****	**ns**
Fertilizer treatment (FT)					
NPK as farmers practice[1]		93	17	293	6.9
Recommended NPK[2]		105	24	375	12.9
Recommended NPK + FYM[3]		156	31	587	24.6
Significance (LSD *p* <0.05)		**37.6**	**8.2**	**57.8**	**9.1**
Cropping system	**Kabal**				
Wheat-maize		100	17	300	12.3
Wheat-mung		115	28	377	16.9
Significance (P<0.05)		**ns**	**ns**	*****	**ns**
Fertilizer treatment (FT)					
NPK as farmers practice[1]		80	15	217	7.6
Recommended NPK[2]		98	22	307	14.1
Recommended NPK + FYM[3]		144	31	491	22.1
Significance (LSD *p*<0.05)		**23.5**	**7.4**	**44.8**	**6.7**
Cropping system	**Matta**				
Wheat-maize		168	12	435	15.9
Wheat-mung		211	17	572	24.6
Significance (*p*<0.05)		**ns**	**ns**	*****	**ns**
Fertilizer treatment (FT)					
NPK as farmers practice[1]		176	8	377	13.5
Recommended NPK[2]		169	14	462	18.0
Recommended NPK + FYM[3]		223	22	671	29.3
Significance (LSD *p*<0.05)		**64.6**	**5.4**	**53.9**	**11.6**

[1]Receiving fertilizers as per farmers practice i.e. N at 60 kg and P at 45 kg P_2O_5 ha^{-1}; [2]Receiving mineral NPK at recommended rate viz., N at 120, P_2O_5 at 90, K_2O at 60 and Zn at 5 kg ha^{-1}; [3]Recommended mineral NPK as above plus FYM at 20 t ha^{-1}; ns = non-significant and * = significant (p <0.05)

mineralizable C was obtained for treatment receiving recommended mineral NPK plus FYM (T3) compared with treatments receiving only recommended NPK (T2) or at farmers practice (T1) at all the three sites. It was noted that the increases in mineralizable C with T3 at Thana were 67 % over T1 and 46 % over T2. At Kabal, the corresponding increases in mineralizable C by T3 were 80% over T1 and 45% over T2. Similarly, the increases in mineralizable C in T3 were % over T1 and % over T2. These results indicated that soils receiving recommended mineral fertilizers along with FYM sustain more mineralizable C than soils receiving only mineral fertilizers at recommended rate or lower.

The pattern of response of mineralizable N to both cropping system, fertilizer treatments or to their interactions was similar to that of mineralizable C. The effects of fertilizer treatments on mineralizable N were significant (P<0.05), while that of cropping systems was non-significant (Table 4). As with mineralizable C, mineralizable N was consistently greater for wheat-mung (CS2) than for wheat-maize (CS1) cropping system at all the three sites. These results indicated that legume (mungbean) involvement in cropping system increased mineralizable N by 28.3% at Thana, 61.5% at Kabal and 37.7% at Matta site compared with cereal-cereal cropping system.

Comparing fertilizer treatments with each other, it was observed that the highest mineralizable N was obtained for the treatment receiving both recommended mineral NPK and FYM (T3).It was observed that the extent of increase in mineralizable N in T3 over T1 (receiving fertilizers as per farmers' practice) and T2 (receiving only recommended mineral NPK) were 255% and 91% at Thana, 190% and 67% at Kabal and 117% and 63% at Matta, respectively.

Our results showed that integrating organic fertilizer (FYM) with mineral fertilizers or incorporating legume (mungbean) in crop rotation improved the level of mineralizable C and N in eroded lands at all the three sites. These results suggest that the addition of organic sources of fertilizers are important for restoring the fertility of eroded lands. Our results are in agreement with the findings of other researchers. Several workers have reported that the inclusion of legumes in crop rotation reduced the C:N ratio which resulted in more mineralization of C and N and availability of more plant nutrients (Karlen *et al*., 1994; Shah *et al*., 2010, Shah *et al*., 2011; Jannoura *et al*., 2014). Similarly organic fertilizers have increased microbial activity several folds which in turn enhanced the availability of nutrients such as N, P, K, Ca, Mg, and micronutrients (Groffman *et al*., 1987; Bullock, 1992, Černý *et al*., 2003; Lin *et al*., 2010; Shah *et al*., 2010; Šimon and Czakó, 2014; Luo *et al*., 2015). Jannoura *et al* (2014) observed that organic fertilizers increased C mineralization but cropping systems had no effects on C mineralization. Changhui *et al* (2014) reported that addition of P and N fertilizers significantly stimulated mineralization rate during the growing season in saline-alkaline grassland soil. Many other researchers have also reported that addition of organic fertilizers increased C mineralization in different lab incubation and field experiments (Groffman *et al*., 1987; Bullock, 1992, Černý *et al*., 2003; Lin *et al*., 2010; Shah *et al*., 2010; Šimon and Czakó, 2014; Luo *et al*., 2015).

