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Physico-chemical properties and fertility status of water eroded soils of Sharkul area of district Mansehra, Pakistan

Farmanullah Khan[1*], A. Iqbal[1], Naveedullah[2], M. K. Khattak[3] and W. J. Zhou[4]
[1]Soil and Environmental Sciences, KP Agricultural University Peshawar, Pakistan
[2]College of Environment and Resource Sciences, Zhejiang University, P.R. China
[3]Agricultural Mechanization, KP Agricultural University Peshawar, Pakistan
[4]College of Agriculture and Biotechnology, Zhejiang University, P.R. China

Abstract

Soil degradation is the major threat to agricultural sustainability because it affects the soil productivity. Present study was conducted in 2008 to evaluate physico-chemical properties and fertility status of some eroded soil series of Sharkul area district Manshera, Hazara division, Khyber Pakhtunkhwa, Pakistan. Six soil series including slightly eroded (Dosera and Girari), moderately eroded (Nakholi and Sharkul) and severely eroded (Ahl and Banser) were selected. Soil samples were collected from surface (0-15 cm), subsurface (30-45 cm) and substrata soil (60-75cm) depths and were analyzed for various soil properties. Due to severity of erosion, bulk density increased, while total porosity, saturation percentage and organic matter decreased significantly. AB-DTPA extractable P, K, Fe, Cu, Zn, and Mn concentrations were decreased due to the severity of erosion in surface and sub surface soils, whereas in the substrata soils (60-75 cm depth), the effect of erosion was almost non significant. Sub-surface and sub-strata soils were found deficient in available P (< 3 mg kg^{-1}) while available K was in medium range (50-120 mg kg^{-1}). Seventeen percent surface and 33% subsurface samples were deficient in available K. Organic matter (0.42-1.82%) was deficient only in severely eroded soils while satisfactory in moderately and slightly eroded soils All the soils were non saline (EC < 4 dS m^{-1}), pH (7.0-8.6) and slightly calcareous (lime content 0.25-5.20%). Zinc, Fe and Mn contents were low in 44, 39 and 28% samples in surface soils, respectively. The extent of nutrient deficiency was in the order of P > Zn > Fe > Mn. The physical and chemical properties of eroded soils varied significantly and the increasing severity of erosion resulted in corresponding deterioration of soil quality.

Keywords: Water erosion, nutrient deficiencies, soil series, Manshera

Introduction

The soils of the Sharkul area district Manshera are mostly developed from loess deposits and piedmont alluvium and are highly heterogeneous. In the sloping highland areas, soil erosion reduces soil quality through the loss of clay particles, plant nutrients and organic matter. Shafiq *et al*. (1988), in a simulated soil erosion study, observed that de-surfacing of top 15 cm reduced maize and wheat yield by 50%. These losses were restored by the application of 150 kg N + 100 kg P_2O_5 ha^{-1} in wheat. The widespread deficiencies of all major nutrients in the eroded areas are attributed to the loss of relatively fertile surface layer due to accelerated water erosion, coupled with continuous nutrient mining by crops.

Heavy soil losses in Khyber Pakhtunkhwa have been reported by many workers (Ahmad, 1990; Bhatti *et al*., 1997; Khan and Bhatti, 2000; Khan *et al*., 2001). Bhatti *et al*. (1998) revealed that AB-DTPA extractable P was either low or medium in 18 out of 38 sites tested. Out of 12 fields tested from Swat and Malakand Agency, 6 fields were low to medium in available P and all tested sites were low in organic matter contents. Shafiq *et al.* (2005) reported that 98% samples from top soils were deficient in extractable P and 35% samples from top soils and 53 % samples from subsoils were deficient in extractable K in Gujar Khan (Pakistan) eroded areas. These soils were also deficient in Zn and Fe contents.

