J.Natn.Sci.Foundation Sri Lanka 2014 42 (1): 45-62
DOI: http://dx.doi.org/10.4038/jnsfsr.v42i1.6680

RESEARCH ARTICLE

Remediation of soil past erosion effects through amendments and agronomic practices

Wiqar Ahmad[1*] and Farmanullah Khan[2]
[1] *Department of Soil and Environmental Sciences, University of Agriculture, Peshawar, Ameer Muhammad Khan Campus, Mardan, Pakistan.*
[2] *Department of Soil and Environmental Sciences, University of Agriculture, Peshawar, Pakistan.*

Revised: 1 June 2013; Accepted: 12 September 2013

Abstract: In Pakistan there has been a trend to shift agriculture towards steep lands, where soil erosion is one of the most significant ecological restrictions to sustainable agricultural production. This study was focused to find ways to ameliorate the soil fertility degraded by past soil erosion. Different cropping patterns *viz* maize-wheat-maize rotation (C1), maize-lentil-maize rotation (C2) and maize-wheat+lentil intercrop-maize rotation (C3) and different soil treatments, namely, the control (T1), 50 % NP (also called the farmer's practice) (T2), 100 % NPK or the recommended dose of NPK (T3) and 20 t ha^{-1} farmyard manure integrated with 50 % N and 100 % PK (T4) were tested in a randomized complete block (RCB) design with split plot arrangements. Integrated use of organic manure (farmyard manure) and inorganic NPK fertilizers (T4) produced the highest wheat grain yield (4730 kg ha^{-1}), which was 9 % higher than the 100 % inorganic NPK (T3, 4349 kg ha^{-1}) and more than twice the control (T1, 2072 kg ha^{-1}). The increase in lentil grain yield in T4 (1112 kg ha^{-1}) was 7.4 % higher than in the recommended NPK levels for lentils (T3, 1035 kg ha^{-1}) and 79 % higher than the control. A significant nutrient enrichment and an improvement in soil fertility parameters was recorded by T4 over T3. This was further augmented by the application of cereal-legume rotation (C2) in the traditional cereal-cereal rotation (C1) and their combination showed a significantly improved residual effect on soil fertility in the subsequent year. In conclusion the degraded soil fertility of Missa gullied soil cannot be ameliorated to its full potential with only the recommended dose of mineral fertilizers. 50 % N from organic fertilizer sources and the inclusion of legumes in the crop rotation is necessary to ensure agricultural sustainability on such soils.

Keywords: Agricultural sustainability, cropping patterns, eroded soil, farmyard manure, legumes, soil fertility.

INTRODUCTION

The increasing population and the attendant growing demand for food and fiber along with the shrinking of traditionally cultivable extent of land due to the development of infrastructure, has resulted in a trend to shift agriculture towards the sloping land areas in Northern Pakistan. Farmers lacking the knowledge regarding the land capability classification have been practicing the traditional cereal-cereal cropping system on these lands. Furthermore, the use of improper tilling and land levelling implements have exposed the soils resulting in erosion. The newly exposed soils being fragile, is easily affected by sheet and rill erosion, which removes the top fertile layer. During the field survey conducted under the supervision of Soil Survey Staff, Field Office Peshawar, Khyber Pakhtunkhwa, Pakistan in May 2006, calcium carbonate cankers were observed on the soil surface, which were assumed to have been exposed by the continuous removal of the plough layer due to erosion. Due to the continuous removal of the fertile surface, the soil layer has been exposed the fragile sub-surface soil and the cumulative effect resulted in the degradation of soil quality with respect to sustainable crop production. Furthermore, lack of knowledge regarding the proper dose and application methods of chemical fertilizers caused economic loss to the farmers and further deterioration of the soil environment (Yoo *et al*., 1974). The fertility and crop productivity of soils can be improved by practices that increase soil organic matter content (Banning *et al*., 2008). Previous investigations have shown that the potential of mineral

* Corresponding author (wiqar280@yahoo.co.uk)

fertilizers have increased in many folds when used in combination with organic sources (Yang *et al*., 2007; Purakayastha *et al*., 2008). To restore their natural fertility and crop productivity, these soils require careful handling and land management according to scientific recommendations.

The present study was, carried out on a severely eroded Missa gullied soil series in the Swabi District, Kyber Pakhtunkhwa Province, Pakistan during the period 2006 − 2008, to study the effect of combined organic and inorganic fertilizer sources and the inclusion of legumes in the fixed cereal-cereal cropping system on the restoration of properties and nutrient status of soil. The application of organic and mineral fertilizers in integrated form was supposed to enhance the soil fertility and crop productivity on a sustained basis. The increase in soil organic matter content improved the soil structure, reducing soil fragility and susceptibility to erosion over time. The inclusion of legumes in crop rotations protects soil erosion by decreasing the flow velocity on the soil surface and may even counteract erosive forces by restoring the organic matter and N fertility of these soils. Soil fertility replenishment using a combination of organic and inorganic fertilizers increases the farm income and also minimizes the dependence on costly chemical fertilizers.

METHODS AND MATERIALS

Site selection

The selected study site was from a field in the village Maneri Payan, in the Swabi District. The study was conducted through a survey in collaboration with the Department of Soil Survey of Pakistan, Field Office Peshawar in May, 2006. Pre-sowing soil samples were collected from 0 − 20 cm and 20 − 40 cm depths and were analysed for the assessment of fertility status. The study site was classified according to the principles in Key to Soil Taxonomy (USDA, 1998). Pre-sowing soil fertility status and USDA classification of the experimental site are given in Table 1.

Field experiment

The field experiment was conducted during four consecutive seasons (Spring 2006, Fall 2006 − 2007, Spring 2007, Fall 2007 − 2008) in a randomized complete block design with split plot arrangements. Treatment combinations for cropping patterns (main plot factor) and fertilizer treatment combinations for each crop (sub-plot factor) are given in Table 2. Each main plot and sub-plot factor were replicated three times. Maize

Table 1: Pre-sowing fertility status and USDA classification of the experimental site

Property		Mean value (0 − 20 cm)	Mean value (20 − 40 cm)
Clay		32.1 %	37.0 %
Silt		53.2 %	49.1 %
Sand		14.7 %	13.9 %
Textural class		Silty clay loam	Silty clay loam
pH (1:5)		7.96	8.2
EC (1:5)		0.15 dS m^{-1}	0.14 dS m^{-1}
Organic matter		3.4 g kg^{-1}	2.6 g kg^{-1}
Lime ($CaCO_3$)		17.71 %	18.42 %
Total N		0.09 g kg^{-1}	0.13 g kg^{-1}
Mineral N		12.25 mg kg^{-1}	5.54 mg kg^{-1}
		AB-DTPA extractable	
P		2.1 mg kg^{-1}	2.25 mg kg^{-1}
K		80.6 mg kg^{-1}	68.9 mg kg^{-1}
Fe		5.52 mg kg^{-1}	3.52 mg kg^{-1}
Zn		0.01 mg kg^{-1}	0.06 mg kg^{-1}
Mn		0.45 mg kg^{-1}	0.57 mg kg^{-1}
Cu		0.37 mg kg^{-1}	0.26 mg kg^{-1}
Local name	**Soil series**	**Erosion hazard**	**USDA classification**
Stifa	Missa gullied	Severely eroded	Coarse silty, mixed, hyperthermic, Udic Haplustalf

Table 2: Layout of the experiment

Cropping patterns	Crop seasons	Treatments (R1)			
		T1	T2	T3	T4
		Control	50 % NP	100 % NPK	20 t FYM + 50 % N
C1	Kharif 2006	Maize	Maize	Maize	Maize
	Rabi 2006	Wheat	Wheat	Wheat	Wheat
	Kharif 2007	Maize	Maize	Maize	Maize
	Rabi 2007	Wheat	Wheat	Wheat	Wheat
C2	Kharif 2006	Maize	Maize	Maize	Maize
	Rabi 2006	Lentil	Lentil	Lentil	Lentil
	Kharif 2007	Maize	Maize	Maize	Maize
	Rabi 2007	Lentil	Lentil	Lentil	Lentil
C3	Kharif 2006	Maize	Maize	Maize	Maize
	Rabi 2006	I/Crop	I/Crop	I/Crop	I/Crop
	Kharif 2007	Maize	Maize	Maize	Maize
	Rabi 2007	I/Crop	I/Crop	I/Crop	I/Crop

Cont: (control treatment, 50 % NP : traditional fertilizer dose used by the farmers, 100 % NPK: recommended fertilizer dose, FYM: farmyard manure

(*Zea mays*) variety 'Azam', Wheat (*Triticum aestivum*) variety 'Uqab' and lentil (*Lens esculentum*) variety 'MN-92' were grown during both seasons. The plot size was 20 m^2. Urea, single super phosphate and potassium sulphate were used as inorganic fertilizer sources. Well decayed farmyard manure (FYM) was obtained from the Univeristy of Agricuture, Peshawar Dairy Farm and was applied during each season one month before field cultivation. In the case of 100 % NPK, the fertilizer N was applied in two split treatments. At crop harvest, soil samples from 0 – 20 and 20 – 40 cm depths were collected from each treatment plot for soil fertility analysis.