Microbial biomass –C and -N

Data obtained on microbial biomass-C as affected by cropping systems and fertilizer treatments showed that the effects of both fertilizer treatments and cropping systems were significant ($P<0.05$) at all the three sites (Table 4). The interactive effect of cropping system x fertilizer treatments was also significant. The results showed that microbial biomass C was significantly greater for wheat-mung (CS2) than for wheat-maize (CS1) cropping system at all the three sites. These results indicated that legume (mungbean) involvement in cropping system increased microbial biomass C by 29.9% at Thana, 25.7% at Kabal and 31.2% at Matta site compared with cereal-cereal cropping system.

The trend of fertilizer treatments effect at all the three sites was almost identical. All the three fertilizer treatments were significantly different from one another at all the sites. The significantly highest microbial biomass-C was found in treatment receiving FYM in integration with mineral NPK (T3).The microbial biomass-C in T3 was 100 % greater over treatment receiving fertilizers as per farmers practice (T1) and 57% over treatment receiving only mineral NPK (T2) at Thana. The corresponding increases were 126% over T1 and 60% over T2 at Kabal, and 78% over T1 and 55% over T2 at Matta by the T3 treatment.

The effect on microbial biomass-N (MBN) was somehow different than on microbial biomass-C (MBC). The effect of fertilizer treatments on MBN was significant ($P<0.05$) but that of cropping system was non-significant at all the three sites (Table 4). Although the effect of cropping system was statistically non-significant, microbial biomass N was consistently greater for wheat-mungbean (CS2) than for wheat-maize (CS1) cropping system at all the three sites. It was observed that legume (mungbean) involvement in cropping system increased microbial biomass N by 55.2% at Thana, 37.4% at Kabal and 54.7% at Matta site compared with cereal-cereal cropping system. With respect to the effect of fertilizer treatments, the maximum MBN was obtained for treatment receiving organic fertilizer (FYM) in integration with mineral NPK (T3) compared with treatments receiving only mineral fertilizers at recommended rate (T2) or as per farmers' practice (T1) at all the three sites. It was noticed that the increases in MBN in T3 were 255% over T1 and 91% at Thana, 190% over T1 and 57% over T2 at Kabal, and 117% over T1 and 63% T2 at Matta. Our results are consistent with those of Jannoura *et al* (2014) who also observed significant increases in microbial biomass C & N with organic fertilizers but no significant increases with cropping system. The increase in microbial biomass C in organic fertilized treatments could be due to increase in organic C with organic fertilization. Changhui *et al* (2014) reported that P addition significantly stimulated mineralization rate but had no significant effect on MBC and MBN. Whereas N fertilizers significantly increased MBN but decreased the ratio of MBC/MBN, and had no significant effect on soil MBC during the growing season in saline-alkaline grassland soil. Geisseler and Scow (2014) thoroughly reviewed the literature with respect to the responses of soil microorganisms to mineral fertilizer using data from long-term fertilization trials in cropping systems and found that mineral fertilizer application led to a 15.1% increase in the microbial biomass above levels in unfertilized control treatments. However, the effect of mineral fertilizers on microbial biomass changes with soil environment. Mineral fertilizers tended to reduce microbial biomass C in soils with a pH below 5 in the fertilized treatment, it had a significantly positive effect at higher soil pH values (Geisseler and Scow, 2014).The input of N per se appeared to have not negatively affected microbial biomass C in cropping systems (Geisseler and Scow, 2014). Other studies have revealed that application of urea at about 100 kg N ha^{-1} caused changes in microbial community composition during 10 days of incubation; however, the effects were not sustained over the 91-day incubation period (Stark *et al.*, 2007). Similarly, in a greenhouse experiment with different soil types and crops, the use of ammonium nitrate had no significant effect on bacterial community structure in the rhizosphere (Marschner *et al*., 2001). Moreover, urea applications at around 90 kg ha^{-1} to no-till barley had no consistent effect on microbial biomass and bacterial functional diversity in two field trials (Lupwayi *et al*., 2011; Lupwayi *et al*., 2012). The application of increasing level of urea (120 kg N ha^{-1}), on the other hand tended to decrease microbial biomass and functional diversity (Lupwayi *et al*., 2011). Similarly, a 3-year cotton-cereal rotation experiment showed no significant differences in microbial PLFA profiles between treatments with urea-N additions of 20 or 130 kg ha^{-1} (Roberts *et al*., 2011). In other study, using 100 and 2000 μg N g^{-1} soil as potassium nitrate had no significant effect on microbial biomass compared to the unfertilized control in a laboratory incubation of soils collected under annual crops (Yevdokimov *et al*., 2008 and Yevdokimov *et al*., 2012). These results suggested that the effect of applications of mineral fertilizers on microbial biomass varies and seems to depend on environmental and crop management related factors.