Soil degradation is the major threat to agricultural sustainability because it affects soil productivity. Therefore, land management and soil degradation control measures are needed to increase agricultural production and ensure conservation of the land resources of the area. For the best management of the soil resources of the area, it is very important to have information about the fertility status of that area. Therefore, the objectives of this study were **i)** to determine physical and chemical properties and soil nutrient status of some of the agriculturally important eroded soil series of Sharkul district and **ii)** to delineate areas into low, medium and high nutrient contents of soils for realizing the agricultural potential of these areas and future planning.

*Email: farmankhan380@hotmail.com

Materials and Methods

The study was conducted on six agriculturally important soil series of Sharkul area district Mansehra, Hazara Division, Khyber Pakhtunkhwa. The climate is humid temperate with an average rainfall of 1111 mm. Based on their extensive and variable degree of erosion status, the series were categorized as slightly eroded (Dosera and Girari), moderately eroded (Nakholi and Sharkul) and severely eroded (Ahl and Banser) (Table 1). These series represent major portion of the arable land.

Site Selection

The soil series were identified according to the Reconnaissance Soil Survey Reports of the Soil Survey of Pakistan (Mian and Javed, 1989). Representative sites of each soil series were identified in the field and soil samples were collected for laboratory analysis.

Profile Study

Each soil series was separately sampled and described. The field in each series was divided into three transacts randomly for the purpose of replications. A pit of 1 m^3 was dug in each transact for detail soil profile description. Description was made according to the principles laid down in the Key to Soil Taxonomy (USDA, 1998). Soil horizons were designated and each of them was described in terms of color, texture, structure, consistence, porosity, calcareousness, kanker and pH. Soil series and their phases were identified on the basis of observations made during the profile study.

Soil sampling

Soil samples from the selected series were collected from surface (0-15 cm), subsurface (30-45 cm) and substrata (60-75 cm) to make comparison among these layers. Soil samples were analyzed for mechanical analysis (Gee and Bauder, 1986), bulks density (Blake and Hartage, 1986), saturation percentage (Gardner, 1986), electrical conductivity (Rhoads and Miyammoto, 1990), organic matter (Nelson and Sommer, 1982), soil pH (Mclean, 1982), AB-DTAPA extractable P and K (Soltanpour and Schwab, 1977), total porosity (Danielson and Sutherland, 1986) and lime content by acid neutralization method (Nelson, 1982).

Statistical Analysis

The data collected was subjected to classical statistical techniques (Steel *et al*., 1997) to obtain summary statistics and to categorize soils into low, medium and high levels of the nutrients as compared with the standard reported by Soltanpour (1985) in Table 2.

Results and Discussion

Soil texture

The data showed significant variation ($P < 0.01$) in sand, silt and clay contents of different soil series at different layers (Table 3). Sand content was greater in moderately eroded soils ((Nakholy and Sharkul series) than slightly eroded soils (Dosera and Girarai series), while in severely eroded soil series, the sand content showed deceasing trend. Within the profile, sand content decreased from surface to subsurface soil in most of the series. The results are supported by Naseem (1998), Khan *et al*. (2003) and Salako *et al*. (2006), who reported that sand content decreased with increasing soil depth. The silt content decreased from surface to subsurface soil in most of the series. Khresat and Qudah (2006) reported that silt content increased toward the surface indicating eolian activity. The clay content increased from surface to subsurface soil showing illuviation of clay. Clay content in subsurface soil was higher than surface soil in most of the series. The clay contents have been eroded from the surface soil. Subsurface soil contains generally higher clay content than the surface soil. Similar results were also reported by Khresat and Qudah (2006) and Salako *et al.* (2006).

