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Some physico-chemical properties of soil as influenced by surface erosion under different cropping systems on upland-sloping soil

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Abstract

Considering the importance of erosion, this experiment was conducted on sloping land in northern NWFP, Pakistan for 3-years. The objectives of this study were to monitor runoff, soil loss and enrichment of eroded soil material and to assess the effect of cumulative soil loss on some soil properties under mono-cropping of wheat and maize and inter-cropping of barley-legume and maize-legume in comparison with bare fallow. Total runoff and soil losses from bare plots were 1.64 and 1.92 times higher than from inter-cropped plots. Inter-cropped plots reduced erosion by 48% whereas mono-cropping by 36%. Nutrient enrichment ratio of the sediment was > 1, indicating higher losses of nutrients in sediment. Changes in soil pH, soil organic matter and K content were significantly correlated with cumulative soil loss whereas lime content, bulk density, N and P were non-significantly correlated with soil loss. Bare plots showed a significant decline in organic matter, N, P and K content following erosion. Inter-cropping was more efficient in maintaining soil properties.

Key words: soil erosion, soil properties, cropping systems, mono-cropping, legume-intercropping, bare-fallow.

Introduction

Soil erosion and water loss hazards in rainfed areas are very severe. It has been reported that 76% of the total area of Pakistan is subjected to erosion in one form or the other. Out of which water erosion is active on 36% and wind erosion on 40% area (Rafiq, 1984). The high rates of erosion are likely to occur in the highlands of northern NWFP, Pakistan, where a near absence of a protective vegetative cover and steep cultivated slopes are formed without adequate soil conservation measures.

Research findings on the relationship between soil loss and productivity indicate that erosion causes considerable deterioration in soil fertility and crop yields (National Soil Erosion-Soil Productivity Research Planning Committee, 1981). The erosion hazards cause a loss of available plant nutrients and organic matter, degradation of soil structure, decrease rooting depth and decreased soil storage capacity for crop production, which is based on the quality of the soil physical, chemical and biological properties. According to Lal and Singh (1998), soil degradation process with reference to productivity encompass physical, chemical and biological degradation. Soil physical degradation can affect crop growth and yield by decreasing root depth, available water and nutrient reserves and soil erosion can lead to yield loss by affecting soil organic carbon, nitrogen, phosphorus and potassium contents and soil pH. Chemical degradation is caused by the processes of nutrient depletion and/or loss of organic matter, acidification and toxic aluminium, salinization and industrial and mining activities.

Various measures like crop and soil management practices can be adopted to control soil losses and conserve the fertility of the soil and to avoid the deterioration of soil physico-chemical properties on sloping lands. Chaudry and Shafiq (1986) concluded that crop management being the easiest tool of soil conservation can be accomplished by making an appropriate combination of crop selection, method of sowing, mulching, cover crops, strip cropping and application of fertilizers. Elwell (1981) demonstrated an exponential decrease in soil loss with increasing percentage of interception of rainfall energy by increasing canopy cover. Khisa *et al.* (2002) recorded the highest (3.30 t ha^{-1}) and the lowest (0.35 t ha^{-1}) soil losses from 0.0% and 43.20% crop cover, respectively.

The selection of inter-crops for a cropping system can be based on their efficiency in controlling soil erosion and for their beneficial effects on the growth and yield of major crops.

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Good plant cover controls erosion by minimizing the erosive effects of raindrops and runoff. Almas and Jamal (1999) reported that inter-crop of banana-pineapple reduced soil and runoff losses by 75 and 43% respectively in comparison with bare fallow, while N P K losses were reduced by 74, 50 and 26% under inter-cropping. Khisa *et al.* (2002) recorded 88% reduction in soil losses under maize-Mucuna pruriens inter-crop as compared to the pure stand of maize.

