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Characterization of Surface Runoff, Soil Erosion, Nutrient Loss and their Relationship for Agricultural Plots in India

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ABSTRACT

The present study was carried out to explore the existence of relationship among rainfall, runoff, soil loss and nutrient losses from the agricultural plots located at Roorkee, Uttarakhand, India. The natural rainfall generated runoff and soil loss from the 12 agricultural runoff plots (with four land uses namely sugarcane, maize, black gram and fallow land and having slope 5%, 3% and 1% for each land use) were recorded during monsoon period (June 2013 to September 2013). The highest grade plot was found to yield the highest magnitude of runoff (i.e. runoff coefficient) for a given land use and soil type. The soil loss from the experimental plots of various characteristics shown that for given rainfall input, on average, the plots with sugarcane land use were found to produce high amount of soil loss followed by Maize, fallow land and Blackgram. The nutrients losses were very low in the sediment as compared to the dissolved losses. Nutrients concentrations in sediment and runoff water were found to be more during the critical period. The higher limit of seasonal sediment yield obtained from the present study is lower than soil loss tolerance limit of 2.5 to 12.5 t/ha /yr for Indian subcontinent.

Key words: Agricultural plots, Soil erosion, Nutrient loss, Tolerance limit, Critical period.

INTRODUCTION

The effect of agricultural practices on soil fertility is growing concern in many parts of the world. In the recent years, agricultural practices were increasingly shifted towards forest and very steep slopes of mountains for meeting the increasing demand of household food. The natural cycle of a watershed is usually altered whenever native vegetation replaced by agricultural plants; and leads nutrients to be easily transported by runoff and sediments. Intensive agriculture for high productivity and production requires substantial fertilization. The higher amount of nutrients applied to crops imply environmental pollution both from runoff (liquid phase) as well as sediment (solid phase) (Zuazo *et al*., 2004).

The variability of runoff and soil loss from a watershed largely depend on the characteristics such as climate, physiography, geology, soil type, land use/land cover conditions, and socio-economic features of watershed (Kang *et al*., 2001). The transfer of suspended sediment particle caused by soil erosion have the adverse effect like removal of topsoil, soil organic material reduction and loss of nutrients on the native soil quality (Creamer *et al*., 2010; Guerra, 1994). Removal of nutrients through sediments and runoff water not only decline the soil fertility but also causes environmental problems when these nutrients transported further down the valleys, lakes and reservoirs (Kunimatsu, 1986; Kin-Che *et al*., 1997). The difficult part of soil erosion study is to assess it reliably and precisely along with the environmental effect caused by soil erosion (Lal, 1994). The erosion-plot method for the direct evaluation in the field is the most effective to quantify soil erosion (Albadalejo *et al*., 1989; Soto *et al*., 1995).

In literature, various study dealing with relationship among surface runoff, soil loss, and nutrient loss under different land use conditions from all over the world are available (Battany and Grismer, 2000; Girmay *et al*., 2009; Kang *et al*., 2001; McGrath *et al*., 2011; Pardini *et al*., 2003; Xing-Chang *et al*., 2003; Zuazo *et al*., 2004). However, only limited information is available on dynamics of runoff-sediment and nutrient loss from agricultural field under natural rainfall condition in Himalayas and other parts of India (Kothyari *et al*., 2004; Mandal *et al*., 2012; Narayan *et al*., 1991; Rai and Sharma, 1998; Singh, 1999; Sharma *et al*., 2001). Sharma *et al*. (2001) reported that the open agricultural (cropped) fields were found to produce higher amount of surface runoff, soil and nutrient losses as compared to other land uses in Khanikhola watershed in Sikkim (India). Rai and Sharma (1998) found that the soil loss from the micro watersheds in Sikkim Himalayas (North East India) ranged from 4.18 to 8.82 t /ha/yr during the three-year study period. The annual total nitrogen loss measured at the watershed outlet was at a rate of 33 kg/ha/yr, while organic carbon and total phosphorus were 267 kg/ha/yr and 5 kg/ha/yr, respectively. Kothyari *et al*. (2004) reported 0.06 to 5.47 t/ha/yr soil loss from various land uses natural experimental plots in Central Himalayan region of India. Mandal *et al*. (2012) reported that the annual surface runoff was found to vary from 96 to 1821 m^3/ha, whereas soil loss ranged between 0.28 and 5.41 t/ha from an agricultural field in semi-arid tropical region of India.