Table 1: Classification of soil series sampled from Sharkul area district Manshera, Khyber Pakhtunkhwa, Pakistan

Soil Series	Erosion hazard	Sampling depth (cm)	Series classification
Dosera	Minor	0-15, 30-45, 60-75	Fine loamy, mixed, thermic typic Haplodalfs
Girari	Minor	0-15, 30-45, 60-75	Fine loamy, mixed, thermic Typic Dystrudepts
Nakholi	Moderate	0-15, 30-45, 60-75	Coarse loamy, mixed, thermic Typic Dystrudepts
Sharkul	Moderate	0-15, 30-45, 60-75	Coarse loamy, mixed, thermic, Typic Udorthents
Bansar	Severe	0-15, 30-45, 60-75	Coarse loamy, mixed, thermic, Lithic Udorthents
Ahl	Severe	0-15, 30-45, 60-75	Coarse loamy, mixed, thermic, Lithic Udorthents

Bulk density

Variation in bulk density was significant ($P < 0.01$) among different soil series. Bulk density was the lowest in surface soil, followed by subsurface soil and the highest bulk density was found in the substrata of different series (Table 3). Increase in bulk density with severity of erosion may partly be attributed to organic matter depletion and low aggregation due to severity of erosion. Salako *et al*. (2006) reported that bulk density increased with soil depth from 1.35-1.64 g cm^{-3} indicating that subsoil horizons were more compact due to higher clay and gravel contents and sticky consistency. Similar results were also reported by Shafiq *et al*. (1988) and Khan *et al*. (2003), who reported that loose and porous top soil had low bulk density than compact subsoil.

Table 2: Generalized guideline for interpreting soil nutrient status

AB-DTPA extractable nutrients	Low	Medium	High
	mg kg^{-1}		
	Havelin and Soltanpour (1981)		
P	≤ 3	4-7	>11
K	≤ 60	61-120	>120
	Soltanpour (1985)		
Zn	≤ 0.9	0.9-1.5	> 1.5
Cu	≤ 0.3	0.3-0.5	> 0.5
Fe	≤ 3.0	3.1-5.0	> 5.0
Mn	≤ 0.6	0.6-1.0	> 1.0

Saturation percentage

Variation in saturation percentage among different soil series was significant ($P < 0.01$). Saturation percentage was highest in slightly eroded soil series (Desera and Girarari), followed by moderately eroded soil series (Nakholi and Sharkul) while, severely eroded soil series (Ahl and Banser) had the lowest saturation percentage (Table 3). Variation in saturation percentage may be due to the change in soil structure, soil texture and decrease in organic matter content. Organic matter improves soil aggregate formation, which consequently improves moisture retention in soil. Frye (1987) reported that soils having more organic matter form granular aggregates and are comparatively more receptive to water.

Soil reaction (pH)

Variation in soil pH value was highly significant ($P < 0.01$) among different soil series (Table 4). Soil pH showed increasing trend down the profile depending on increasing salt concentration due to leaching. Thus pH values of severely eroded series (Ahl and Banser) was higher than the pH of slightly eroded series (Dosera and Girarai). The low pH of surface soil may be attributed to the leaching of the salts. The results are supported by the findings of Khattak (1996), who reported that organic matter decomposition and mono-ammonium-phosphate (MAP) fertilizers produce H^+ ions in soil solution, which significantly decrease soil pH of the surface soil.

Electrical conductivity (EC 1:5)

Variation in EC among the different soil series was non significant (Table 4). The lowest EC values (2.50 and 2.65 dS m^{-1}) were observed in the surface soils of moderately eroded series (Nakholi and Sharkul) and the highest values (2.90 to 2.94 dS m^{-1}) were observed in the surface soils of the slightly eroded series (Girari) and severely eroded soil (Banser). As compared to the surface soil, EC was high in subsurface soil within the profile. This may be attributed to the leaching of salts from top soil and accumulation in the compact subsoil. Putman and Alt (1987) observed that soil erosion depletes soil productivity by changing concentration of salts in the root zone and William *et al*. (1981) reported that subsoil conditions include high soluble salts, high EC and high bulk density.