Soil analysis

Soil texture was determined by the procedure described by Tagar & Bhatti (1996). The organic matter content in soil samples was determined by the Walkley-Black procedure (Nelson & Sommers, 1982). Total soluble salts in the soil were determined by measuring soil electrical conductivity (EC) in a 1:5 (soil:H_2O) suspension following 30 min of stirring and read on EC meter as reported by Rhodes (1996). Soil pH was measured in a 1:5 (soil:H_2O) suspension after 30 min of stirring and read on pH meter (Model German Type B-124 using glass and calomel

Table 3: Fertilizer treatments and cropping pattern combinations used in the experiment

Trt.	N	P_2O_5	K_2O	FYM	N	P_2O_5	K_2O	FYM	N	P_2O_5	K_2O	FYM
	---------- Wheat ----------				--------- Maize ----------				--------- Lentil ---------			
T1	0	0	0	0	0	0	0	0	0	0	0	0
T2	60	45	0	0	60	45	0	0	15	22	0	0
T3	120	90	60	0	120	90	60	0	30	45	0	0
T4	60	90	60	20	60	90	60	20	15	45	0	20
Cropping patterns												
C1	Maize-wheat-maize rotation											
C2	Maize-lentil-maize rotation											
C3	Maize-wheat+lentil intercrop-maize rotation											

N, P_2O_5, K_2O : kg ha^{-1}, FYM: farmyard manure-t ha^{-1}, Trt: treatments electrodes) (McLean, 1982). The lime content was determined by acid neutralization Method (US Salinity Lab Staff, 1954). AB-DTPA extractable P, K, Zn, Fe, and Mn were determined by the procedure described by Soltanpour and Schwab (1977). AB-DTPA extractable P was determined at 880 nm using a spectrophotometer. K was determined using a flame photometer and the micro-nutrients were determined using an atomic absorption spectrophotometer (Perkin Elmer Model 2380, USA) directly in filtrate. Mineral N was analyzed using the method developed by Mulvaney (1996). Total N in soil was determined by the Kjeldhal method of Bremner (1996) and total P, K and micronutrients in farmyard manure were determined by the perchloric acid-nitric acid digestion method as described by Kue (1996). For total K, the solution was directly read on flame photometer and for micronutrients (Fe, Zn, Mn, Cu), the solution was directly read on atomic absorption spectrophotometer (Perkin Elmer Model 2380, USA). The characteristics (A) and the quantity of nutrients (kg) in the 20 t ha^{-1} of applied FYM (B) are given in Table 4.

Statistical analysis

The data collected from soil analysis was statistically analyzed using the analysis of variance (Gomez & Gomez, 1984) using M.STATC and MS Excel softwares. Mean value for each parameter was calculated and the variation amongst means of different treatments/cropping patterns/ crop seasons were determined using LSD test of significance at the $p < 0.05$ level (Steel & Torrie, 1980).

RESULTS AND DISCUSSION

Effect of fertilizer treatments and cropping patterns on wheat productivity during 2007-2008

The fertilizer treatments significantly ($p < 0.01$) affected grain yield, biological yield and 1000 grain weight. The results (Table 5) revealed that integrated use of organic manure (farmyard manure) and inorganic NPK fertilizers (T4) produced the highest grain yield (4730 kg ha^{-1}), which was 9 % higher than in the case of inorganic NPK (T3, 4349 kg ha^{-1}) and more than twice that of the control (T1, 2072 kg ha^{-1}). Similarly, the biological yield in T4 (12.7 t ha^{-1}) was 12 % higher than in T3 (11.3 t ha^{-1}) and approximately 3 times higher than in the control plot (4.7 t ha^{-1}). The maximum 1000 grain weight was recorded in T4 (44 g) followed by T3 (43 g), while the lowest 1000 grain weight was recorded in the control (T1: 40 g). The improved organic and inorganic fertility due to the application of organic and inorganic fertilizers to the soil plus the residual effect of similar application to the previous crop, improved the availability of nutrients in T4 plots (Patra *et al*., 2000). Nutrients from the inorganic sources of fertilizers become readily available to the plants at their early growth stage whereas farmyard manure releases nutrients slowly for plant uptake, which

Table 4: (A) Characteristics of farmyard manure used in the experiment

Parameter	Value
Moisture content	47.5 %
Total N	10.6 g kg^{-1}
Total organic carbon (O.C)	206.4 g kg^{-1}
C/N ratio	19.47
Total P	478.7 mg kg^{-1}
Total K	2.9 g kg^{-1}
Fe	0.11 g kg^{-1}
Cu	22.57 mg kg^{-1}
Zn	42.42 mg kg^{-1}
Mn	121.75 mg kg^{-1}

(B) Quantity of nutrients (kg) in the 20 t ha^{-1} of applied FYM

Total N	Total O.C	AB-DTPA extractable					
		P	K	Fe	Zn	Mn	Cu
212	4128	9.574	58	2.2	0.4514	0.8484	2.435

Cost of FYM: Pak Rupees 1000 per 5 tons
Source: local market during 2005 − 2006 and 2006 − 2007

become available at the latter stage of plant growth thus ensuring higher grain and biological yield and a higher 1000 grain weight. Mussgnug *et al*. (2006) has reported improved grain yield upon the application of farmyard manure to degraded soils.

There was some improvement in wheat yield due to the inclusion of legumes as an intercrop with wheat (C3) but that increase was statistically not significant compared to wheat only (C1) (Table 5). Continuous crops of cereals (C1) might have led to low or declining soil organic matter levels with associated chemical, physical and biological limitations on crop growth (Dalal & Mayer, 1986). Furthermore, cereal-legume intercroping might have provided more space and sunlight to wheat rows in-between lentil rows causing vigorous vegetative growth of wheat crop along with other benefits of soil fertility (N-fixation). The results further showed that the cropping patterns and fertilizer treatments had significant ($p < 0.05$) interactive effect on 1000 grain weight of wheat whereas the interaction effect was not significant on the grain yield and biological yield. Thus improvement in 1000 grain weight was the result of both the effects of fertilizer treatments and cropping patterns

Effect of fertilizer treatments and cropping patterns on lentil productivity during 2007 − 2008

The fertilizers had a highly significant effect ($p < 0.01$) on lentil grain yield, biological yield and 1000 grain weight (Table 6). The highest lentil grain yield was observed in T4 (1112 kg ha^{-1}), which was 7.4 % higher than in the plot using the recommended NPK for lentils (T3, 1035 kg ha^{-1}) and 79 % higher than the control (619 kg ha^{-1}). The maximum biological yield (4.5 t ha^{-1}) was obtained in T4, which was 12.5 % higher than in T3 and 87.5 % higher than in the control (2.4 t ha^{-1}). The results further indicated that the highest 1000 grain weight was recorded in T4 (22 g) followed by T3 (21 g) while the lowest 1000 grain weight (19 g) was observed in the control. The cropping pattern effect was also significant on the lentil grain yield ($p < 0.05$), the biological yield ($p < 0.05$) and the 1000 grain weight ($p < 0.01$). The inbuilt mechanism of N_2 fixation enables pulses to meet 80 − 90 % of their N requirements but in the recent years, 20 − 30 kg ha^{-1} of S and suitable doses of Zn, B, Mo and Fe have improved the productivity of pulses. Farmyard manure provides some of these nutrients depending upon the type of farmyard manure, hence T4 showed superiority in the yield and yield parameters of lentils. The carry-over effect of fertilizer applied to previous crops (Ali *et al*., 2008) and its resultant favourable soil environment synergistically improved the growth efficiency of the subsequent crop (Anderson, 2005). The inclusion of lentil in crop rotation (maize-lentil-maize, C2) produced higher lentil grain yield (1031 kg ha^{-1}) as compared to lentil inclusion with wheat as an intercrop (C3, 785 kg ha^{-1}). Similarly, C2 also produced the highest biological yield (4.0 t ha^{-1}) as compared to C3 (3.0 t ha^{-1}) and the highest 1000 grain weight (26 g) as compared to C3 (14 g). Lentils in the intercrop with wheat suffered severe shading effect from wheat at the flowering stage, which caused reduction in the biological nitrogen fixation of lentils (Fujita *et al.,*

Table 5: Effect of fertilizer treatments and cropping patterns on wheat yield parameters during 2007 − 2008

Fertilizer treatments	Grain yield (kg ha^{-1})	Biological yield (t ha^{-1})	1000 grain weight (g)
T1	2072 d	4.7 d	40 d
T2	3116 c	7.2 c	41 c
T3	4349 b	11.3 b	43 b
T4	4730 a	12.7 a	44 a
LSD (<0.05)	106.9	0.6	0.7
Cropping patterns			
C1	3482	8.8	42
C3	3652	9.2	42
T-test	ns	ns	ns

Treatments: T1 = Control, T2 = N:P_2O_5:K_2O (60:45:0 kg ha^{-1}), T3 = N:P_2O_5:K_2O (120:90:60 kg ha^{-1}) T4 = N:P_2O_5:K_2O (60:90:60 kg ha^{-1}) + FYM (20 t ha^{-1})
Cropping patterns = Maize-Wheat-Maize (C1), Maize-wheat + lentil Intercrop-Maize (C3)
Means followed by the same letters are not significantly different at the $p < 0.05$ level.

Table 6: Effect of fertilizer treatments and cropping patterns on lentil yield parameters during 2007 − 2008

Fertilizer Treatments	Grain yield (kg ha^{-1})	Biological yield (t ha^{-1})	1000 grain weight (g)
T1	619 d	2.4 c	19 d
T2	866 c	2.9 b	20 c
T3	1035 b	4.0 a	21 b
T4	1112 a	4.5 a	22 a
LSD (<0.05)	42.6	0.5	0.6
Cropping patterns			
C2	1031 a	4.0 a	26 a
C3	785 b	3.0 b	14 b
T-test	0.001	0.02	0.002

Treatments: T1 = Control, T2 = $N:P_2O_5:K_2O$ (60:45:0 kg ha^{-1}), T3 = $N:P_2O_5:K_2O$ (120:90:60 kg ha^{-1}), T4 = $N:P_2O_5:K_2O$ (60:90:60 kg ha^{-1}) + FYM (20 t ha^{-1}).
Maize-Lentil-Maize (C2), Maize-Intercrop-Maize (C3)
Means followed by the same letters are not significantly different at the $p < 0.05$ level.

1992) causing a reduced grain yield, biological yield and 1000 grain weight. The high root density of wheat for extracting of nutrients from the already nutrient deficient soil leaves an improper nutrient balance for lentils and this resulted in the reduction of intercropped lentil yield. The interaction effect between fertilizer treatments and cropping patterns on lentil 1000 grain weight was highly significant as the increase in 1000 grain weight in lentil was due to the combined effect of fertilizer treatments and cropping patterns. The interaction effect on the lentil grain yield and biological yield was not significant.