Thus, under the magnitude of the problem, no systematic effort appears to have been made for evaluating runoff-sediment associated nutrient losses along with their relationships under different agricultural land uses, soil type and slopes in the study region, which invokes the need of the study. In this study, we monitored the transport of nutrients in runoff and sediments from an agricultural field for monsoon season to evaluate the rainfall-runoff-sediment and nutrient loss relationships under rainfed agriculture.

MATERIALS AND METHODS

Site Description

The present study was conducted in an experimental field located at 29° 50' 09" N and 77° 55' 21" E, in Roorkee, district Haridwar, Uttarakhand (India) (fig. 1). The experimental field comes under the catchment area of Solani River, which is a sub

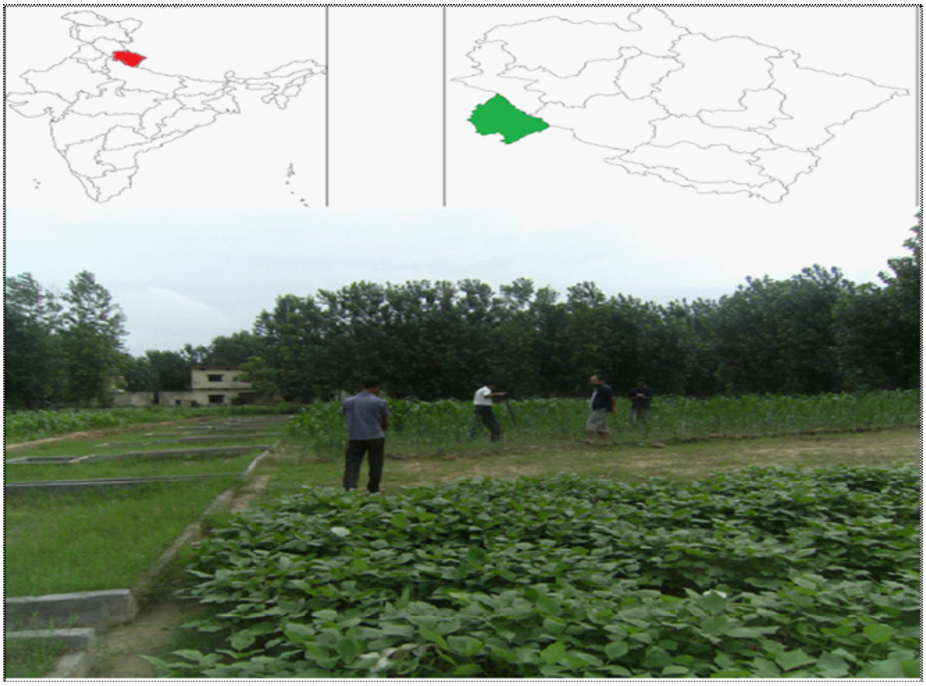

Fig.1: Experimental field located in Roorkee, Distt. Haridwar, Uttarakhand, India

watershed of Ganga River-the largest river basin in India. The area represents the humid sub-tropical type climate with three seasons; monsoon, winter and summer. The average elevation of the experimental filed is about 266m above mean sea level (amsl). On average, the maximum and minimum monthly temperature values are respectively 27°C and 10°C in winter season; and 45°C and 20°C in summer season. The relative humidity varies between 30% to 99%, and average annual PET of the order of 1340 mm. The study area receives an annual precipitation varies from 1120 to 1500 mm, mostly concentrated between June and September i.e. monsoon season. The soil type in the study area is loam with an average proportion of 50–55 % of sand, 35–42 % silt and 8-15 % clay (Kumar *et al.*, 2012). Sugarcane is the major crop grown in the study area along with wheat, maize, paddy and pulses grown as seasonal crops.