Lime content (%)

Variation in lime content of different series was non-significant ($P < 0.05$) in Table 4. In slightly eroded series, lime content was more in surface soils as compared to subsurface soils, while in severely eroded series, lime content was higher in subsurface and substrata soils. The greater lime content of the subsurface soils of eroded series may be due to leaching of lime from surface to subsurface horizons. Miller *et al*. (1984) and Shafiq *et al*. (2005) also found higher $CaCO_3$ cocentration as the severity of erosion increased. But the effect of parent material on lime concentration is also important. If parent material contains more lime stone, more $CaCO_3$ is expected in C-horizon (Khattak, 1996).

Soil organic matter (%)

Variation in soil organic matter content among different soil series was significant ($P < 0.01$) (Table 4). The highest organic matter content of 1.82 and 1.67% was found in the surface layer of Dosera and Girari soil series (slightly eroded) respectively, followed by surface soils of moderately eroded series (Sharkul and Nakholi). The lowest organic matter content of 0.84 and 0.87 % was found in the surface layers of severely eroded series (Ahl and Banser). When the surface soil is removed by erosion, the subsoil containing low organic matter is exposed and thus soils with erosion hazards had low organic matter as compared to that of slightly eroded soils. The reduction in soil organic matter due to erosion is reported by Helberg *et al.* (1978), Bhatti *et al.* (1998), Khan *et al.* (2004). Ailincai *et al*. (1992) also reported that eroded soils were low in organic matter content.

Table 3: Mean values of some physical properties of different soil series of Sharkul area district Manshera, Khyber Pakhtunkhwa, Pakistan

Soil Property	Soil Depth (cm)	Soil Series						LSD $_{0.05}$
		Slightly eroded		Moderately eroded		Severely eroded		
		Dosera	Girari	Nakholi	Sharkul	Ahl	Banser	
Sand %	0-15	32.40 d	53.20 c	60.00 b	71.40 a	22.10 e	59.80 b	1.66
	30-45	30.80 e	27.40 f	63.70 a	51.30 b	35.30 d	49.20 c	1.17
	60-75	39.20 bc	32.00 c	54.20 a	34.60 c	45.90 b	53.90 a	7.65
Silt %	0-15	49.70 b	33.20 c	30.40 d	19.80 e	69.10 a	32.50 c	1.69
	30-45	45.20 b	40.00 cd	27.40 f	31.90 e	58.90 a	40.90 c	2.01
	60-75	36.90 b	47.40 a	30.80 c	38.20 b	46.20 a	34.90 bc	5.68
Clay %	0-15	17.90 a	13.50 b	9.60 c	8.80 cd	8.80 cd	7.60 d	1.55
	30-45	23.90 b	32.50 a	8.90 d	16.70 c	5.70 e	9.80 d	2.60
	60-75	23.80 ab	20.60 b	14.90 c	27.20 a	7.80 e	11.00 ce	4.27
Bulk	0-15	1.28 c	1.30 c	1.35 b	1.35 b	1.44 a	1.44 a	0.04
density	30-45	1.34 c	1.35 c	1.40 b	1.41 b	1.44 a	1.44 a	0.02
(Mg m^{-3})	60-75	1.44 a	1.44 a	1.42 a	1.43 a	1.43 a	1.42 a	0.03
	0-15	40.10 a	38.30 ab	36.20 b	36.50 b	29.20 c	29.40 c	2.81
Saturation	30-45	33.70 a	32.20 a	30.10 b	29.40 b	26.70 c	26.50 c	1.68
%	60-75	26.50 a	27.50 a	26.80 a	26.00 a	25.70 a	25.90 a	3.10

Means followed by common letters within a column are non-significant with each other at 5% level of significance