Variation in soil fertility status due to fertilizer treatments and cropping patterns

Mineral N (mg kg^{-1})

The amount of available mineral nutrients in soil indicates the level of soil fertility resulting from long-term crop and soil management practices. Determination of the mineral nutrient levels in soil was therefore essential to confirm the sustainability of the soil and crop management practices. Different combinations of fertilizer applications significantly ($p < 0.01$) increased the mineral N content both in the surface (0 − 20 cm) and sub-surface (20 − 40 cm) soil as compared to soils that received no fertilizer (the control). It was observed (Table 7) that fertilizers in its integrated form (T4) showed the maximum increase in mineral N (69 %) over the control in surface soil (0 − 20 cm). Mineral fertilizer alone, 100 % NPK treatment (T3) and 50 % NP treatment (T2) also showed increases in the mineral N content but the performance of integrated organic and inorganic fertilization (T4) was superior over the mineral fertilizer treatments (T3 and T2). The increase in mineral N content in T4 was 13 % over T3. A similar trend of increase in mineral N content with fertilizer application both in organic and inorganic form was observed in sub-surface soil (20-40 cm). The higher mineral N in T4 might be due to the mineralization of FYM in addition to the 50 % mineral N applied. The post-harvest inorganic N increase in soil could be related to the amount of manure and fertilizer N applied (Jokela, 1992). Farmyard manure has been a source of nutrients and also improves the efficiency of fertilizer use (Swarup, 2001) thereby reducing the loss of applied mineral N from soil (Patra *et al*., 2000).

The results showed that the cropping patterns significantly ($p < 0.01$) affected mineral N in the surface (0 − 20 cm) soil, while in sub-surface (20 − 40 cm) its effect on mineral N was not significant (Table 8). It was observed that mineral N content in the cereal-legume rotation (C2) was the highest (25.3 mg kg^{-1}) and it was 10 % and 16 % higher over the cereal-cereal rotation (C1, 22.8 mg kg^{-1}) and cereal-legume intercrop (C3, 19.7 mg kg^{-1}), respectively. Legumes not only provide additional N through NO_3^- spraying (Evans *et al*., 1991) and the mineralization of fixed N in the residues but also capture soil available N and reduce NO_3 losses from

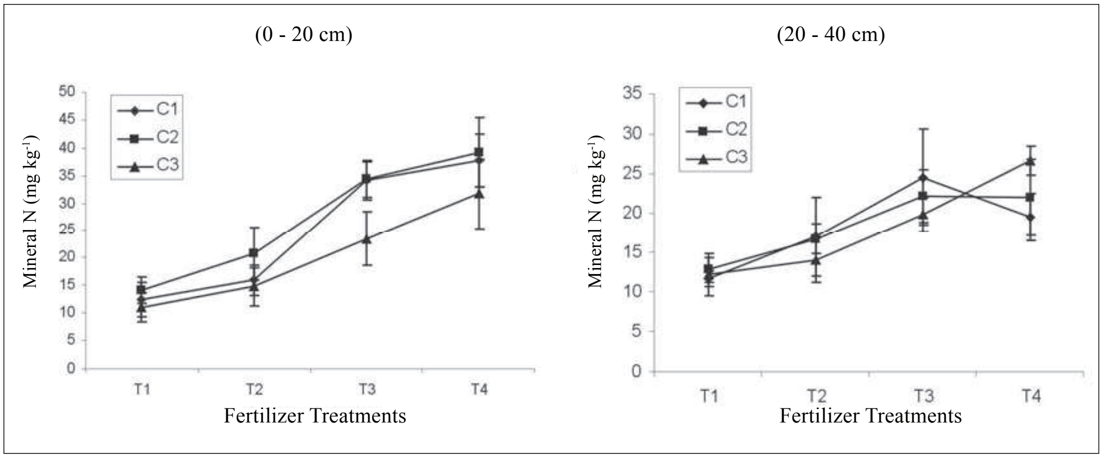

Figure 1: Interaction effect between fertilizer treatments and cropping patterns on mineral N content in surface and sub - surface soil

soil (Campbell *et al*., 1991). Furthermore, fertilizer (as starter dose) and FYM application to legumes may have increased the population of nitrogen fixing bacteria, which may have increased the N content in the soil (Basu *et al*., 2008). Biological N fixation by legumes and their nodulated roots left over in the soil after crop harvest has been considered a very important source of organic nitrogen input to the soil (Wartainen *et al*., 2008).

It is further observed that the nutrient concentration decreased with increasing depth. Taking the average of all the fertilizer treatments (T1 to T4), it was noted that mineral N content in surface soil was 20.5 % higher over the sub-surface soil. In surface soil, the higher nutrient balance might be due to the surface application of inorganic N or due to its accumulation in the soil from mineralization of organic matter added through farmyard manure, a portion of which leaches down through the soil profile (Crews & Peoples, 2004).

The data analysis shows that the interaction effect between fertilizer treatments and cropping patterns on mineral N content was not significant in surface soil, while in sub-surface soil (20 − 40 cm), the interaction effect on mineral N content was significant ($p < 0.05$). Thus, the fertilizer treatments and cropping patterns increased the

Table 7: Effect of fertilizer treatments on soil fertility status

Parameters	T1	T2	T3	T4	LSD (<0.05)	T1	T2	T3	T4	LSD (<0.05)
	0 − 20 cm					20 − 40 cm				
Min. N (mg kg^{-1})	10.6	15.0	30.4	34.3	1.9	11.9	15.6	22.1	22.2	2.4
O.M (g kg^{-1})	4.3	5.2	5.9	8.2	0.6	3.7	4.7	5.3	6.0	0.4
Soil pH	7.91	7.87	7.82	7.75	0.3	7.91	7.9	7.87	7.87	ns
E.C. (dS m^{-1})	0.18	0.21	0.28	0.30	0.01	0.17	0.21	0.29	0.33	0.01
AB-DTPA extractable (mg kg^{-1})										
P	3.0	5.2	6.8	9.7	0.8	2.5	3.2	3.8	4.8	0.3
K	61.8	63.4	93.4	107.8	3.8	55.7	58.9	75.8	82.0	3.5
Fe	4.1	4.3	5.0	6.9	0.4	4.1	4.0	3.8	5.4	0.3
Zn	0.5	0.8	1.2	1.8	0.3	0.6	0.6	0.8	1.3	0.17
Mn	2.2	2.9	3.0	5.0	0.6	2.5	2.2	2.5	3.5	0.6
Cu	0.6	0.7	0.8	1.8	0.1	0.6	0.6	0.8	1.6	0.1

Note: Data has been combined from 4 seasons, 3 cropping patterns and 3 repeats at each treatment application.
Treatments: T1 = Control, T2 = N:P_2O_5:K_2O (60:45:0 and 15:22 kg ha^{-1}), T3 = N:P_2O_5:K_2O (120:90:60 and 30:45 kg ha^{-1}), T4 = N: P_2O_5:K_2O (60:90:60 and 15:45 kg ha^{-1}) + FYM (20 t ha^{-1}), O.M.- Organic matter, Min. N - Mineral nitrogen

Table 8: Effect of cropping patterns on soil fertility status

Parameters	C1	C2	C3	LSD (<0.05)	C1	C2	C3	LSD (<0.05)
	------------------------ 0 − 20 cm			-------------------	------------------------ 20 − 40 cm			-------------------
Min. N (mg kg^{-1})	22.8	25.3	19.7	2.0	17.7	18.0	18.2	ns
O.M. (g kg^{-1})	5.0	6.9	5.6	0.5	4.5	5.4	4.9	0.6
Soil pH	7.84	7.82	7.85	ns	7.87	7.88	7.91	ns
E.C. (dS m^{-1})	0.24	0.24	0.24	ns	0.25	0.25	0.24	ns
AB-DTPA extractable (mg kg^{-1})								
P	6.0	6.2	6.4	ns	3.4	3.6	3.7	ns
K	85.4	77.5	83.7	3.4	69.0	66.5	68.8	ns
Fe	4.77	5.2	5.25	ns	4.11	4.34	4.46	ns
Zn	0.91	1.04	1.2	ns	0.77	0.87	0.86	ns
Mn	3.14	3.24	3.41	ns	2.67	2.98	2.48	ns
Cu	0.98	1.05	0.88	ns	0.87	1.04	0.85	ns

Note: Data have been combined from 4 seasons, 4 fertilizer treatments and 3 repeats at each treatment application.
Maize-Wheat-Maize (C1), Maize-Lentil-Maize (C2), Maize-Intercrop-Maize (C3), O.M. - Organic matter, Min. N - Mineral nitrogen

mineral N content in surface soil independent of each other, while the gradual increase in mineral N content in sub-surface soil was due to the combined effect of fertilizer application and cropping patterns. It may also be due to the fact that the plants/crop were feeding from the surface soil depleting the N reserve while in the sub-surface soil, the roots of the previous crop and the current crop served as reserves of N supply upon its decomposition. It may be due to N leaching and its illuvation in sub-surface soil.