Experiment setup, data collection and laboratory analysis

The selected agricultural field for experimental work was divided into twelve plots having size of 22m x 5m each. Four different land uses (Sugarcane, Maize, Black gram and Fallow land) were used for measuring the runoff, sediment and nutrient losses. The plots were constructed in such a manner that each land use should have three different slopes (5%, 3% and 1%). The infiltration tests were carried out in each plot by using a double ring infiltrometer for knowing the hydrologic soil group (HSG). The land preparation and crop cultivation was made properly with standard agricultural practices for achieving the objectives under rain fed agriculture. Rainfall data were measured by using ordinary type rain gauge as well as by recording type rain gauge for verification. The collection chambers of size 1m x 1m x 1m constructed at downstream side of each plot was used for the runoff collection. Each chamber was connected to the respective plot by a 3m long conveyance channel in connection with screen and multi slot divisor having five slots. The measured volume of collected surface runoff in collection tank was multiplied by 5 times to get the total volume of runoff generated by rainfall event (for past 24 hours).

Chemical Analysis

Firstly, a portion of runoff samples was collected in a bottle followed by filtration for analyzing sediment and nutrient loss. The sediment retained

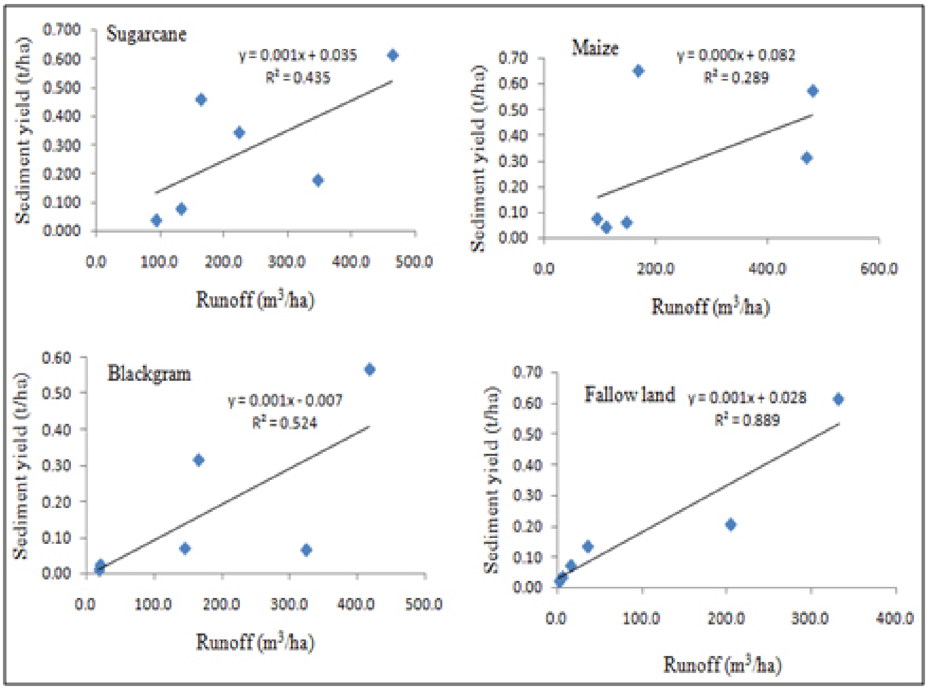

Fig.2a: Runoff-sediment yield relationship for 1% slope among different land uses

after filtering the runoff sample was oven drying at 50°C for 24 hours. The soil loss was calculated by multiplying the volume of the total surface runoff with concentration of sediment measured in runoff water. Similarly, the total N was also calculated by multiplying the runoff volume with amount of concentration of total N detected in runoff water. In case of total P and total K determination, both dried samples and filtrate runoff were used for analysis. The total nutrients losses were calculated by summing the nutrient loss through runoff and through sediments.

Nitrogen (N) was determined by using micro Kjeldahl method (Jan-Åke, 2008), whereas phosphorus (P) and potassium (K) were measured by acid digestion method using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Ammann, 2007).