Long term use of a wheat-maize rotation on a typical chernozem affected by erosion, made soil physico-chemical properties worse compared to a pea-wheat-maize crop rotation, decreasing the humus content by 0.67 units, pH by 0.8 units and the base saturation degree by 3% (Ailincai *et al.*, 1997). The fertile soil favours high yield and good plant cover which consequently improves/maintains the soil structure and minimizes the erosive effects of rain drops and runoff. It is, therefore, important to develop a package of technology for cropping pattern and management practices in accordance with rainfall pattern and soil characteristics under local conditions for obtaining an increase in yield and reduction in soil and water losses. It is also necessary to provide data for erosion modeling and simulation to prevent soil physical and chemical degradation. In this paper an attempt has been made to assess soil losses and the effect of these soil losses on soil physico-chemical properties under wheat and maize mono-cropping and barley-legume and maize-legume inter-cropping in comparison with bare fallow to understand the relationship between soil erosion and soil physico-chemical properties and generate data for development of soil and moisture conservation techniques.

Material and methods

The experiment was conducted at village Thana, Malakand Agency, NWFP on an eroded field for 3-years (03 rabi + 03 kharif seasons) from October 1999 to September 2002. The field is located on sloping land and is mainly used for rainfed agriculture. Erosion, shortage of moisture and traditional management are the main limitations of the area. Land is degraded due to past soil erosion and crop productivity is very low. About one acre field of 6% slope was selected and permanent plots of 2 x 5 m^2 size each were established. Cemented sediment tanks measuring 1.5 x 1 x 1 m^3 each, were constructed at the bottom of plots to collect total runoff and sediment from each respective plot.

The experimental design was RCB with three replications. The treatments maintained were, wheat (mono-cropping), barley+lentil (inter-cropping) and control (bare soil) in Rabi season and maize (mono-cropping), maize+mung-beans (inter-cropping) and control (bare soil) in Kharif season. Sowing of wheat and barley in Rabi season was done in the mid of October, 1999, 2000 and 2001 and sowing of maize in Kharif season was done in the mid of June, 2000, 2001 and 2002. A fertilizer rate of 120-90-60 kg N-P_2O_5-K_2O ha^{-1} was applied. Fertilizer sources were urea for N, SSP for P and potassium sulfate for K. All the recommended cultural practices were followed during the growth period of the crops.

Composite soil samples from experimental site were collected from 0-20 cm depth before sowing. All the samples were analyzed for organic matter (Nelson and Sommers, 1982), pH (McLean, 1982), lime (Nelson, 1982), and AB-DTPA extractable P and K (Olsen and Sommer, 1982), and mineral nitrogen by semi-Kjeldahl digestion method (Jackson, 1982). Some physico-chemical properties of the experimental soil are shown in Table1.

Table 1. Physico-chemical characteristics of the experimental site

Characteristics	Value
Sand (%)	18
Silt (%)	59
Clay (%)	23
Textural Class	Silt Loam
Bulk Density (Mg m^{-3})	1.28
Soil $pH_{(1:5)}$	8.25
Organic Matter (%)	0.87
Lime (%)	22.33
Mineral N (mg kg^{-1} soil)	23
ABDTPA Ext. P (mg kg^{-1} soil)	5.03
ABDTPA Ext. K (mg kg^{-1} soil)	131

After every storm, runoff was measured with volume depth ratio of each tank. Ten liters sample of runoff was collected from each tank for analyzing nutrient loss in sediment and surface runoff. Sediment in g L^{-1} was also calculated. Analysis for organic matter and plant nutrients in sediment was carried out after each storm. The nutrient enrichment ratio for the nutrients was calculated by dividing the concentration of the nutrients in sediment by its concentration in the native soil. Total runoff, soil and nutrient losses were monitored for a total period of 3-years (03 Rabi and 03 Kharif seasons). The incident rainfall amount was measured at the site.

All the data collected on runoff, soil and nutrient losses were statistically analyzed according to the procedures given by Steel and Torrie, 1980. Coefficient of correlation (r) between soil losses and changes in soil physico-chemical properties were also calculated.

Results and discussion

The results on soil properties as influenced by soil losses under wheat and maize mono-cropping and barley-legume and maize-legume inter-cropping in comparison with bare fallow for 3-years (October, 1999 to September, 2002) are presented and discussed as follows:

Rainfall Distribution

The amount and distribution of precipitation that causes runoff varied during this 3-year study. Table 2 shows the monthly distribution of rainfall at the experimental site. Number of rainfalls that produced runoff during Rabi season were 4, 3 and 5 in 1999-2000, 2000-01 and 2001-02, respectively, while during Kharif season, the recorded number of rainfalls that causes runoff were 4, 5 and 5 in 2000, 2001 and 2002 respectively.