AB-DTPA extractable P (mg kg^{-1})

The fertilizer treatments significantly ($p < 0.01$) affected AB-DTPA extractable P content both in surface (0 − 20 cm) and sub-surface (20 − 40 cm) soil as compared to soils that received no fertilizer (the control). It was observed (Table 7) that fertilizers in the integrated form (T4) resulted in high increase in AB-DTPA extractable P (69 %) over the control treatment in surface soil (0 -20 cm) and 79 % in the sub-surface (20 - 40 cm) soil while its improvement in the AB-DTPA extractable P over the recommended dose of NPK (T3) and farmers practice (T2) was 30 and 46 % in surface and 16 and 34 % in sub-surface soils, respectively. The surface application of P both in mineral form and the P released by FYM through mineralization caused higher P content in T4. These results are in agreement with those of Morari *et al*. (2008) in which a higher available P with the use

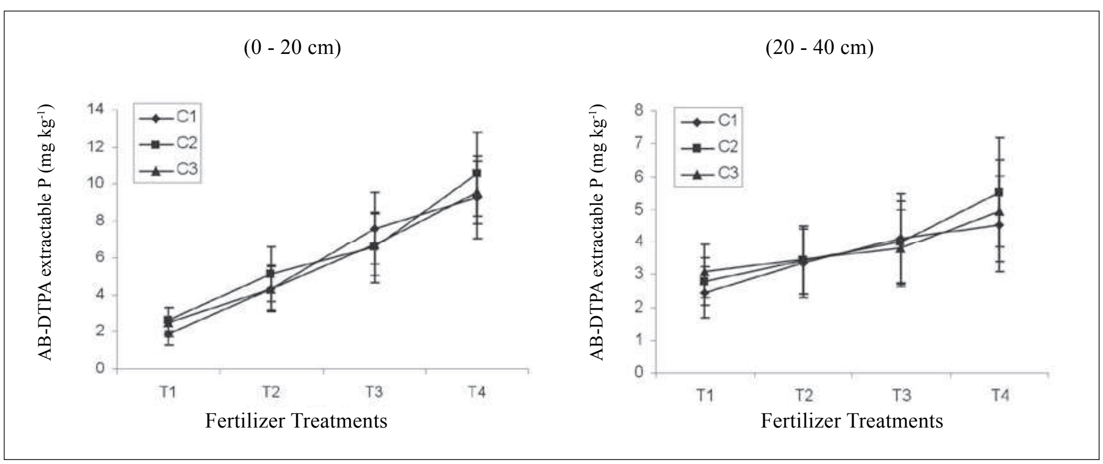

Figure 2: Interaction effect between fertilizer treatments and cropping patterns on AB-DTPA extractable P content in surface and sub-surface soil

of organic fertilizers was reported. The increased microbial activity with the combined application of farmyard manure (Ayaga *et al*., 2006) and P fertilizers increased the cycling of P through microbiological processes, thus decreasing P fixation and increased plant availability with time. The higher available P in T3 could be attributed to the mineral P applied in excess to that removed by the crop. These findings are in line with the findings of McCullum (1991) who reported that the application of P in excess to that removed by harvested crops can result in a large build-up of soil P reserves.

The results (Table 8) further showed that the cropping patterns containing legumes either as sole crop (C2) or inter cropped with cereal (C3) registered a non-significant increase in AB-DTPA extractable P over cereal-cereal rotation (C1) at both depths. The higher AB-DTPA extractable P in cereal-legume rotation may be attributed to the P fertilizer application to legume crops and altering the pH of the rhizosphere (Wilson *et al*., 1982). This might also be attributed to cycling of P through the soil microbiological and associated metabolite pools, thus decreasing P fixation and increased plant availability (Ayaga *et al*., 2006).

The data analysis showed that the interaction effect between fertilizer treatments and cropping patterns on soil AB-DTPA extractable P was insignificant in surface soil (0 − 20 cm). In sub-surface soil (20 − 40 cm), the interaction effect was significant on AB-DTPA extractable P ($p < 0.05$). Similar to mineral N, the increase in P in the surface soil due to fertilizer treatments and cropping patterns was independent of each other whereas it was due to the combined effect of fertilizer treatments and cropping patterns in the sub-surface soil. Similar to mineral N, P depleted from surface soil while it accumulated in the sub-surface soil due to either leaching of dissolved organic matter (OM) or due to the increased microbial activity, which might have increased its mineralization and unlocking of the fixed P.

AB-DTPA extractable K (mg kg^{-1})

The fertiizer application significantly ($p < 0.01$) increased AB-DTPA extractable K content in both the surface (0 − 20 cm) and sub-surface (20 − 40 cm) soil. Based on the data averaged over seasons (Table 7), it was observed that T4 recorded the maximum (107.8 mg kg^{-1}) AB-DTPA extractable K in surface soil followed by T3 (93.4 mg kg^{-1}) and T2 (63.4 mg kg^{-1}) while the lowest AB-DTPA extractable K (61.8 mg kg^{-1}) was observed in the control (T1). A similar trend was also observed in sub-surface soil. Thus, the integrated application of fertilizer (T4) registered 13 % higher AB-DTPA extractable K than in the treatment with recommended NPK (T3), 41 % higher than the farmers practice (T2) and 43 % higher than the control in surface soil. In sub-surface soil, this increase over T3, T2 and the control was 7.6, 28 and 32 %, respectively. The additional K coming from farmyard mineralization further increased the K content in addition to the 100 % mineral K applied in T4. The results confirms the findings of Blaise *et al*. (2005) who had found that the K balance was positive only when FYM was applied. Dressel *et al*. (1993) have reported that medium and high fertilization of soil caused enrichment of K in top soil. AB-DTPA extractable K in the surface soil is 16.5 % higher over the sub-surface soil. This might be due to the decreasing organic matter content with the depth, having a highly significant correlation (0.86) with K content and these results are in line with the results of Bullock (1992) who also reported a K increase with the increasing organic matter content.

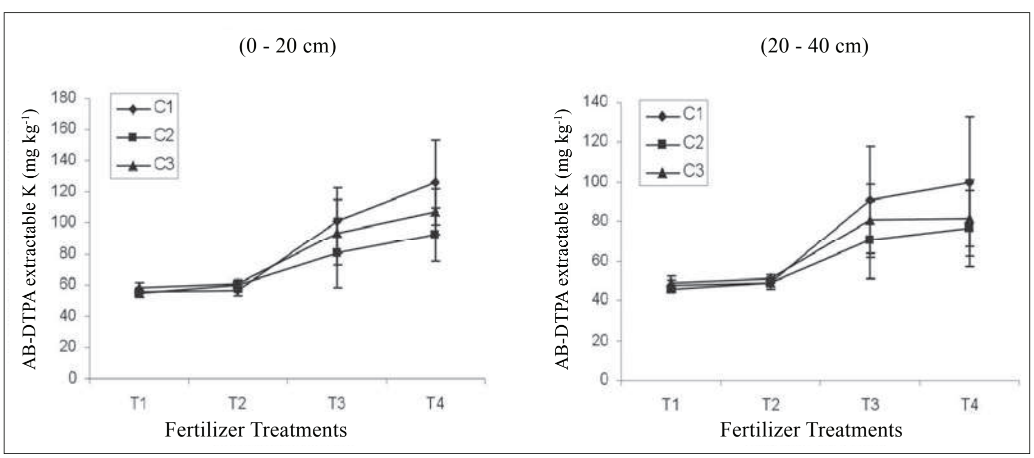

Figure 3: Interaction effect between fertilizer treatments and cropping patterns on AB-DTPA extractable K content in surface and sub-surface soil

The effect of cropping pattern on AB-DTPA extractable K was also highly significant ($p < 0.01$) in the surface soil (0 − 20 cm) and not significant in the sub-surface (20 − 40 cm) soil. The cereal-cereal rotation (C1) recorded 9.2 % higher AB-DTPA extractable K content than in cereal-legume rotation (C2) whilst in the cereal-cereal rotation (C1) and cereal-legume intercrop (C3), the means were statistically similar (Table 4). A significantly higher K content in the cereal-cereal rotation (C1) followed by cereal-legume intercrop (C3) might be attributed to the surface application of 100 % K in T3 and T4. Bengtson *et al*. (2003) also found a positive K balance in the conventional system instead of the organic system.

The data analysis showed that the interaction effect between fertilizer treatments and cropping patterns on AB-DTPA extractable K was highly significant ($p < 0.01$) in the surface soil, while in the sub-surface soil (20 − 40 cm) the interaction effect between fertilizer treatments and cropping patterns was not significant. Thus, the significant variation in the K content in surface soil is due to the combined effect of fertilizer application at various doses and forms and at various rates recommended for different cropping patterns. The maximum increase in T4 × C1 plot might be due to the 100 % inorganic K (60 kg ha^{-1}) application and the K mineralization from FYM applied. In T4 × C3 plot, the 100 % inorganic K was applied to only wheat rows (a total of 30 kg ha^{-1}) combined with the K from the FYM mineralization, thus it was the second in K content amongst T4 treatments, while T4 × C2 showed the lowest K content amongst T4 treatments due to no inorganic application into C2 cropping patterns.

Soil organic matter (g kg^{-1})

The fertilizer application significantly ($p < 0.01$) increased the OM content both in the surface (0 − 20 cm) and sub-surface (20 − 40 cm) soil as compared to the control. It was observed (Table 7) that fertilizers in integrated form (T4) showed the maximum soil OM content (8.2 and 6 g kg^{-1}), which was 47.6 % and 38 % higher than in the control in surface and sub-surface soil, respectively. It was further noted that the same treatment (T4) also recorded 28 % and 11.7 % higher soil OM content over the recommended dose of NPK (T3) in surface and sub-surface soil, respectively. With regard to the farmers practice (T2), this increase was 36.6 and 21.7 %, respectively. Farmyard manure and fertilizer applications are important management practices used to improve the nutrient status and organic matter in soils and thus to increase the crop productivity (Yang *et al*., 2007). Monaco *et al*. (2008) also found a higher OM content in FYM treated soil. When animal manure with a plant nutrient content equivalent to that of the mineral fertilizers is applied, the soil receives an additional input of organic material, which is equivalent to the difference in the organic matter derived from the mineral fertilizers alone and that with farmyard manure (Christensen, 1988). Organic matter in inorganic fertilizer plots was significantly higher than the control plots. The effect of mineral fertilizers on soil organic matter content might, at least partly, be compared to that of straw incorporation (Christensen, 1988).

