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EFFECT OF SLOPE STEEPNESS AND WHEAT CROP ON SOIL, RUNOFF AND NUTRIENT LOSSES IN ERODED LAND OF MALAKAND AGENCY, NWFP, PAKISTAN

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ABSTRACT

Field experiment was conducted during 2003-2005 on slopping land near Thana Malakand Agency, NWFP on wheat plots in comparison with bare plots. The test plots were maintained at three slope positions, i.e. top-slope (6 %), mid-slope (3 %) and bottom-slope (0 %). The effect of both slope position and wheat crop was statistically significant on runoff, soil and nutrient losses. The respective losses of runoff and soil were 33 and 42% higher from mid-slope as compared to bottom-slope, 24 and 30 % higher from top-slope as compared to mid-slope, and 49 and 59 % higher from top-slope as compared to bottom-slope. Wheat crop reduced runoff losses by 60 % and soil losses by 64% as compared to bare plots. The order of nutrient losses from all plots during the experimental period was: K > OM > N > Fe > P > Cu > Mn > Zn. Nutrient enrichment ratio of the sediments was greater than 1 for all the nutrients which indicated higher losses of nutrients through surface runoff. From the effect of slope and wheat crop on soil and runoff losses, empirical equations were developed which can be expressed as: Eq (1) SL = 426.66 + 203.35 S – 233.3 C (r^2 = 0.94), Eq (2) RL = 69. 47 + 21.3 S – 30.7 C (r^2 = 0.95), where, SL = total soil loss (kg ha^{-1}), RL = runoff loss (m^3 ha^{-1}), S = slope (%) (S = 1 for normal slope, 2 for 2-3 % and 3 for 4-6 % slope), while C = cropping (C = 1 for crop cover and 0 for fallow). This study concluded that increasing extent of erosion due to slope effect can further deteriorate soil properties, but to control the damaging effects of erosion, conservation strategies such as aforestation and selection of suitable crops are suggested for sustainable farming on sloping land.

INTRODUCTION

Soil erosion in northern NWFP is a serious threat to agriculture as it is reducing soil fertility of the area. It has been estimated that in some areas of Malakand Agency, NWFP soil loss due to erosion is 102 t ha^{-1} $year^{-1}$ (Ahmad, 1990). In a study by Khan and Bhatti (2001) soil loss due to water erosion was about 7000 Kg ha^{-1} per season during Summer (Kharif).

Erosion would normally be expected to increase with increase in slope steepness and slope length as a result of respective increase in velocity and volume of surface runoff. Vliet *et al.* (1995) showed a significant effect of slope on soil and runoff losses, with a doubling of slope steepness from 5 to 10% resulted in an increase in both soil and runoff losses. Increased amount of cover results in decrease in the frequency of the surface runoff and a small variation in cover can drastically affect the surface runoff (Lang, 1979). Hofman *et al.* (1985) further stated that vegetation cover was a dominant factor in controlling the surface runoff and water erosion from agricultural lands.

Nutrient loss is an important aspect of surface erosion, since nutrients are concentrated in the surface layers. Nutrients losses to the extent of 0.7 kg N, 0.27 kg P, 9.8 kg K, 3.26 Kg Cu and 4.7 kg Fe ha^{-1} through soil erosion are reported in sub tropical region of china (Kuhnt, 1988), while Khan and Bhatti (2001) reported nutrient losses of 8.46 kg mineral N, 19 kg P, 46 kg K, 8.55 kg Zn, 1.69 kg Cu, 11.96 kg Fe, 19 kg Mn and 220 kg organic matter ha^{-1} during Kharif season 2001 due to water erosion from maize crop in upland sloping soil.

Keeping in view the long term sustainability and productivity of eroded lands, the present research was carried out to study the effect of slope steepness and wheat crop on soil, runoff and nutrient losses to improve fertility of eroded lands through land and crop management practices.

MATERIALS AND METHODS

Site Selection

The experiment was conducted on sloping land in Thana, Malakand Agency, NWFP in Burhan soil series during 2003-2005, which is mainly used for rainfed agriculture. The geo-position of the

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experimental site is 34°-36'-51" N and 72°-05'-28"E, with elevation of 796 m at a vernacular position of 3 km from Thana on Null-Palai road. 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.