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

Variation in P content among different soil series was significant ($P < 0.01$) (Table 4). Phosphorus content was higher (4.40 and 4.6 mg kg^{-1}) in slightly eroded soil series (Dosera and Girari) in surface than subsurface layers (2.3 and 2.7 mg kg^{-1}) followed by moderately eroded soil series (Nakholi and Sharkul) with P content 3.77 to 3.45 mg kg^{-1} in surface and 1.25 and 1.34 mg kg^{-1} P in the subsurface soils. Severely eroded soil series (Ahl and Banser) had the lowest P content (2.77 and 2.84 mg kg^{-1}) in surface and subsurface soil (0.82 and 0.96 mg kg^{-1}). The P contents in all series were deficient (Rashid, 1996). Pruess *et al*. (1992) observed that soil organic matter decreased due to erosion which decreased available P content of the soil. The other reason for P deficiency might be due to continuous cropping without applying proper amount of phosphorus fertilizers. The lower level of available P in severely eroded soils is also reported by Miller *et al*. (1984), Langdale and Shrader (1991), Khan *et al*. (2004) and Shafiq *et al*. (2005).

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

There was significant variation ($P < 0.01$) in AB-DTPA extractable potassium content. (Table 4). Potassium contents were more in slightly eroded soil series (Dosera and Girari) in surface and subsurface soils than moderately eroded soil series (Nakholi and Sharkul). Severely eroded soil series (Ahl and Banser) had the lowest K content in surface and subsurface soils. The decrease in K content of eroded series may be attributed to the removal of top fertile soil due to water erosion. About 87% samples from surface soils had medium range of K content and it appears that the soils will become deficient in K in the near future. The lower level of available K in severely eroded soils was also reported by Miller *et al*. (1984), Khan *et al*. (2004) and Shafiq *et al*. (2005). Bhatti *et al*. (1998) also reported low organic matter content and P, K and Zn deficiencies in the eroded lands of district Swat and Malakand Agency.

Micronutrients (mg kg^{-1})

Variation in extractable iron contents among different soil series was significant (Table 4). Iron contents were more in slightly eroded soil series (Dosera and Girari) in surface and subsurface soils than moderately eroded soil series (Nakholi and Sharkul). Severely eroded soil series (Ahl and Banser) had the lowest Fe contents in surface and subsurface layers. Copper content was more in slightly eroded soil series (Dosera and Girari) at surface, subsurface and substrata soils than moderately eroded soil series (Nakholi and Sharkul), while severely eroded soil series (Ahl and Banser) had the lowest Cu contents at surface, subsurface and substrata soil layers.

Variation in extractable zinc contents among different soil series was significant ($P < 0.05$) (Table 6). Zinc content was more in slightly eroded soil series i.e. (Dosera and Girari) at subsurface, and substrata soils than moderately eroded soil series (Nakholi and Sharkul). While severely eroded soil series (Ahl and Banser) had the lowest Zn contents at surface, subsurface and substrata soil layers.

Table 4: Mean values of some chemical properties of different soil series of Sharkul area district Manshera KP, Pakistan