The effect of cropping pattern on soil OM content was also highly significant ($p < 0.01$) both in surface (0 − 20 cm) and sub-surface (20 − 40 cm) soil. The

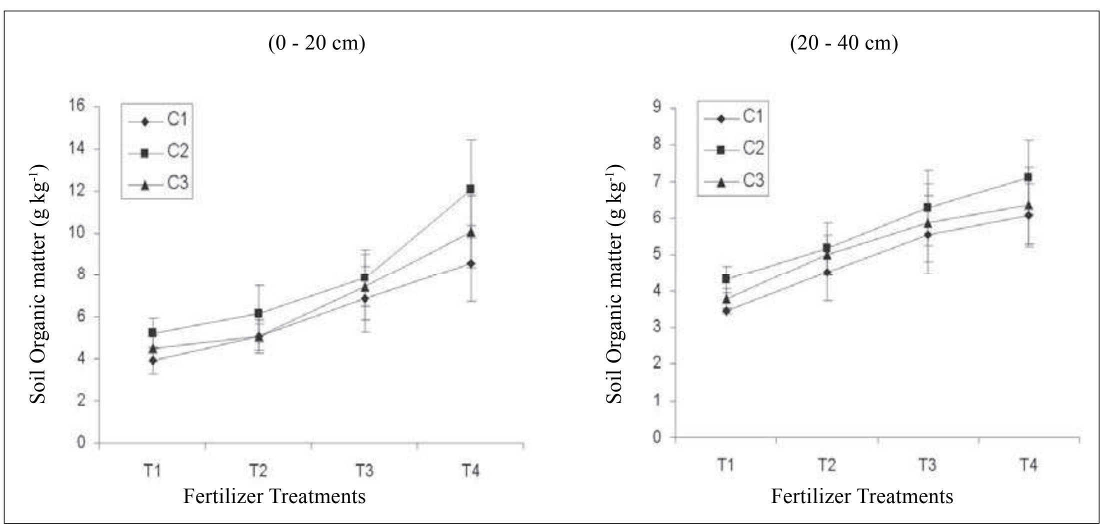

Figure 4: Interaction effect between fertilizer treatments and cropping patterns on soil organic matter content in surface and sub-surface soil

results (Table 8) showed that the highest organic matter content (6.9 g kg^{-1}) was recorded in cereal-legume rotation (C2), which was 27 % higher than the cereal-cereal rotation (C1) and 23 % higher than the cereal-legume intercrop (C3). In sub-surface soil, the cereal-legume rotation (C2) showed a 20 % and 10 % increase in soil OM content over the cereal-cereal rotation (C1) and cereal-legume intercrop (C3), respectively. Similar to N, P and K, a decreasing trend in soil OM content was observed with depth in respective fertilizer treatments. At maturity, the lentils shed more than half of its leaves producing a thin layer of litter on the soil surface, which is equivalent to the application of organic material to soil that increased organic matter and soil nutrient content (Courtney & Mullen, 2008). In C1 (cereal-cereal rotation), the low organic matter content might be due to the intensive crop production and the higher organic matter mineralization that prevent organic matter accumulation in soil. These findings are in line with Zhao *et al*. (2008) who found a lowest organic C and higher mineralization in an intensive crop production system. In C2 (cereal-legume rotation) the process was opposit to that in C1. Purakayastha *et al*. (2008) have reported that the increase in soil organic carbon concentration under long term cereal-legume cropping systems was due to the fact that the annual C input by the system was higher than the annual exhaust. Ussiri *et al*. (2006) reported that below - ground biological parts are also an important source of C in soils, especially in the sub-surface.

The data analysis showed that the interaction effect between fertilizer treatments and cropping patterns on soil OM was highly significant ($p < 0.01$) in the surface soil and not significant in the sub-surface soil (20 − 40 cm). Thus, the variation in soil OM in surface soil was due to the combined effect of fertilizers and cropping patterns, while in sub-surface soil, the effect of fertilizer treatments and cropping patterns on soil OM was independent of each other. This might be due to the surface application of FYM and the higher content of residues received by the surface soil as compared to the sub-surface soil.

Soil pH

Based on the pooled data over seasons, a significant ($p < 0.05$) reduction in soil pH was observed due to the application of fertilizers both in the organic and inorganic forms. It was noted from the data (Table 7), that mixed fertilizer application (organic and inorganic) recorded the maximum 2 % reduction in soil pH over the control while reduction in soil pH in the same treatment over the recommended NPK (T3) and farmer's practice (T2) was 0.9 and 1.4 %, respectively. The data (Table 7) further showed that the fertilizer treatment effect on soil pH was non-significant in sub-surface soil. Simek *et al*. (1999) have reported that the effects of the manure and inorganic fertilizers reduced soil pH. Numerous studies have reported soil acidification with continuous use of nitrogenous fertilizers (Fox & Hoftinan, 1981; Juo *et al*., 1995). With the increasing soil depth, an increase in soil pH was noted compared to surface soil. This might be due to the downward movement of lime with percolating water to sub-surface soil (Hao & Chang, 2003). Farmyard manure has been reported to increase the pH of the acid soils (Ashiono *et al*., 2005). The use of N fertilizers alone or in combination with FYM reduced the soil pH as compared to the control plots. This study further showed that the ability of N fertilizers to reduce soil

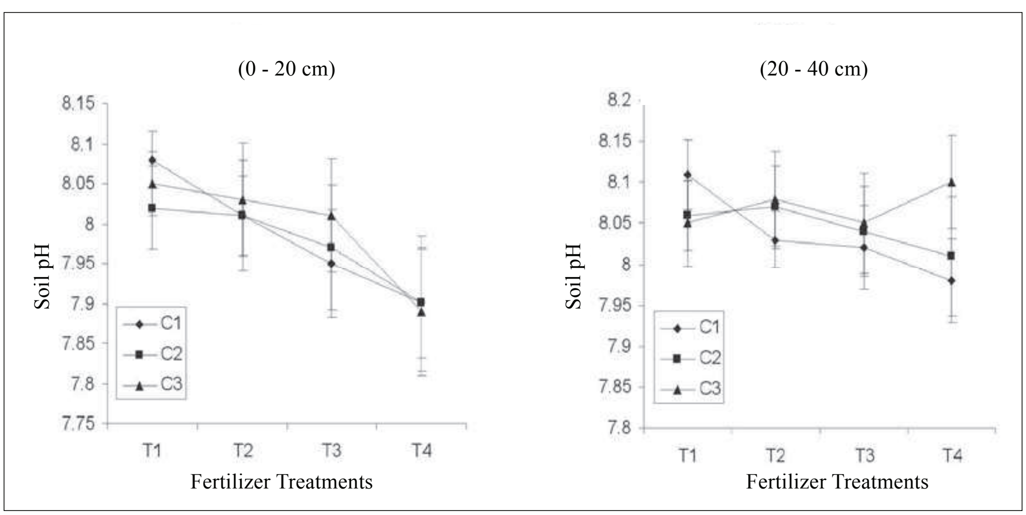

Figure 5: Interaction effect between fertilizer treatments and cropping patterns on soil pH in surface and sub-surface soil

pH of alkaline soils is not affected by the combined use with farmyard manure. Regarding the cropping patterns effect, it was noted from the data (Table 8), that there was no significant reduction in soil pH both in the surface and sub-surface soil. The data analysis showed that the interaction effect between the fertilizer treatments and the cropping patterns on soil pH was not significant both in the surface and sub-surface soil. Thus, any change in soil pH was due to the individual effect of fertilizer treatments in surface soil.

Electrical conductivity (dS m^{-1})

The results revealed that the electrical conductivity ($EC_{1:5}$) in both the surface and the sub-surface soil significantly ($p < 0.01$) increased with fertilizer application. The maximum increase in surface soil was observed in the treatment receiving mixed organic and inorganic fertilizers (T4), which was 40 % higher than in the control, 30 % higher than in the farmer's practice (T2) and 6.7 % higher than in the recommended NPK (T3). A similar trend was observed in sub-surface soil where T4 recorded 48, 36 and 12 % higher EC over the control, farmer's practice (T2) and the recommended NPK dose (T3), respectively. These finding are in line with the findings of Stamatiadis *et al*. (1999) who found a 1.5 unit increase in the electrical conductivity (EC) with the surface application of ammonium nitrate. These results also confirmed the findings of Hao and Chang (2003) who reported that livestock manure contains a considerable amount of salt and the continued application to agricultural land may result in an accumulation of salt in soil. Based on the averaged data of treatments, a 3 % increase in EC was observed in sub-surface soil over the surface soil showing the downward movement of soluble ions (Na^+, K^+, Mg^{2+}, Cl^-, HCO_3^-) in the eroded soil. The cropping pattern effect on soil $EC_{(1:5)}$ was not significant both in the surface (0 − 20 cm) and sub-surface (20 − 40 cm) soil. Data analysis showed that the interaction effect between fertilizer treatments and cropping patterns on soil $EC_{1:5}$ was highly significant ($p < 0.01$) in surface soil and non-significant in sub-surface soil. Thus, the variation in soil $EC_{(1:5)}$ in surface soil was due to the combined effect of fertilizer application at various doses and in various forms and at various rates to different cropping patterns. $EC_{(1:5)}$ was the highest in C1 and lowest in C2 from T1 to T3 treatments. But the situation was reversed in the case of T4 × C2 where the soil $EC_{(1:5)}$ was the maximum and this might be due to the salts accumulation from FYM mineralization and the salts saved from leaching to sub-soil due to higher content of soil OM.