Mean runoff coefficient determination

The mean runoff coefficient of plot was determinate by taking the mean of all individual rainfall events runoff coefficient.

$$\text{Mean runoff coefficient} = \frac{\sum_i^n \frac{Q_i}{P_i}}{n}$$

Where, Q_i is the direct surface runoff for event i, P_i is the rainfall amount for event i, and n is the total number of events.

Statistical analysis

The observed field data were analyzed using the SPSS version 20.0. Regression analyses were performed and Coefficient of determination (R^2) values was calculated to show the relationships among rainfall, runoff, soil and nutrient losses. The relationship between two variables were considered statistically significant at $P<0.05$.

RESULTS AND DISCUSSION

In present study, data from all experimental plots were analyzed individually in order to examine their effect on the variables being studied. The total number of rainfall-runoff events captured during the study (monsoon) period was 20 out of which only six events had produced sufficient amount of runoff to collect samples for sediment and nutrients analysis (table 1).

Rainfall-Runoff Relationship

A simple linear regression model was tested for studying the relationship between rainfall

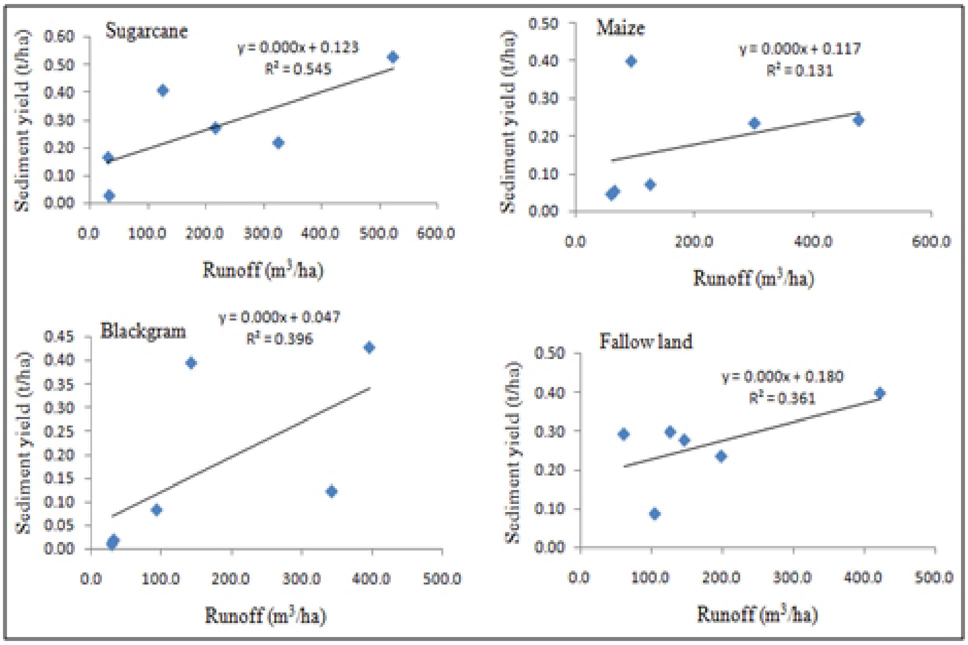

Fig. 2b: Runoff-sediment yield relationship for 3% slope among different land uses

and runoff. In present study, the relationship between rainfall and runoff for all the plots was found to be statistically significant (R^2=0.675-0.928, $p<0.05$, n=13) (table 2). These relationships showed that the runoff increased with increase in rainfall with good positive correlations. Plot land use, slope and soil type significantly influenced runoff generation (table 1). As shown in table 1, it was found that the highest grade plot yield the highest magnitude of runoff (i.e. runoff coefficient) for a given soil type and land use. However, sugarcane plot with 5 and 1% slope was the exceptional case where higher slope could not produce higher runoff. In both the sugarcane plots infiltration rate of plot having 5% slope was higher in comparison to plot of 1% slope. Therefore, in these two plots, the effect of slope of plot is not as prominent as that of soil, and thus, it could possible that a plot of higher grade generated lesser runoff. The rainfall-runoff data from the experimental plots of various characteristics shown that for given rainfall input, the plot of sugarcane landuse with 1% slope was found to produce highest amount of runoff. Similarly, the plot of fallow land with 1% slope produced the least runoff.