Soil Property	Soil Depth (cm)	Soil Series						LSD $_{0.05}$
		Slightly eroded		Moderately eroded		Severely eroded		
		Dosera	Girari	Nakholi	Sharkul	Ahl	Banser	
pH	0-15	7.12 d	7.53 c	7.7 7 bc	7.9 8ab	8.31 a	8.35 a	0.39
	30-45	7.58 b	7.71 b	825 a	8.28 a	8.58 a	8.48 a	0.46
	60-75	8.3 8 ab	8.15 b	8.55 a	8.43 ab	8.56 a	8.39 ab	0.33
EC	0-15	2.74 a	2.94 a	2.50 a	2.65 a	2.80 a	2.90 a	0.74
(dS m^{-1})	30-45	2.70 a	2.57 a	2.93 a	2.87 a	3.08 a	3.03 a	0.56
	60-75	2.72 b	2.94 b	2.88 b	3.18 b	3.80 a	3.90 a	0.58
Lime (%)	0-15	2.57 ab	1.84 b	4.46 a	3.41 ab	3.65 ab	3.04 ab	2.04
	30-45	1.41 b	1.72 ab	2.11 ab	3.15 a	3.36 a	1.73 ab	1.64
	60-75	1.70 b	1.59 b	1.59 b	4.55 a	4.62 a	3.18 ab	1.95
Organic	0-15	1.82 a	1.67 b	1.10 c	1.13 c	0.84 d	0.87 d	0.13
matter (%)	30-45	0.93 a	0.88 a	0.67 b	0.67 b	0.46 c	0.49 c	0.09
	60-75	0.42 a	0.42 a	0.41 a	0.41 a	0.41 a	0.42 a	0.03
AB-DTPA	0-15	4.46 a	4.59 a	3.77 b	3.45 b	2.77 c	2.84 c	0.38
P (mg kg^{-1})	30-45	2.26 b	2.74 a	1.25 c	1.34 c	0.82 d	0.96 d	0.21
	60-75	1.17 a	1.18 a	1.17 a	1.17 a	1.17 a	1.17 a	0.07
AB-DTPA	0-15	113.02 a	118.22 a	77.62 c	88.15 b	61.12 d	58.59 d	6.34
K (mg kg^{-1})	30-45	99.25 a	95.18 a	71.92 b	69.19 b	54.15 c	54.62 c	7.80
	60-75	78.72 a	77.02 a	76.69 a	75.56 a	75.95 a	75.16 a	4.57
AB-DTPA	0-15	4.95 a	4.48 b	3.18 c	3.16 c	2.41 d	2.40 d	0.46
Fe (mg kg^{-1})	30-45	3.73 a	3.72 a	2.52 b	2.74 b	1.96 c	1.85 c	0.28
	60-75	2.10 a	1.94 ab	2.02 ab	2.24 a	1.33 b	1.33 b	0.76
AB-DTPA	0-15	0.55 a	0.45 b	0.37 c	0.34 cd	0.32 cd	0.29 d	0.07
Cu (mg kg^{-1})	30-45	0.43 a	0.42 a	0.29 b	0.27 bc	0.22 c	0.21 c	0.07
	60-75	0.28 a	0.22 ab	0.22 b	0.18 b	0.17 b	0.12 c	0.05
AB-DTPA	0-15	1.51 a	1.47 a	0.92 c	0.91 c	0.37 e	0.36 e	0.16
Zn (mg kg^{-1})	30-45	0.36 ab	0.41 a	0.33 ab	0.29 bc	0.20 c	0.22 c	0.11
	60-75	0.29 ab	0.32 a	0.27 ab	0.21 bc	0.12 c	0.12 c	0.09
AB-DTPA	0-15	0.95 a	0.94 a	0.66 b	0.60 b	0.43 c	0.44 c	0.09
Mn (mg kg^{-1})	30-45	0.87 a	0.82 a	0.50 b	0.43 b	0.26 c	0.24 c	0.09
	60-75	0.75 a	0.65 b	0.36 c	0.36 c	0.24 d	0.18 d	0.08

Means followed by common letters within a column are non-significant with each other at 5% level of significance

Bhatti *et al.* (1998) also reported (Zn) deficiency in eroded soils of northern areas.

Variation in extractable manganese contents among different soil series was significant ($P < 0.05$) in Table 6. Manganese content was more in slightly eroded soil series (Dosera and Girari) at surface, subsurface and substrata soil layers than moderately eroded soil series (Nakholi and Sharkul). While severely eroded soil series (Ahl and Banser) had the lowest Mn contents at surface, subsurface and substrata soil layers.

Descriptive statistics of soil properties

Soil Texture

Sand content ranged from 22 to 71% with a mean value of 50%, 27 to 65% with a mean value of 44% and 24 to 58% with a mean value of 43% in surface, subsurface and substrata soils of different soil series respectively (Table 5). However, the coefficient of variation of the three depths were not similar which shows variable distribution in all the depths. Silt content ranged from 19 to 69% with a mean value of 39%, 26 to 61% with a mean value of 41% and 28 to 48% with a mean value of 39% in surface, subsurface and substrata soils of different soil series, respectively (Table 5). The distribution of silt content was also variable. Clay content ranged from 6 to 19% with a mean value of 11%, from 5 to 33% with a mean value of 10% and 8 to 30% with a mean value of 18% in surface, subsurface and substrata soils of different soil series, respectively (Table 5).