AB-DTPA extractable micro-nutrients (Fe, Zn, Mn, Cu)

The fertilizer treatments significantly ($p < 0.01$) increased the micro-nutrient concentration in both the surface and sub-surface soil. It was observed (Table 7) that mixed application of farmyard manure and mineral fertilizer showed the highest increase in micro-nutrient concentration with 40.6, 38 and 27.5 % increase in Fe over the control (T1), farmers practice (T2) and recommended NPK (T3) in surface soil, respectively. Similarly, T4 recorded 72, 56.6 and 33 % increase in Zn concentration, 56, 42 and 40 % increase in Mn concentration over the T1, T2 and T3, respectively, and 66.7, 61 and 55.6 % increase in Cu concentration in surface soil, respectively. A similar trend of increase in micro-nutrients with respect to treatments was observed in sub-surface soil. Laboratory analysis results of farmyard manure showed 121.1 mg kg^{-1} Mn, 45.1 mg kg^{-1} Zn, 18.3 mg kg^{-1} Cu and 1100 mg

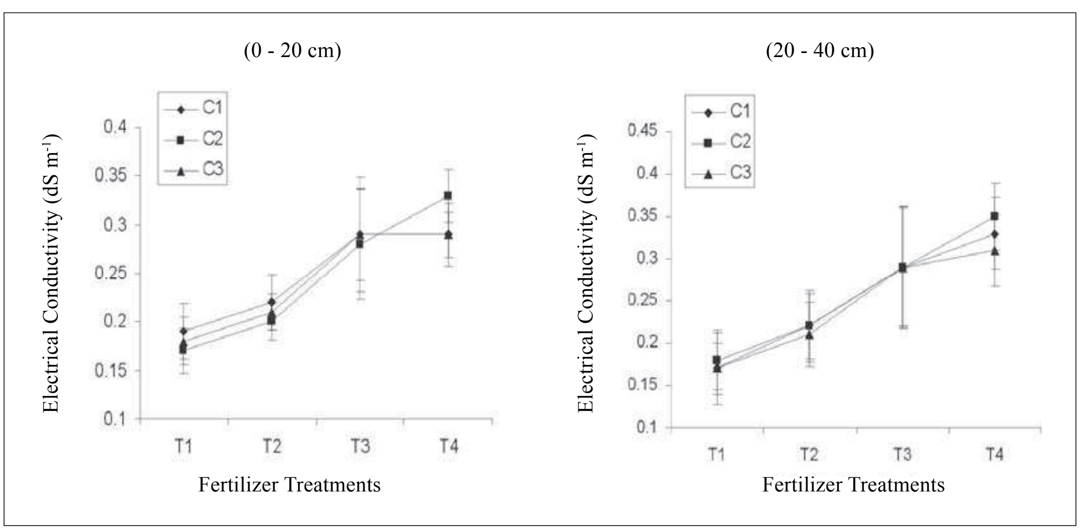

Figure 6: Interaction effect between fertilizer treatments and cropping patterns on soil $EC_{1:5}$ in surface and sub-surface soil

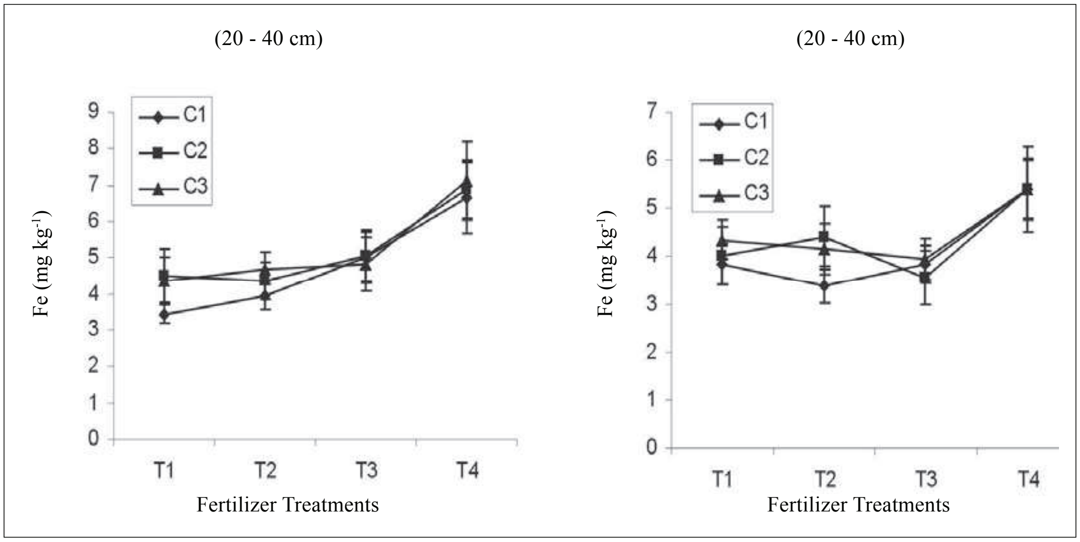

Figure 7: Interaction effect between fertilizer treatments and cropping patterns on micro-nutrients Fe in surface (0 − 20 cm) and sub-surface (20 − 40 cm) soil

kg^{-1} Fe. A gradual increase in the concentration of these nutrients was also observed with time due to continuous application of farmyard manure to soil. Many researchers have confirmed that farmyard manure application to agricultural soils increase soil nutrient concentration including micro-nutrients (Timsina & Connor, 2001; Dawe *et al*., 2003; Pratt, 2008). Based on the average data over treatments, it was observed that micro-nutrient concentration also decreased with depth and a 14, 23, 18 and 7.7 % decrease in Fe, Zn, Mn and Cu was observed in sub-surface soil over the surface soil, respectively. The changing concentrations of micronutrients in sub-surface soil might be due to the downward mobility of these nutrients or the organic matter particles with water into sub-surface soil. Toribio and Romanya (2006) reported a higher mobility of Zn and Cu as compared to the control plots.

It was further observed (Table 8) that cropping patterns effect on AB-DTPA extractable micro-nutrient concentration in soil was not significant both in the surface and sub-surface soil. The data analysis further showed that interaction effect between fertilizer treatments and cropping patterns was only significant on AB-DTPA extractable Fe ($p < 0.01$) and Cu ($p < 0.05$) in sub-surface soil while it was not significant with regard to the other micro-nutrients at the same depth and all four micro-nutrients in surface soil. Thus, any variation in Fe and Cu in sub-surface soil was due to the combined effect of fertilizers and cropping patterns, while the rest of the micro-nutrients in sub-surface soil and the four micro-nutrients under study in the surface soil changed in content due to the individual effect of either the fertilizer treatment or the cropping pattern.

Variation in soil fertility status with time (temporal variation)

Statistical analysis of the combined data over seasons revealed that mineral N, AB-DTPA extractable P, K and soil organic matter (OM) content were significantly ($p < 0.01$) increased by the combined organic and inorganic fertilizer application and the inclusion of legumes in cropping patterns at both depths. In the surface soil (0 − 20 cm), mineral N, AB-DTPA extractable P, and K content showed 42, 50 and 30 % increase, respectively, whilst soil OM content showed a 2.5 times increase during fall 2007 over spring 2006 (Table 9). A similar pattern was observed in sub-surface soil. It was noted from further statistical analysis that soil OM content showed a significant correlation with mineral N, AB-DTPA extractable P and K contents ($r = 0.95$, 0.87 and 0.70 respectively) in surface soil and sub-surface soil ($r = 0.84$, 0.98 and 0.89, respectively). These results showed that the mineral nutrient concentration gradually increased at both depths over the years. Nitrate accumulated in soil either from mineralization of organic matter or from the mineral fertilizer application (Crews & Peoples, 2004). The residual effect of the applied P i.e application of P in excess of that removed by harvested crops, resulted in a build-up of soil P reserves with time (McCullum, 1991) and the decomposition of organic fertilizers liberated the P locked in it (Guo *et al*., 2008). Mineral K application and those coming from the decomposition of farmyard manure resulted in a significant increase of available K content in both surface and sub-surface soil over time (Kaihura *et al*., 1999). Farmyard manure showed a residual effect because of slow mineralization and its continuous application increased the organic

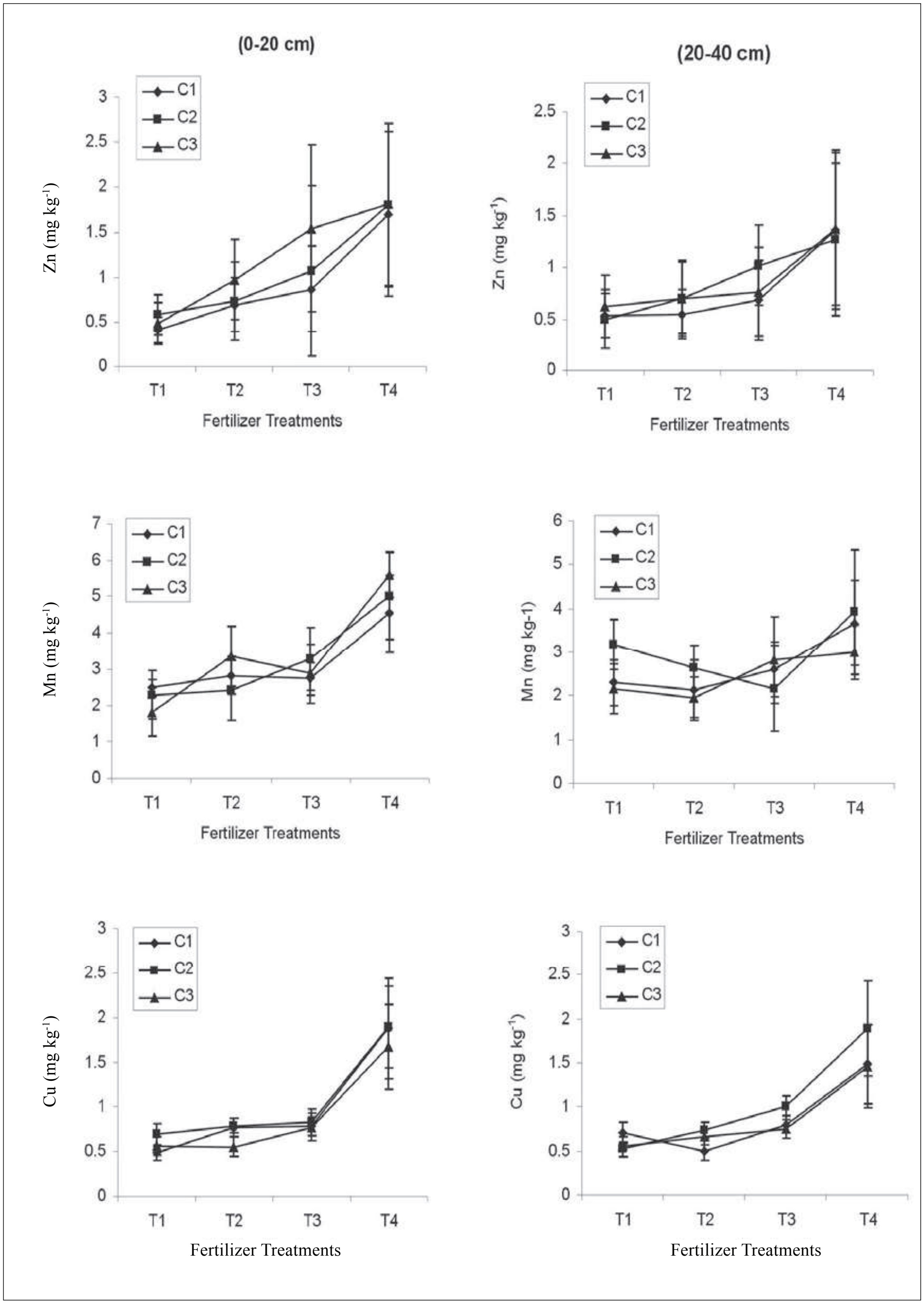

Figure 6: Interaction effect between fertilizer treatments and cropping patterns on micro-nutrients Zn, Mn and Cu in surface (0 − 20 cm) and sub-surface (20 − 40 cm) soil