Total precipitation during Kharif season was almost 1.51 times higher than the precipitation occurred in Rabi season. During Rabi seasons annual rainfall that causes runoff in 1999-2000, 2000-01 and 2001-02 was 161, 105 and 202 mm, respectively with 30, 20, 17 and 19% falling in December, January, March and April respectively. While during Kharif seasons, annual precipitation that causes runoff in 2000, 2001 and 2002 was 215, 244 and 248 mm, respectively with 46 and 45% falling in July and August.

Total Runoff and Soil Loss

From October 1999 to September 2002, total runoff from bare plots (T3) was almost 1.32 and 1.64 times higher than from T1 (mono-cropping) and T2 (inter-cropping), respectively (Table 3). T2

Table 2. Monthly distribution of rainfall that caused runoff during the experimental period

RABI			KHARIF		
	1999-2000			**2000**	
	Month	**Rain fall (mm)**		**Month**	**Rain fall (mm)**
1	Nov	25	1	July	40
2	Dec	40	2	July	60
3	Jan	48	3	Aug	50
4	Mar	48	4	Aug	65
	Total	**161**		**Total**	**215**
	2000-01			**2001**	
1	Dec	35	1	July	48
2	Mar	30	2	July	40
3	Apr	40	3	Aug	28
--	--	--	4	Aug	68
--	--	--	5	Sep	60
	Total	**105**		**Total**	**244**
	2001-02			**2002**	
1	Dec	30	1	July	30
2	Dec	35	2	July	45
3	Jan	45	3	July	65
4	Feb	40	4	Aug	68
5	Apr	52	5	Aug	40
	Total	**202**		**Total**	**248**

Table 3. Runoff and Soil losses for 3-years

Treatments	Runoff	Soil Loss
Cumulative Runoff and Soil Losses for 03 Rabi Seasons		
	m^3	kg ha^{-1}
T1. Wheat	0.69b	5920b
T2. Barley+Lentil	0.62b	5159c
T3. Bare	1.10a	7946a
LSD (0.05)	0.124	319.4
Cumulative Runoff and Soil Losses for 03 Kharif Seasons		
T1. Wheat	10.32b	31394b
T2. Barley+Lentil	8.23b	25557c
T3. Bare	13.40a	50976a
LSD (0.05)	2.53	4529
Cumulative Runoff and Soil Losses for 3-years (06 seasons)		
T1. Mono-Cropping	11.0b	37314b
T2. Inter-Cropping	8.85b	30716c
T3. Bare	14.50a	58922a
LSD (0.05)	2.33	4374

Means followed by similar letters in each column do not differ significantly from one another at 5% level of probability using LSD Test.

reduced runoff losses significantly than T3 but was comparable statistically with T1. Inter-cropping (T2) reduced runoff by 39%. The same trend was found individually in both the seasons, Rabi and Kharif. Runoff produced during Kharif season was higher than from runoff produced during Rabi season. It was due to high rainfall in Kharif season.

Cumulative soil loss for the entire 3-years and individually for each season (total of 03 Rabi and 03 kharif seasons) is given in table 3. The highest soil loss in each season was obtained from the T3 treatment (bare plots) while the lowest soil loss was recorded from T2 (inter-cropping). Total soil losses from bare plots (T3) were 1.58 and 1.92 times higher than from T1 (mono-cropping) and T2 (inter-cropping), respectively. Inter-cropping reduced soil losses by 48%. All the plots showed significant difference when plots were under different cropping systems due to the difference in plant cover and sediment filtering capacity. Variation in soil loss among different plots needed to be achieved before assessing the effect of variable soil erosion on soil properties.