Field Procedure

About 4000 m^2 field was selected and plots of 2x5 m^2 each were established at three slope gradients of 6 % (top-slope), 3 % (mid-slope) and 0 % (bottom-slope). Sediment tanks measuring 1.5 x1x1 m^3 each were constructed at the bottom of the plots to collect surface runoff and sediment from each plot. The experimental design was RCBD Split-plot with two factors and three replications. The treatments maintained were: (1) Wheat (2) Fallow.

Wheat was sown on November 11, 2003. Fertilizer was applied at the rate of 120-90-60 kg N-P_2O_5-K_2O ha^{-1} in the form of urea for N, SSP for P and Potassium Sulphate for K. All the recommended cultural practices were followed during the growth period of the crops. After every storm during winter (Rabi) season runoff was measured with volume depth ratio of each tank. Ten L sample of runoff was collected from each tank to determine soil and nutrient losses. The samples were analyzed for organic matter (Nelson and sommer, 1982), AB-DTPA extractable P and K (Olsen and Sommer, 1982), mineral nitrogen by distillation method (Keeney and Nelson, 1982). The incident rainfall was measured at the site. The nutrient enrichment ratio was calculated by dividing the concentration of the nutrients in sediment by its concentration in the native soil.

Physical and chemical properties of the experimental soil are presented in Table-I. In order to study the nutrient status of the soil and to determine nutrient enrichment ratio, composite soil samples form each plot at 0-20 cm depth were taken and analyzed for organic matter, pH, lime, AB-DTPA extractable P and K and mineral nitrogen by standard procedures as stated above.

Table I. ***Physical and chemical properties of the experimental soil***

Characteristics	Values	Characteristics	Values
Sand (g kg^{-1})	500	Lime (g kg^{-1})	235.7
Silt (g kg^{-1})	417.8	Total N. (g kg^{-1})	0.32
Clay (g kg^{-1})	82.1	ABDTPA Ext. P (mg kg^{-1} soil)	2.66
Textural Class	Loam	ABDTPA Ext. K (mg kg^{-1} soil)	75.16
B. Density (Mg m^{-3})	1.37	ABDTPA Ext. Zn (mg kg^{-1}soil)	0.806
Soil pH (1:5)	8.02	ABDTPA Ext. Cu (mg kg^{-1}soil)	2.30
EC (1:5) (dS m^{-1})	0.213	ABDTPA Ext. Fe (mg kg^{-1}soil)	3.33
O. Matter (g kg^{-1})	6.7	ABDTPA Ext. Mn (mg kg^{-1}soil)	3.71

Statistical Analysis

All the data collected on runoff, soil and nutrient losses were statistically analyzed for calculating descriptive statistics according to the procedures given by (Steel and Torrie, 1980). Multiple regression equations were developed to establish empirical relationship for total runoff and soil losses with slope and crop cover.

RESULTS AND DISCUSSION

Effect of Slope Position and Wheat Crop on Runoff and Soil Losses

The effect of slope position and crop cover (wheat) was statistically significant ($P< 0.05$) on both runoff and soil losses (Table-II). Total runoff losses were 261.32, 199.5 and 133.77 m^3 ha^{-1} while total soil losses were 2056.5, 1440.2 and 836.65 kg $ha^{-1}$from Top-slope, Mid-slope and Bottom-slope positions, respectively. There was significant difference in both runoff and soil losses as slope increased from 0 to 3%, 3 to 6% or 0 to 6%. For example the respective losses of runoff and soil were 33 and 42% higher from 3% (mid-slope) as compared to 0 % (bottom-slope), 24 and 30% higher from 6 % (top-slope) as compared to 3% (mid-slope) and 49 and 59% higher for 6% (top-slope) as compared to 0% (bottom-slope). Wheat crop reduced runoff losses by 60 % and soil losses by 64% as compared to bare plots.

Effect of Slope Position and Crop Cover on Nutrient Losses

The effect of slope position and wheat crop was statistically significant ($P < 0.05$) on total losses of organic matter and nutrients (Table-II and III). Total losses of organic matter and nutrients were more from bare as compared to wheat plots. More losses of nutrients from bare plots were the result of high losses of soil from bare plots. By comparing the effect of slope position on nutrient losses, the losses of NPK from 6% slope were 2.14, 2.13 and 1.34 times higher respectively from the NPK losses from 0% slope.