Table 9: Combined effect of soil amendments and cropping patterns on soil fertility status with time

Parameters	Spring 2006	Fall 2006	Spring 2007	Fall 2007	LSD (<0.05)	Spring 2006	Fall 2006	Spring 2007	Fall 2007	LSD (<0.05)
	---------------------- 0 − 20 cm ------------------					---------------------- 20 − 40 cm ------------------				
Min. N (mg kg^{-1})	18.3	21.4	24.7	25.9	2.8	14.7	15.3	20.6	21.3	4.8
O.M (g kg^{-1})	2.8	6.0	7.3	7.3	0.7	2.8	5.0	5.9	6.0	0.3
Soil pH	7.86	7.84	7.85	7.8	0.02	7.89	7.89	7.9	7.88	ns
E.C. (dS m^{-1})	0.23	0.19	0.22	0.33	0.01	0.23	0.18	0.20	0.38	0.01
AB-DTPA extractable (mg kg^{-1})										
P	5.0	5.6	6.7	7.5	0.9	0.9	3.3	4.6	5.4	0.4
K	74.0	77.1	81.6	96.1	4.3	63.0	65.4	72.9	71.0	4.4
Fe	3.80	4.33	5.60	6.57	0.57	3.40	3.49	4.62	5.70	0.41
Zn	0.10	0.44	1.14	2.53	0.36	0.11	0.27	0.88	2.08	0.22
Mn	1.57	2.83	3.75	4.90	0.42	1.02	2.24	2.64	4.02	0.47
Cu	0.45	0.89	1.15	1.39	0.2	0.43	0.81	1.09	1.35	0.28

Data have been combined from 3 cropping patterns, 4 fertilizer treatments and 3 replications

matter content of the soil (Patra *et al*., 2000). A long term experiment by Goyal *et al*. (2006) revealed that the amount of soil organic matter and mineralizable C and N increased with the addition of mineral fertilizers.

Crop season effect on soil pH and EC was significant ($p < 0.01$) only in the surface soil (0 − 20 cm) only. It was observed that soil fertility management practices (fertilizer treatments and cropping patterns) showed a decreasing trend in soil pH in the surface soil (0 − 20 cm) with time (from spring 2006 to fall 2007), whilst in the sub-surface soil (20 − 40 cm) the trend was inconsistent (Table 9). Aref and Wander (1998) reported lowering of soil pH with long term fertilizer applications. Farmyard manure has been reported to increase the pH of the acid soils (Ashiono *et al*., 2005) but due to the use of N fertilizers alone or in combination with FYM that reduced the soil pH. It was also observed that soil $EC_{1:5}$ increased with time at both depths, which might be due to the mineral fertilizer application or due to the salts coming from farmyard manure. Livestock manure contains a considerable amount of salt and the continued application to agricultural land may result in an accumulation of salt in soil (Hao & Chang, 2003).

Soil fertility management effect on soil micro nutrients Fe, Zn, Mn, and Cu was highly significant ($p < 0.01$) at both depths (0 − 20 cm and 20 − 40 cm). It was observed that the concentration of these micro-nutrients increased with time at different soil depths. At each soil depth, the lowest value was found in spring 2006 for each micro-nutrient while the highest value was recorded during the fall 2007. Many researchers have confirmed that farmyard manure application to agricultural soils increase the soil nutrient concentration including micro-nutrients (Pratt, 2008).

CONCLUSION

It is concluded that there has been sufficient potential to improve soil fertility of the severely eroded Missa gullied soil. This cannot be achieved solely with the practice of the recommended dose of mineral fertilizers. It is also necessary to obtain 50 % of the inorganic N from organic sources like farmyard manure that also supplements the rest of the nutrients in eroded soil. Moreover, legumes must be included in the traditional cereal-cereal cropping pattern to further improve the N input, soil OM and reduce the velocity of water flow on these soils.

Acknowledgement

The authors are thankful to the Higher Education Commission of Pakistan for financial support.

REFERENCES

1. Ali S., Bhatti A.U., Khan F. & Ghani A. (2008). Performance of mungbean in wheat-mungbean system under integrated plant nutrient management on eroded lands. *Sarhad Journal of Agriculture* **24**(3): 445 − 452.

2. Anderson R.L. (2005). Are some crops synergistic to following crops. *Agronomy Journal* **97**: 7 − 10.
3. Aref S. & Wander M.M. (1998). Long term trends of corn yield and soil organic matter in different crop sequences and soil fertility treatments on the Morrow plots. *Advances in Agronomy* **62**: 153 − 161.
4. Ashiono G.B., Wasike W., Ouma J.P., Gatwiku S.W. & Gachuki P.N. (2005). Residual effects of farmyard manure on stover and grain yield of cold tolerant dual purpose sorghum in the dry highlands of Kenya. *Journal of Agronomy* **4**(4): 300 − 303.
DOI: http://dx.doi.org/10.3923/ja.2005.300.303
5. Ayaga G., Todd A. & Brookes P.C. (2006). Enhanced biological cycling of phosphorus increases its availability to crops in low-input sub-Saharan farming systems. *Soil Biology and Biochemistry* **38**(1): 81 − 90.
DOI: http://dx.doi.org/10.1016/j.soilbio.2005.04.019
6. Banning N.C., Grant C.D., Jones D.L. & Murphy D.V. (2008). Recovery of soil organic matter, organic matter turnover and nitrogen cycling in a post-mining forest rehabilitation chronosequence. *Soil Biology and Biochemistry* **40**(8): 2021 − 2031.
DOI: http://dx.doi.org/10.1016/j.soilbio.2008.04.010
7. Basu M., Bhadoria P.B.S. & Mahapatra S.C. (2008). Growth, nitrogen fixation, yield and kernel quality of peanut in response to lime, organic and inorganic fertilizer levels. *Bioresource Technology* **99**(11): 4675 − 4683.
DOI: http://dx.doi.org/10.1016/j.biortech.2007.09.078
8. Bengtsson H., Oborn I., Jonsson S., Nilsson I. & Andersson A. (2003). Field balances of some mineral nutrients and trace elements in organic and conventional dairy farming- a case study at Öjebyn, Sweden. *European Journal of Agronomy* **20**(1-2): 101 − 116.
9. Blaise D., Singh J.V., Bonde A.N., Tekale K.U. & Mayee C.D. (2005). Effects of farmyard manure and fertilizers on yield, fibre quality and nutrient balance of rain-fed cotton (*Gossypium hirsutum*). *Bioresource Technology* **96**(3): 345 − 349.
DOI: http://dx.doi.org/10.1016/j.biortech.2004.03.008
10. Bremner J.M. (1996). Chemical methods-nitrogen-total. *Methods of Soil Analysis* (ed. D.L. Sparks), pp. 1085 − 1122. Soil Science Society of America Book Series No.5, Madison, Wisconsin, USA.
11. Bullock D.G. (1992). Crop rotation: critical review. *Plant Science* **11**: 309 − 326.
12. Campbell C.A., Beiderbecke V.O., Center R.P. & Lafond G.P. (1991). Effect of crop rotations and cultural practices on soil organic matter, microbial biomass and respiration in a thin black chernozem. *Canadian Journal of Soil Science* **71**: 363 − 376.
DOI: http://dx.doi.org/10.4141/cjss91-035
13. Christensen B.T. (1988). Effects of animal manure and mineral fertilizer on the total carbon and nitrogen contents of soil size fractions. *Biology and Fertility of Soils* **5**: 304 − 307.
DOI: http://dx.doi.org/10.1007/BF00262136
14. Courtney R.G. & Mullen G.J. (2008). Soil quality and barley growth as influenced by the land application of two compost types. *Bioresource Technology* **99**(8): 2913 − 2918.
DOI: http://dx.doi.org/10.1016/j.biortech.2007.06.034
15. Crews T.E. & Peoples M.B. (2004). Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs. *Agriculture, Ecosystems and Environment* **102**: 279 − 297.
DOI: http://dx.doi.org/10.1016/j.agee.2003.09.018
16. Dalal R.C. & Mayer R.J. (1986). Long-term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. 11. Total organic carbon and its rate of loss from the soil profile. *Australian Journal of Soil Research* **24:** 281 − 292.
DOI: http://dx.doi.org/10.1071/SR9860281
17. Dawe D., Dobermann A., Ladha J.K., Yadav R.L., Bao L., Gupta R.K., Lal P., Sanaullah G., Sariam O., Singh Y., Swarup A. & Zhen Q.X. (2003). Do organic amendments improve yield trends and profitability in intensive rice systems? *Field Crops Research* **83**: 191 − 213.
18. Dressel J., Weigelt W. & Mockel D. (1993). Changes in the nutrient potential of soil according to long-term dressing of farmyard manure and mineral fertilizer. *Agribiological Research* **4**(46): 321 − 330.
19. Evans J., Fettell N.A., Coventry D.R., O'Connor G.E., Walsgott D.N., Mahoney J. & Armstrong E.L. (1991). Wheat response after temperate crop legumes in South-Eastern Australia. *Australian Journal of Agriculture Research* **42**: 31 − 43.
DOI: http://dx.doi.org/10.1071/AR9910031
20. Fox R.H. & Hoftinan L.D. (1981). The effect of N fertilizer source on grain yield, N uptake, soil pH, and lime requirement in no-till corn. *Agronomy Journal* **73**: 891 − 895.
21. Fujita K., Ofosu-Budu K.G. & Ogata S. (1992). Biological nitrogen fixation in mixed legume-cereal cropping systems. *Plant & Soil* **141**: 155 − 175.
DOI:http://dx.doi.org/10.1007/BF00011315
22. Gomez K.A. & Gomez A.A. (1984). *Statistical Procedures for Agricultural Research*, 2nd edition, pp. 680. John Willey & Sons, New York, USA.
23. Goyal S., Sakamoto K., Inubushi L. & Kamaewada K. (2006). Long-term effects of inorganic fertilization and organic amendments on soil organic matter and soil microbial properties in Andisols. *Archives of Agronomy and Soil Science* **52**(6): 617 − 625.
DOI: http://dx.doi.org/10.1080/03650340601048595
24. Guo S.L., Dang T.H. & Hao M.D. (2008). Phosphorus changes and sorption characteristics in a calcareous soil under long-term fertilization. *Pedosphere* **18**(2): 248 − 256.
25. Hao X. & Chang C. (2003). Does long-term heavy cattle manure application increase salinity of a clay loam soil in semi-arid southern Alberta? *Agriculture, Ecosystems and Environment* **94**(1): 89 − 103.
26. Jokela W.E. (1992). Nitrogen fertilizer and dairy manure