More effectiveness of inter-cropping as compared to the mono-cropping in reducing runoff and soil losses was due to providing more surface cover to soil and strong barrier to runoff flow. Inter-cropping reduced runoff velocity and provided much time for infiltration of runoff water and also for sediment to settle down and had a good filtration capacity for sediment to filter out from the surface runoff and ultimately less amount of sediment contributed to the sediment tanks. The effectiveness of surface cover can be influenced by the amount and intensity of rainfall, but increase in surface cover effectively reduced soil loss as shown in Fig. 1. This trend indicates that adequate surface cover is necessary to protect soil from erosion. Highest surface cover and lowest soil losses from the inter-cropped plots as compared to mono-cropping were observed by Khisa *et al.* (2002). The canopy might have reduced soil surface sealing by raindrop impact and thus maintained higher infiltration rates (Almas and Jamal, 1999). These results are well in agreement with the findings of Gilley *et al.* (1986), Almas and Jamal (1999) and Khan and Bhatti (2000), who demonstrated that maintenance of adequate surface cover may serve to conserve soil and water resources.

Nutrient Enrichment Ratio

Chemical and organic losses can be expressed as "enrichment ratio". The ratio of nutrient concentration in the eroded sediment to that in the original soil is called nutrient enrichment ratio (Gachene *et al.*, 1997; Almas and Jamal, 1999). A comparison of the nutrients in sediments to that in the original soil for each treatment is shown in Table 4. The nutrient enrichment ratio for all the plots is greater than 1, which suggests that there is a higher loss of nutrients due to soil erosion. The nutrient losses in surface runoff may be further attributed to lower aggregate stability, dispersion of nutrient enriched clay particles and break down of aggregates by direct raindrops impact, causing more transportation of soil particles. Almas and Jamal (1999) and Gachene *et al.* (1997) also reported that the enrichment ratio was greater than 1, indicating that there was higher loss of nutrients in sediment and soil erosion resulted in the depletion of soil fertility.

Soil Properties

Marked changes can be observed in soil properties when upland sloping soils are cropped continuously for a long period of time. On sloping lands erosion is active which disturbs both the soil physical and chemical properties by removing the top soil layer. During this study for 3-years, cropping maintained soil properties more efficiently

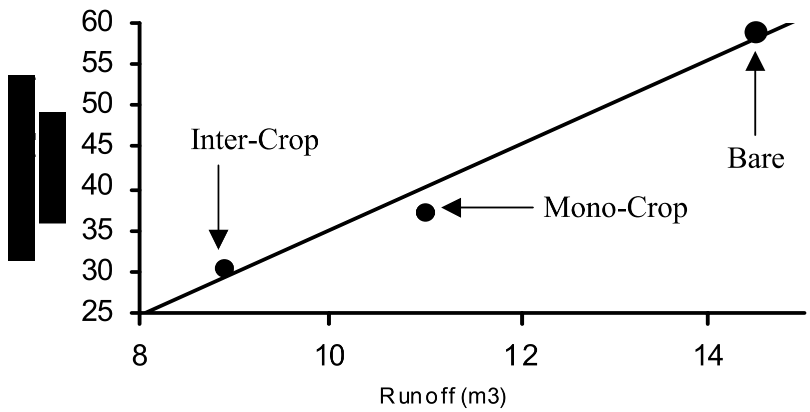

Fig. 1. Effect of different treatments on Runoff and Soil Loss.

Table 4. Nutrient enrichment ratio for different plots

Nutrients	Nutrient concentration in original soil			Nutrient concentration in sediment			Nutrient enrichment ratio (E R)		
	Mono-Crop	Inter-Crop	Bare	Mono-Crop	Inter-Crop	Bare	Mono-Crop	Inter-Crop	Bare
Organic Matter (%)	0.89	0.90	0.90	0.98	0.96	1.11	1.10	1.07	1.23
Mineral N (mg kg^{-1})	27	27	28	39.16	34.89	40.14	1.45	1.29	1.43
AB-DTPA Ext. P (mg kg^{-1})	7.00	7.20	6.95	18.81	18.97	19.4	2.69	2.63	2.79
AB-DTPA Ext. K (mg kg^{-1})	133	135	130	373.66	367.17	376.9	2.81	2.72	2.90
AB-DTPA Ext. Zn (mg kg^{-1})	1.00	1.05	1.10	1.81	1.82	2.16	1.81	1.73	1.96
AB-DTPA Ext. Cu (mg kg^{-1})	0.73	0.75	0.71	3.3	3.22	4.92	4.52	4.29	6.93
AB-DTPA Ext. Fe (mg kg^{-1})	7.50	7.90	7.60	21.51	21.73	22.49	2.87	2.75	2.96
AB-DTPA Ext. Mn (mg kg^{-1})	3.40	3.50	3.45	25.75	25.56	28.26	7.57	7.30	8.19