Runoff-Soil loss Relationship

Firstly, the event soil loss (t/ha) was plotted against the corresponding rainfall (mm) values. These relationships confirm the poor correlation to exists between rainfall and soil loss. The daily soil loss (t/ha) values, therefore, plotted against the corresponding runoff values (m^3/ha), as shown in figs. 2(a-c). Relatively low value of R^2 (0.131-0.931) associated with these relations may be noted. The soil loss from the experimental plots of various characteristics shown that for given rainfall input, on average the plots with sugarcane landuse were found to produce high amount of soil loss followed by Maize, fallow land and Blackgram.

Soil loss-nutrient loss relationship

The nutrients losses were very low in the sediment as compared to the dissolved losses (i.e. runoff water). Nutrients concentration in sediment and runoff water was found to be more during the initial stage of crop growth. The initial stage of crop growth cycle considered as the critical period in terms of soil erosion (Laflen and Tabatabai, 1984; Yoo *et al.*, 1988). In present study, crops were planted during the last week of May, 2013. Therefore, the critical period for current study was considered up to July, 2013, during which high amount of sediment concentration and nutrient loss was observed as compared to other period. All the three primary nutrients viz. TN, TP, TK loss (kg/ha) values were plotted against the corresponding

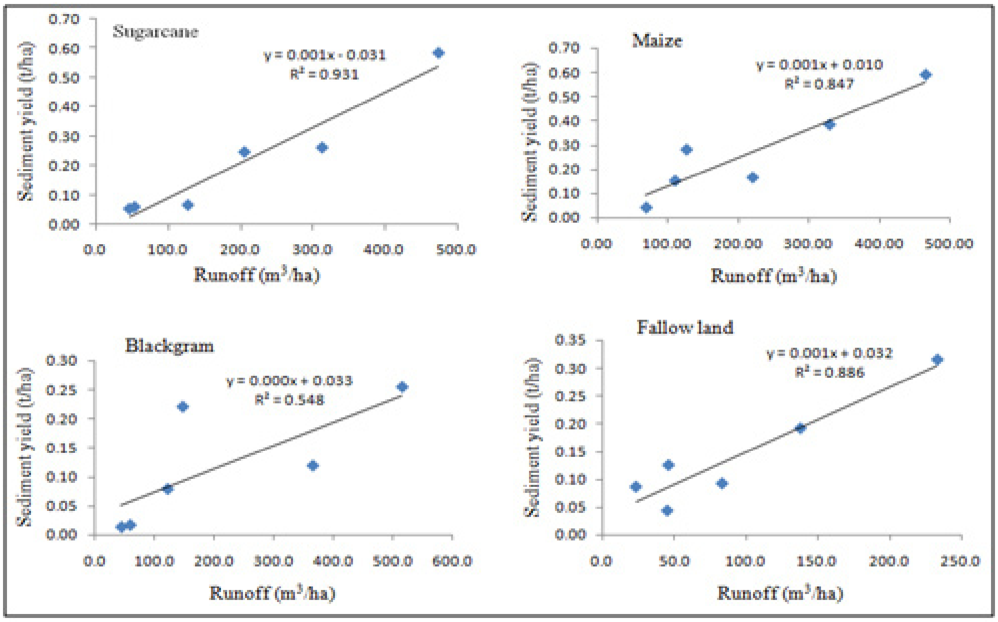

Fig. 2c: Runoff-sediment yield relationship for 5% slope among different land uses

Table 1: Runoff coefficients, sediment yield and nutrients losses for the plots of various characteristics