effects on corn yield and soil nitrate. *Soil Science Society of America Journal* **56**: 148 − 154.

27. Juo A.S.R., Dabiri A. & Franzluebbers K. (1995). Acidification of a kaolinitic Alfisol under continuous cropping with nitrogen fertilization. *Plant and Soil* **171**: 245 − 253.
DOI:http://dx.doi.org/10.1007/BF00010278
28. Kaihura F.B.S., Kullaya I.K., Kilasara M., Aune J.B., Singh B.R. & Lal R. (1999). Soil quality effects of accelerated erosion and management systems in three eco-regions of Tanzania. *Soil and Tillage Research* **53**(1): 59 − 70.
29. Kue S. (1996). Chemical methods-phosphorus. *Methods of Soil Analysis* (ed. D.L. Sparks), pp. 869 − 919. Soil Science Society of America Book Series No.5, Madison, Wisconsin, USA.
30. McLean E. O. (1982). Soil pH and lime requirement. *Methods of Soil Analysis* (eds. A.L. Page, R.H Miller & D.R. Keeney) Part 2, 2nd edition, pp. 209 − 223. American Society of Agronomy, Madison, Wisconsin, USA.
31. McCullum R.E. (1991). Build up and decline in soil P: 30 years trend. *Agronomy Journal* **83**: 77 − 85.
32. Monaco S., Hatch D.J., Sacco D., Bertora C. & Grignani C. (2008). Changes in chemical and biochemical soil properties induced by 11-yr repeated additions of different organic materials in maize-based forage systems. *Soil Biology and Biochemistry* **40**(3): 608 − 615.
33. Morari F., Lugato E. & Giardini L. (2008). Olsen phosphorus, exchangeable cations and salinity in two long-term experiments of north-eastern Italy and assessment of soil quality evolution. *Agriculture, Ecosystems and Environment* **124**(1-2): 85 − 96.
DOI:http://dx.doi.org/10.1016/j.agee.2007.08.001
34. Mulvaney R.L. (1996). Chemical methods - nitrogen – inorganic forms. *Methods of Soil Analysis,* part 3 (ed. D.L. Sparks), pp. 595 − 624. Soil Science Society of America Book Series No.5, Madison, Wisconsin, USA.
35. Mussgnug F., Becker M., Son T.T., Buresh R.J. & Vlek P.L.G. (2006). Yield gaps and nutrient balances in intensive, rice-based cropping systems on degraded soils in the Red River Delta of Vietnam. *Field Crops Research* **98**(2-3): 127 − 140.
DOI: http://dx.doi.org/10.1016/j.fcr.2005.12.012
36. Nelson D.W. & Sommers L.E. (1982). Total carbon, organic carbon, and organic matter. *Methods of Soil Analysis* (ed. A.L. Page), 2nd edition, pp. 574 − 577. American Society of Agronomy, Madison, Wisconsin, USA.
37. Patra D.D., Anwar M. & Chaud S. (2000). Integrated nutrient management and waste recycling for restoring soil fertility and productivity in Japanese mint and mustard sequence in Uttar Pradesh, India. *Agriculture, Ecosystems and Environment* **80**: 267 − 275.
38. Pratt R.G. (2008). Fungal population levels in soils of commercial swine waste disposal sites and relationships to soil nutrient concentrations. *Applied Soil Ecology* **38**(3): 223 − 229.
DOI:http://dx.doi.org/10.1016/j.apsoil.2007.10.013
39. Purakayastha T.J., Rudrappa L., Singh D., Swarup A. & Bhadraray S. (2008). Long-term impact of fertilizers on soil organic carbon pools and sequestration rates in maize-wheat-cowpea cropping system. *Geoderma* **144**(1-2): 370 − 378.
DOI: http://dx.doi.org/10.1016/j.geoderma.2007.12.006
40. Rhoades J.D. (1996). Chemical methods: salinity; electrical conductivity and total dissolved salts. *Methods of Soil Analysis* (ed. D.L. Sparks), pp. 417 − 436. American Society of Agronomy, Madison, Wisconsin, USA.
41. Simek M., Hopkins D.W., Kalcik J., Picek T., Santruckove H., Stana J. & Travnik K. (1999). Biological and chemical properties of arable soils affected by long term organic and inorganic fertilizer applications. *Biology and Fertility of Soils* **29**: 300 − 308.
DOI: http://dx.doi.org/10.1007/s003740050556
42. Soltanpour P.N. & Schwab A.P. (1977). A new soil test for simultaneous extraction of macro and micro nutrients in alkaline soils. *Communication in Soil Science and Plant Analysis* **8**: 195 − 207.
DOI: http://dx.doi.org/10.1080/00103627709366714
43. Stamatiadis S., Werner M. & Buchanan M. (1999). Field assessment of soil quality as affected by compost and fertilizer application in a broccoli field (San Benito County, California). *Applied Soil Ecology* **12**(3): 217 − 225.
44. Steel R.G.D. & Torri J.H. (1980). *Principles and Procedures of Statistics; A Biometrical Approach*, 2nd edition, pp. 633. McGraw-Hill, New York, USA.
45. Swarup A. (2001). *Lessons from Long-term Fertility Experiments.* Project Coordinating Cell, Indian Council for Agriculture Research, Indian Institute of Soil Science, Bhopal, India.
46. Tagar S. & Bhatti A.U. (1996). Soil physical properties. *Soil Science* (eds. B. Elena & R. Bantel), pp. 250. National Book Foundation, Islamabad, Pakistan.
47. Timsina J. & Connor D.J. (2001). Productivity and management of rice–wheat cropping systems: issues and challenges. *Field Crops Research* **69**: 93 − 132.
48. Toribio M. & Romanya J. (2006). Leaching of heavy metals (Cu, Ni and Zn) and organic matter after sewage sludge application to Mediterranean forest soils. *Science of the Total Environment* **363**(1-3): 11 − 21.
DOI: http://dx.doi.org/10.1016/j.scitotenv.2005.10.004
49. United States Department of Agriculture (1998). *Key to Soil Taxonomy,* 8th edition. Natural Resource Conservation Service, Whitten Building, 14th and Independence Avenue, SW, Washington, DC, USA.
50. US Salinity Laboratory Staff (1954). Alkaline earth carbonates from acid nutralization (Method 23c). *Diagnosis and Improvement in Saline and Alkali Soils* (ed. L.A. Richard), pp. 105. Soil and Water Conservation Research Branch, Agricultural Research Service, USA.
51. Ussiri D.A., Lal R. & Jacinthe P.A. (2006). Post-reclamation land use effects on properties and carbon sequestration in mine soils of southeastern Ohio. *Soil Science* **171**: 261 − 271.

DOI:http://dx.doi.org/10.1097/01.ss.0000199702.68654.1e
52. Wartiainen I., Eriksson T., Zheng W. & Rasmussen U. (2008). Variation in the active diazotrophic community in rice paddy-NIFH PCR-DGGE analysis of rhizosphere and bulk soil. *Applied Soil Ecology* **39**: 65 − 75.
DOI: http://dx.doi.org/10.1016/j.apsoil.2007.11.008
53. Wilson G.F., Lal R. & Okigbo B.N. (1982). Effects of cover crops on soil structure and on yield of subsequent arable crops grown under strip tillage on an eroded Alfisol. *Soil and Tillage Research* **2**: 233 − 250.
54. Yang Z., Singh B.R. & Hansen S. (2007). Aggregate associated carbon, nitrogen and sulfur and their ratios in long-term fertilized soils. *Soil and Tillage Research* **95**(1-2): 161 − 171.
55. Yoo S.H., Jung Y.S. & Shin Y.H. (1974). Deterioration of the physical and chemical properties of vinyl house soils by continuous vegetable cropping. *Journal of the Korean Society of Soil Fertility* **7**: 227 − 234.
56. Zhao M., Zhou J. & Kalbitz K. (2008). Carbon mineralization and properties of water-extractable organic carbon in soils of the south Loess Plateau in China. *European Journal of Soil Biology* **44**(2): 158 − 165.