The losses of micronutrients i.e. Zn, Cu, Fe and Mn from bare plots were 2.58, 1.57, 1.46, and 1.87 times greater than the losses of these nutrients from wheat crop. The losses of Zn, Cu, Fe and Mn under bare plots for 6% slope were also higher as compared to the losses of these nutrients from 0% and 3% slopes. Organic matter losses were 2.37 times greater for 6% slope as compared to its losses for 0% slope. Wan Sulaiman *et al.* (1981) in their experiment with annual crops reported that nutrient losses were high from bare plots and were considerably reduced as a result of cropping.

The order of nutrient losses from all plots during the experimental period was: K > OM > N > Fe > P > Cu > Mn > Zn. This order of nutrient loss was the same as reported by Almas and Jamal (1999) in Malaysia. They observed that greater amounts of N, organic C and K were lost in the sediments, however, P loss was very low as compared to other nutrients.

Table-II. ***Total soil and runoff losses from wheat and bare plots under different slope positions for one season***

Treatments	**Slope Positions**			**Mean**
	Top-slope (6%)	**Mid-slope (3%)**	**Bottom-slope (0%)**	
		Runoff (m^3 ha^{-1})		
Wheat	198.83	148.8	110.21	152.61 b
Bare	323.80	250.2	157.33	243.78 a
Mean	261.32 a	199.5 b	133.77 c	LSD (0.05) =1.41
LSD (0.05) = 16.55				
		Soil losses (kg ha^{-1})		
Wheat	1517.66	1088.12	678.15	1094.64 b
Bare	2595.38	1792.20	995.15	1794.22 a
Mean	2056.52 a	1440.16 b	836.65 c	LSD (0.05) =13.75
LSD (0.05) = 171.8				
		Sand (kg ha^{-1})		
Wheat	402.89	265.12	183.94	283.98 b
Bare	553.08	420.59	250.15	407.94 a
Mean	477.99 a	342.86 b	217.05 c	LSD (0.05) =3.78
LSD (0.05) = 58.64				
		Silt (kg ha^{-1})		
Wheat	928.67	636.21	412.64	659.17 b
Bare	1696.44	1139.09	619.05	1151.53 a
Mean	1312.56 a	887.65 b	515.85 c	LSD (0.05) =9.01
LSD (0.05) = 95.91				
		Clay (kg ha^{-1})		
Wheat	193.30	128.60	82.50	134.80 b
Bare	341.22	246.33	126.28	237.94 a
Mean	267.26 a	187.47 b	104.39 c	LSD (0.05) =2.64
LSD (0.05) = 26.94				
		Organic matter (kg ha^{-1})		
Wheat	22.73	14.97	10.23	15.98 b
Bare	36.06	26.75	14.50	25.77 a
Mean	29.40 a	20.96 b	12.37 c	LSD (0.05) =0.21
LSD (0.05) = 4.437				

Means followed by different letters are statistically different from one another at 5 % level of probably using LSD Test.

Table III ***Total nutrient losses from wheat and bare plots under different slope positions for one season.***

Treatments	Slope Positions: Top-slope (6%)	Slope Positions: Mid-slope (3%)	Slope Positions: Bottom-slope (0%)	Mean
		Mineral N (kg ha^{-1})		
Wheat	1.40	1.19	0.69	1.09 b
Bare	2.51	2.19	1.13	1.94 a
Mean	1.95 a	1.69 b	0.91 c	LSD (0.05) =0.035
LSD (0.05) = 0.4534				
		P (kg ha^{-1})		
Wheat	0.97	0.82	0.41	0.73 b
Bare	1.36	1.11	0.68	1.05 a
Mean	1.17 a	0.97 a	0.55 a	LSD (0.05) =0.028
LSD (0.05) = 1.562				
		K (kg ha^{-1})		
Wheat	25.03	23.51	20.17	22.91 b
Bare	39.24	33.81	27.77	33.61 a
Mean	32.14 a	28.66 a	23.97 b	LSD (0.05) =0.199
LSD (0.05) = 6.367				
		Zn (kg ha^{-1})		
Wheat	0.18	0.10	0.09	0.12 b
Bare	0.46	0.29	0.18	0.31 a
Mean	0.32 a	0.19 a	0.13 a	LSD (0.05) =0.0054
LSD (0.05) = 0.2090				
		Cu (kg ha^{-1})		
Wheat	0.61	0.54	0.30	0.49 b
Bare	0.91	0.91	0.49	0.77 a
Mean	0.76 a	0.73 b	0.39 c	LSD (0.05) =0.0067
LSD (0.05) = 0.2028				
		Fe (kg ha^{-1})		
Wheat	1.15	1.01	0.77	0.98 b
Bare	1.88	1.55	0.86	1.43 a
Mean	1.51 a	1.28 b	0.81 c	LSD (0.05) =0.020
LSD (0.05) = 0.221				
		Mn (kg ha^{-1})		
Wheat	0.15	0.21	0.13	0.16 b
Bare	0.37	0.26	0.28	0.30 a
Mean	0.26 a	0.23 a	0.20 a	LSD (0.05) =0.0077
LSD (0.05) = 0.2323				