Table 5. Soil Properties at 0-15 cm depth before and after experiment

Treatments	pH	Lime	OM	BD	N	P	K
		%		g cm^{-3}	mg kg^{-1}		
Before Experiment							
T1. Mono-crop	8.26	22.36	0.89	1.30	27.00	7.00	133
T2. Inter-crop	8.26	22.35	0.90	1.27	27.00	7.20	135
T3. Bare	8.25	22.33	0.90	1.28	28.00	6.95	130
After Experiment							
T1. Mono-crop	8.40b	22.58b	0.65a	1.31	25.50a	6.25a	123
T2. Inter-crop	8.31b	22.49b	0.79a	1.26	27.33a	6.93a	130
T3. Bare	8.96a	24.55a	0.38b	1.33	20.20b	5.95b	103
LSD (0.05)	0.25	1.14	0.15	ns	5.84	0.54	ns

Means followed by similar letters in each column do not differ significantly from each other at 5% level of probability using LSD Test.

in comparison with bare fallow due to reducing the effects of erosive forces by crop cover. Some soil physico-chemical properties at 0-15 cm depth of soil for each plot before and after the experiment are given in Table 5.

Soil pH, lime content and soil bulk density (BD) increased after 3-years for all plots. The largest changes occurred in the most eroded plot (bare plot) followed by mono-cropping while smallest changes were observed in inter-cropped plots. Bare plots were significantly different from both the cropped plots for soil pH and lime content while both the cropped plots were comparable statistically for these two parameters. Changes in soil BD among all the treatments were non-significant but increased generally with increase in the erosion extent. In bare plots, soil pH varied from 8.25 to 8.96, lime content from 22.33 to 24.55% and BD from 1.28 g cm^{-3} to 1.33 g cm^{-3} after 3-years. Soil pH was significantly correlated with soil loss ($r = 0.81$, $n = 9$) whereas the correlation of lime content and soil BD with soil loss was non-significant. Soil of the experimental site was calcareous in nature. Soil organic and inorganic particles were washed away through runoff water and thus increasing the lime content, which consequently increased soil pH. Khattak (1996) reported that the major source of lime in soil is the parent material. Golany *et al.* (1985) reported that $CaCO_3$ increased as the erosion level increased. He also reported that pH values of the surface horizon increased as erosion increased and also confirmed that lime is the cause of high pH in soil. Increase in BD might be due to the compaction of soil as a result of direct hitting of raindrops in bare plots.

Bare plots were also significantly different from cropped plots in soil organic matter (SOM), N and P content while the cropped plots were comparable statistically. Although, all the treatments were not significantly different for K but there was a general decline in K content following erosion. SOM and K content of soil were significantly correlated with soil loss ($r = -0.85$ and -0.78 respectively, $n = 9$). Helberg *et al.* (1978) and Gachene *et al.* (1997) also reported a decrease in SOM due to effect of erosion. Increase in soil BD may also be due to decrease in SOM content of bare plots. N content of inter-cropped plots did not decrease due to the inclusion of leguminous crops in the inter-cropping. Decline of SOM and other elements are due to their higher concentration in the surface soil, which can be easily removed and washed away by surface runoff.

Conclusions

This study shows that considerable amount of soil and plant nutrients were lost through erosion in the northern upland areas of Pakistan. The observed differences in soil loss permitted an assessment of the impact of soil erosion on some soil properties.