Saturation percentage

Saturation percentage ranged from 28 to 29%, 25 to 38% and 23 to 29% with average values of 35,

Table 5: Descriptive statistics of soil properties of Sharkul area district Mansehra, KP, Pakistan

Property	Soil depth(cm)	Range	Mean	SD	CV %
Sand (%)	0-15	21.98-71.40	49.84	17.63	35.36
	30-45	26.98-64.58	43.91	13.12	29.87
	60-75	24.38-57.98	43.32	9.77	22.72
Silt (%)	0-15	19.18-69.18	39.24	16.51	42.06
	30-45	26.38-60.58	40.75	10.40	25.52
	60-75	27.98-47.58	39.10	6.64	11.96
Clay (%)	0-15	6.25-19.24	11.04	3.79	34.31
	30-45	4.85-33.05	16.29	9.76	59.99
	60-75	7.64-30.25	17.80	7.61	42.01
Saturation (%)	0-15	27.68-40.68	34.99	4.53	12.95
	30-45	25.38-34.68	27.79	2.84	9.51
	60-75	23.38-28.68	26.28	1.52	5.76
Bulk density Mg m^{-3}	0-15	1.25-1.45	1.36	0.068	4.99
	30-45	1.34-1.45	1.43	0.040	1.18
	60-75	1.40-1.45	1.43	0.017	1.18
pH	0-15	7.00-8.58	7.45	0.479	6.00
	30-45	7.29-8.59	8.15	0.435	5.35
	60-75	8.00-8.60	8.41	0.205	2.43
EC (1:5) d sm^{-1}	0-15	2.23-3.33	2.76	0.357	12.92
	30-45	2.19-3.29	2.87	0.302	10.52
	60-75	2.36-4.21	3.24	0.531	16.37
Lime content (%)	0-15	0.25-5.20	3.17	1.236	39.03
	30-45	0.55-4.55	2.25	1.086	48.30
	60-75	0.58-5.28	2.87	1.611	56.05
Organic matter (%)	0-15	0.75-1.94	1.241	0.395	31.82
	30-45	0.44-0.94	0.688	0.184	22.09
	60-75	0.39-0.45	0.419	0.020	4.77

Table 6: Plant nutrients status of the soils of Sharkul area district Mansehra, KP, Pakistan

Nutrient (mg kg^{-1})	Soil depth (cm)	Range	Mean	SD	CV %	% of Sample		
						L	M	A
P	0-15	2.55-4.99	3.65	0.760	20.82	28	75	0
	30-45	0.73-2.93	1.62	0.740	45.32	100	0	0
	60-75	1.11-1.23	1.18	0.032	2.72	100	0	0
K	0-15	56.89-120	86.12	24.02	27.8	17	83	0
	30-45	50.89-105	74.05	18.53	25.02	33	67	0
	60-75	71.79-82.2	76.52	3.29	4.30	0	100	0
Fe	0-15	2.06-5.07	3.44	1.02	29.70	39	61	0
	30-45	1.65-4.00	2.76	0.788	28.55	67	33	0
	60-75	1.20-2.99	1.83	0.51	7.80	100	0	0
Cu	0-15	0.29-0.62	0.39	0.098	25.12	0	83	17
	30-45	0.19-0.47	0.31	0.093	30.00	6	94	0
	60-75	0.10-0.31	0.203	0.057	28.07	39	61	0
Zn	0-15	0.15-1.57	0.849	0.458	57.12	44	34	22
	30-45	0.19-0.48	0.307	0.090	29.31	100	0	0
	60-75	0.10-0.42	0.223	0.096	43.04	100	0	0
Mn	0-15	0.40-1.06	0.673	0.222	32.98	28	61	11
	30-45	0.21-0.99	0.525	0.256	48.76	50	50	0
	60-75	0.19-0.90	0.428	0.222	51.86	67	33	0

L = Low: M = Medium: A = Adequate

30 and 26% in surface, subsurface and substrata soils of different soil series, respectively.