Means followed by different letters are statistically different from one another at 5% level of probability using LSD Test.

Nutrient Enrichment Ratio

A comparison (Table-IV) made between the concentrations of the nutrients in the eroded soil and that in the parent soil showed that the eroded soil was richer in nutrients. The nutrient enrichment ratio was greater than one for all the nutrients.

These higher values suggest that there was higher loss of nutrients, due to soil erosion. Almas and Jamal (1999) and Khan and Bhatti (2001) also reported the enrichment ratio of nutrients greater than one, which indicated the substantial degree of enrichment of the sediments due to soil erosion. This may be due to aggregate breakdown, which occurs due to direct impact of raindrop and soil particles transportation through sediment.

Table-IV. Nutrient enrichment ratio for different plots of the experiment

Nutrient	Nutrient concentration			Nutrient Enrichment Ratio (ER)	
	Original soil	Sediments			
		Wheat	Bare	Wheat	Bare
Organic Matter (%)	0.67	1.38	1.44	2.06	2.15
Mineral N (mg kg^{-1})	27.00	35.79	31.52	1.33	1.17
AB-DTPA Ext. P (mg kg^{-1})	2.66	26.86	25.16	10.10	9.46
AB-DTPA Ext. K (mg kg^{-1})	75.16	81.58	87.20	1.09	1.16
AB-DTPA Ext. Zn (mg kg^{-1})	0.806	2.14	1.79	2.66	2.22
AB-DTPA Ext. Cu (mg kg^{-1})	2.30	2.87	2.73	1.30	1.19
AB-DTPA Ext. Fe (mg kg^{-1})	3.33	12.82	12.28	3.85	3.68
AB-DTPA Ext. Mn (mg kg^{-1})	3.71	4.53	4.38	1.22	1.18

Empirical Equations

Empirical relationships of slope and crop cover with soil and runoff losses were developed by using multiple regression. These equations relate slope and crop cover with soil and runoff losses, which can be helpful in determining soil and runoff losses for a certain slope and wheat crop.

$$SL = 426.66 + 203.3\ S - 233.3\ C \quad (r^2 = 0.94)$$

$$RL = 69.47 + 21.3\ S - 30.7\ C \quad (r^2 = 0.95)$$

Where: SL = total soil loss (kg ha^{-1})
RL = runoff loss (m^3 ha^{-1})
S is slope factor (S = 1 for normal slope, S = 2 for 2-3% slope and S = 3 for 4-6% slope
C is cropping (C = 1 for crop cover and C = 0 for bare)

CONCLUSION

The study led to the following conclusions.

i. Runoff, soil and nutrient losses were higher from top-slope as compared to these losses from mid-slope and bottom-slope.

ii. Runoff, soil and nutrient losses were higher from bare plots as compared to those of cropped plots.

iii. The order of nutrient losses from all plots during the experimental period was: K > OM > N > Fe > P > Cu > Mn > Zn.

iv. Nutrient enrichment ratios of the sediment was greater than one for all the nutrients, which indicated higher losses of nutrients in the sediment.

v. Empirical equations for the relationship of slope and crop cover with soil and runoff losses were developed, which can be helpful in determining soil and runoff losses for a certain slope and wheat corp.

It can be concluded from this study that slope affects soil, runoff and nutrient losses but crop cover can reduce slope effect and help reduce soil, runoff and nutrient losses to considerable degree.

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