Nutrient enrichment ratio was > 1 for all nutrients, which indicated higher losses of nutrients in the sediment. This study also indicates that top soil loss due to accelerated erosion results in changes in soil properties. Changes in soil pH, soil organic matter and K contents were highly and positively correlated with cumulative soil loss. Cropped plots maintained their soil properties more efficiently as soil pH, lime content and soil bulk density of bare plots was increased while cropped plots showed no pronounced increase in these parameters. Similarly a high reduction in soil organic matter and plant nutrient content of bare plots was observed as compared to cropped plots.

It can be concluded from this study that inter-cropping is an effective cropping system for controlling long term soil, runoff and nutrient losses and maintaining soil properties of sloping lands.

References

Ailincai, C., D. Ailincai, N. Dumitrescu and D. Buccur. 1997. Research on the evolution of the main soil physical-chemical features as influenced by cropping system and surface erosion. *Cercetari Agronomy Moldova* 30(1): 187-192.

Almas, M. and T. Jamal. 1990. Nutrients loss through sediment and runoff under upland banana-pineapple intercropping system. *Pakistan Journal of Soil Science* 16: 11-16.

Chaudhry, M.A. and M. Shafiq. 1986. Effect of crop management on soil and water conservation. *Journal of Agricultural Research* 24:17-25.

Elwell, H.A. 1981. A soil loss estimation technique for Southern Africa.p. 181-192. In: Soil Conservation: Problems and Prospects. R. P. C. Morgan (ed.). Chichester, Wiley

Gachene, C.K.K., N.J. Jarvis, H. Linner and J.P. Mbuvi. 1997. Soil erosion effects on soil properties in a highland area of Central Kenya. *Soil Science Society of America Journal* 61: 559-564.

Golany, H.T., T.E. Schamacher, M.J. Linstorm and G.D. Lemme. 1985. The effect of erosion and desurfacing on soil physical properties and productivity. American Society of Agronomy Madison WI. 206 p.

Helburg, G.R., N.C. Wallen and G.A. Miller. 1978. A century of soil development in soil derived from loess in Lowa. *Soil Science Society of America Journal* 42: 339-343.

Jackson, M.L. 1982. Soil Chemical Analysis. Prentice-Hall Inc. England, New Jerssy, USA.

Khan, F. and A.U. Bhatti. 2000. Soil and nutrient losses through sediment under wheat mono-cropping and barley-legume inter-cropping from up-land sloping soil. *Pakistan Journal of Soiì Science* 18: 45-50.

Khattak, R.A. 1996. Chemical Properties of Soil. p. 167-197. In: Soil Science. E. Bashir and R. Bantal (eds.). National Book Foundation Islamabad.

Khisa, P., C.K.K. Gachene, N.K. Karanja and J.G. Mureithi. 2002. The effect of post harvest cover on soil erosion in a maize-legume based cropping systems in Gatanga, Kenya. *Journal of Agriculture in Tropics and Subtropics* 103(1): 17-28.

Lal, R. and B.R. Singh. 1998. Effect of soil degradation on crop productivity in East Africa. *Journal of Sustainable Agriculture* 13(1): 15-41.

Maclean, E.O. 1982. Soil pH and lime requirement. p. 199-223. In: Methods of Soil Analysis. Part 2. A. L.Page, R. H. Miller and D. R. Keeney (eds.). American Society of Agronomy., Madison, Wisconsin, USA.

National Soil Erosion-Soil Productivity Research Planning Committee. 1981. Soil erosion effects on soil productivity: A research perspective. *Journal of Soil and Water Conservation* 36: 82-90.

Nelson, D.W. and L.E. Sommers. 1982. Total Carbon, Organic Carbon and Organic Matter. p. 539-577. In: Methods of Soil Analysis. Part 2. A. L. Page, R. H. Miller and D. R. Keeney (eds.) American Society of Agronomy, Madison, Wisconsin, USA.

Olsen, S.R. and L.E. Sommers. 1982. Phosphorus . p. 403-430. In: Methods of Soil Analysis Part 2. Page, A. l., R.H. Miller and D. R. Keeney (eds.). American Society of Agronomy, Madison. Wisconsin, USA

Rafiq, M. 1984. Presentation report of operational watershed management Project, Pakistan Agricultural Research Council, Islamabad, Pakistan.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. A Biometrical Approach 2nd Ed.. McGraw Hill. New York, USA.