Bulk density

Bulk density ranged from 1.25 to 1.45 Mg m^{-3} in surface soil, 1.34 to 1.45 Mg m^{-3} in the subsurface soil and 1.40 to 1.45 Mg m^{-3} in the substrata soil with mean values of 1.36, 1.40 and 1.43 Mg m^{-3}, respectively (Table 5). Bulk density was found higher in sub surface and sub strata soils as compared to surface soil.

Soil pH

Soil pH ranged from 7.0 to 8.58 with a mean value of 7.45, 7.29 to 8.59 with a mean value of 8.15, 8.00 to 8.60 with a mean value of 8.41 in surface, subsurface and substrata soils of different soil series, respectively (Table 5). The pH of the subsurface soil was greater than the pH of the surface soil, obviously because of greater $CaCO_3$ in the subsoil.

EC (1:5) dS m^{-1}

Electrical conductivity ranged from 2.23 to 3.33 with a mean value of 2.76 dS m^{-1}, 2.19 to 4.21 with a mean value of 2.87 dS m^{-1} and 2.36 to 4.21 with a mean value of 3.24 dS m^{-1} in surface, subsurface and substrata soils of different soil series, respectively. The results suggest that the soils are free from salinity problems.

Lime content

Lime content ranged from 0.25 to 5.20, 0.55 to 4.55 and 0.58 to 5.28% with mean values of 3.17, 2.25 and 2.87% in surface, subsurface and substrata soils of different soil series, respectively (Table 5). The soils were non calcareous to slightly calcareous. Eroded soil series had comparatively more lime content than slightly eroded soil series.

Organic matter

Organic matter content ranged from 0.75 to 1.94%, 0.44 to 0.94% and 0.39 to 0.45% with mean values of 1.24, 0.69 and 0.42% in surface, subsurface and substrata soils of different soil series, respectively. Organic matter content was considerably lower in the subsurface soil than in the surface soils of different series.

Soil fertility status

Phosphorus

Available P content ranged from 2.55 to 4.99, 0.73 to 2.93 and 1.11 to 1.23 mg kg^{-1} in surface, subsurface and substrata soils of different soil series, respectively (Table 6). Consequently, 28% surface samples and 100% of the subsurface and substrata soil samples were deficient in available P based on the criteria given by Soltanpour (1985). The P deficiency in these soils is a serious nutrient constraint to crop productivity.

Potassium

Available K content ranged from 56.89 to 120.49, 50.89 to 105.90 and 71.79 to 82.29 mg kg^{-1} with an average of 86.12, 74.05 and 76.52 mg kg^{-1} in surface, subsurface and substrata soils of different soil series, respectively (Table 6). Consequently 17% of the surface samples, 33% of the subsurface samples and 100% of the substrata samples were deficient in available K based on the criteria given by Soltanpour (1985).

Micronutrients

Iron was found deficient in 33% of the surface samples, 67% in the subsurface samples, while the samples of the substrata soils were found 100% deficient in Fe content. Six percent samples of the sub surface soils and 39% samples of the substrata soils were found deficient in Cu, while none of the sample of the surface soil was found deficient in Cu. Zinc was found deficient in 44% of the surface samples, while 100% samples of the subsurface and substrata soils were deficient in Zn content. Manganese deficiency was observed in 28% of the surface samples, 50% of the subsurface samples, while 100% samples of the substrata soils were deficient in Mn content. Coefficients of variation for these micronutrients ranged from 7.80 to 57.12%. The results of this study show that the soils are deficient in various plant nutrients to different extent.

Conclusions

The physical and chemical properties of eroded soils varied significantly and the increasing severity of erosion resulted in corresponding deterioration of soil quality.

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