Microbial population

Data obtained on bacterial population in soils showed that the effect of fertilizer treatments was significant ($P<0.05$) at Kabal but non-significant at Thana and Matta (Table 5). However, the effect of cropping system on bacterial population was significant ($P<0.05$) at all the three sites. The interactive effect of cropping system and fertilizer treatment was also significant. Our results showed that bacterial population was greatest for wheat-mungbean (CS2) than for wheat-maize (CS1) cropping system at all the three sites. It was observed that legume (mungbean) involvement in cropping system increased bacterial population by 28.0% at Thana, 42.1% at Kabal and 13.3% at Matta site compared with cereal-cereal cropping system. With respect to fertilizer treatments, the significantly highest bacterial population was recorded in treatment receiving organic fertilizer (FYM) in integration with mineral NPK (T3) compared with those receiving only mineral NPK at recommended rate (T2) or at farmers rate (T1) at all the three sites. It was noticed that the extend of increase in bacterial population with T3 was 170% over T1 and 109 %over T2 at Thana, 120 % over T1 and 50 % over T2 at Kabal, and 105 % over T1 and 55 % over T2 at Matta. Like bacterial population, fungal population was also significantly ($P<0.05$) influenced by the fertilizer treatments at the three sites. However, the effect of cropping system and their interaction with fertilizer treatments on fungal population was non-significant at all the three sites (Table 5). Thefungal population was generally greater for soil under wheat-mungbean (CS2) than under wheat-maize (CS1) cropping system at all the three sites. It was observed that the inclusion of a legume (mungbean) in the cropping system increased fungal population by 44.1% at Thana, 28.1% at Kabal and 30.2% at Matta site compared with continuous cereals rotation. With respect to fertilizer treatments, the trend of fungal population was almost similar at all the three sites. Treatment receiving organic (FYM) and mineral NPK (T3) was significantly different than that receiving only mineral NPK at recommended rate (T2) or as per farmers' practice (T1). However, differences between T1 and T2 were non-significant at all the three sites. The significantly highest fungal population was recorded in T3 which was 114 % higher over T1 and 67 % over T2 at Thana, 159 % higher over T1 and 84 % over T2 at Kabal and 148 % higher over T1 and 88 % over T2 at Matta.

Our results indicated that microbial population of eroded lands increased substantially with inclusion of organic fertilizers with mineral fertilizers as well as of including a legume in the cropping system. These results are consistent with many researchrs. Olajire-Ajayi *et al* (2015) reported that low microbe population in soil can be increased by amending the soil with fertilizers and organic matter. Das and Dkhar (2011) reported that application of organic fertilizers had enhanced the microbial population compared to NPK (mineral fertilizer) and control treatment with the highest fungal and bacterial population in the vermicompost treatment. Allison and Martiny (2008) revealed after reviewing published literature that microbial community composition is sensitive to N, P, and K fertilization. Meta-analyses based on data predominantly from unmanaged ecosystems suggest that increasing N inputs suppress soil microorganisms (Treseder, 2008; Liu and Greaver, 2010; Lu *et al*., 2011). Other studies have revealed that application of urea at about 100 kg N ha^{-1} caused changes in microbial community composition during 10 days of incubation; however, the effects were not sustained over the 91-day incubation period (Stark *et al*., 2007). Similarly, in a greenhouse experiment with different soil types and crops, the use of ammonium nitrate had no significant effect on bacterial community structure in the rhizosphere (Marschner *et al*., 2001). The effect of mineral fertilizers is mostly indirect through their effect on soil pH and osmotic potential as the application of urea and ammonia fertilizers can temporarily increase pH, osmotic potential and ammonia concentrations to levels inhibitory to microbial communities. Even though impacts of fertilizers are spatially limited, they may strongly affect soil microbial biomass and community composition in the short term. Long-term repeated mineral N applications may alter microbial community composition even when pH changes are small (Geisseler and Scow, 2014).

Table 5: Interactive effect of fertilizer treatments and cropping systems on bacterial and fungal population (x10^6 g^{-1} soil) and total mineral N (µg g^{-1} soil) in eroded lands at three farmers' fields

Treatment	Site	Bacteria	Fungi	Mineral N
Cropping system	Thana			
Wheat-maize		2.5	0.34	22.3
Wheat-mung		3.2	0.49	25.7
Significance (*p*<0.05)		**ns**	**ns**	**ns**
Fertilizer treatment (FT)				
NPK as farmers practice[1]		1.7	0.28	19.7
Recommended NPK[2]		2.2	0.36	19.7
Recommended NPK + FYM[3]		4.6	0.60	22.3
Significance (LSD *p*<0.05)		**2.1**	**0.22**	**2.2**
Cropping system	Kabal			
Wheat-maize		1.9	0.32	19.7
Wheat-mung		2.7	0.41	22.6
Significance (*p*<0.05)		*****	**ns**	*****
Fertilizer treatment (FT)				
NPK as farmers practice[1]		1.5	0.22	15.8
Recommended NPK[2]		2.1	0.31	21.7
Recommended NPK + FYM[3]		3.3	0.57	26.0
Significance (LSD *p*<0.05)		**0.6**	**0.21**	**3.9**
Cropping system	Matta			
Wheat-maize		3.0	0.43	26.4
Wheat-mung		3.4	0.56	34.8
Significance (*p*<0.05)		**ns**	**ns**	*****
Fertilizer treatment (FT)				
NPK as farmers practice[1]		2.2	0.31	26.5
Recommended NPK[2]		2.9	0.41	28.1
Recommended NPK + FYM[3]		4.5	0.77	37.3
Significance (LSD *p*<0.05)		**1.6**	**0.22**	**4.7**

[1]Receiving fertilizers as per farmers practice i.e. N at 60 kg and P at 45 kg P_2O_5 ha^{-1}; [2]Receiving mineral NPK at recommended rate viz., N at 120, P_2O_5 at 90, K_2O at 60 and Zn at 5 kg ha^{-1}; [3]Recommended mineral NPK as above plus FYM at 20 t ha^{-1}; ns = non-significant and * = significant (p <0.05)

Total mineral N

The results showed that the total mineral N was significantly (P<0.05) affected by fertilizer treatments at all the three sites (Table 5). However, the effect cropping system on total mineral N was significant only at Kabal and Matta. Our results showed total mineral N in soil was consistently greater for wheat-mungbean (CS2) than for wheat-maize (CS1) cropping system at all the three sites. We observed that legume (mungbean) involvement in cropping system increased soil mineral N by 15.2% at Thana, 14.7% at Kabal and 31.8% at Matta site compared with cereal-cereal cropping system. With respect to the effect of fertilizer treatments, the significantly highest total mineral N was recorded in T3 at all the three sites. The total mineral N in T3 was greater by 17 % over T1 and 4% over T2 at Thana; 65 % over T1 and 20 % over T2 at Kabal and 40% over T1 and 33 % over T2 at Matta.

These results suggested that the addition of organic fertilizer and of including legume in the cropping system helped improved N fertility of eroded lands. Our results are consistent with the findings of Changhui *et al* (2014) who reported that N and P addition significantly increased soil inorganic N pool, soil extractable C and N pool during the growing season in saline-alkaline grassland soil. Combined application of organic and mineral fertilizers increased microbial biomass and activity both in the short- and long-terms (Changhui *et al*., 2014).

Regression models

Stepwise regression analysis was used to establish relationship between wheat grain yield (data not shown here) and some soil microbiological properties for all the tree sites. Regression models were developed for all the three sites to predict wheat grain yields from soil microbiological properties (eq. 1 to 3).

Thana

Grain yield (kg ha^{-1}): 2332 + 82.32* mineralizable-N (ug g^{-1} soil) + 3.96*mineral-N (µg g^{-1} soil) r^2 = 0.39 (eq.4)

Kabal

Grain yield (kg ha^{-1}): 2414 + 40.48* mineralizable-N (ug g^{-1} soil)+ 15.13*mineral-N (µg g^{-1} soil) + 43.70* bacteria ($x10^{-8}$) r^2 = 0.77 (eq. 5)

Matta

Grain yield (kg ha^{-1}): 2994 + 14.50* mineralizable-N (µg g^{-1} soil) + 18.63*mineral-N (µg g^{-1} soil) +362.30*bacteria ($x10^{-8}$) r^2 = 0.86 (eq. 6)

It can be visualized from these equations that by improving soil microbiological properties through integrated plant nutrient management, wheat grain yields at all the three sits can be significantly increased. For Thana site, mineralizable-N and total mineral N were found important soil microbiological properties for increasing wheat yield explaining 39 % variation in yield. For Kabal and Matta sites, mineralizabel-N, total mineral N and bacterial population were important soil microbiological properties for increasing wheat yields and variation in yields can be explained by 77% for Kabal, and 86 % for Matta site by these soil microbiological properties.

Conclusion

This study has shown that integration of FYM with inorganic fertilizers and the involvement of mungbean in rotation with wheat in the upper Swat river valley improved the soil microbiological properties (such as microbial biomass-C and –N, mineralizable-C and –N, microbial population) and assisted in the restoration and crop productivity of eroded lands.

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