Land use	Hydrologic soil group	Infiltration rate	Mean Runoff Coefficient	Total soil loss (t/ha)	P loss in runoff water (kg/ha)	K loss in runoff water (kg/ha)	P loss in sediment (kg/ha)	K loss in sediment (kg/ha)	TN loss (kg/ha)	TP loss (kg/ha)	TK loss (kg/ha)
5% slope											
Sugarcane	B	7.36	0.36	1.42	27.29	4.42	0.005	0.010	NA	27.291	4.433
Maize	B	4.24	0.40	1.54	8.84	5.63	0.003	0.020		8.843	5.646
Black gram	A	15.22	0.36	0.79	4.20	8.16	0.002	0.009		4.198	8.164
Fallow land	A	12.00	0.16	0.80	0.69	6.12	0.001	0.013	0.15	0.689	6.133
3% slope											
Sugarcane	A	8.77	0.36	1.61	9.70	5.97	0.003	0.021	0.29	9.707	5.995
Maize	B	5.52	0.32	1.00	7.27	7.36	0.002	0.012	0.28	7.271	7.375
Black gram	A	13.82	0.30	1.05	2.48	9.67	0.003	0.011	1.41	2.486	9.685
Fallow land	B	6.00	0.33	1.46	0.74	7.61	0.003	0.020	0.42	0.743	7.629
1% slope											
Sugarcane	B	3.51	0.45	1.75	7.17	7.10	0.003	0.023	0.83	7.172	7.126
Maize	C	1.90	0.44	1.59	7.27	7.52	0.004	0.017	0.65	7.275	7.533
Black gram	B	5.66	0.31	1.10	1.90	10.41	0.003	0.010	0.47	1.898	10.423
Fallow land	A	10.00	0.14	1.06	0.89	3.36	0.002	0.012	0.11	0.895	3.368

Table 2: List of coefficient of determination (R^2) for the relationship between rainfall (mm) and runoff (mm) (n=13)

Landuse/slope	5%	3%	1%
Sugarcane	0.810	0.772	0.868
Maize	0.928	0.907	0.915
Blackgram	0.813	0.834	0.803
Fallow	0.918	0.725	0.675

soil loss (kg/ha) values for each experimental plot. These relationships revealed that a poor correlation to existed between nutrient and soil loss.

Seasonal rainfall, runoff, soil loss and nutrient loss

The seasonal values of mean runoff coefficient, soil loss, and nutrient losses from the experimental plots of various characteristics are shown in table 1. The mean percentage conversion of rainfall into surface runoff was found to vary from 14% to 45%. The soil loss recorded from experimental plots of various characteristics ranged between 0.79 and 1.75 t/ha. Although, the present study is season based, however still its result can be comparable to other annual based studies as around 70% of annual precipitation occurs during monsoon season in India. Kothyari *et al*. (2004) reported 0.06 to 5.47 t/ha/yr soil loss from different land use systems in Central Himalayan region of India. Mishra *et al*. (2010) reported the soil loss as of 0.56-1.01 t/ha/yr from an agricultural soil in semi arid region of India. In addition, the work documented by Rai and Sharma (1998) and Mandal *et al*. (2012) reported a relatively high amount of soil loss from agricultural land use plots, but under tolerance limit in Indian Subcontinent (Bhattacharya *et al*., 2008). The present study revealed that the soil loss is under tolerance limit as per the soil erosion tolerance limit (2.5 to 12.5 t/ha/yr) in Indian Subcontinent (Bhattacharya *et al*., 2008).

As shown from table 1, the seasonal total P loss vary from 0.689 to 27.291 kg/ha and total K recorded from the experimental plots of various characteristics vary from 3.368 to 10.423 kg/ha. The loss of annual total P was 5 kg/ha reported by Rai and Sharma (1998); whereas the average annual nutrient losses reported by Mandal *et al*. (2012) were 10.2 kg/ha for total N, 1.0 kg/ha/yr for total P and 20.07 kg/ha/yr for total K. The total K reported in present study is in similar range as reported in literature. However, the total P reported from present study showed relatively higher variation in comparison to other studies.

CONCLUSIONS

The present study was carried out to explore the existence of relationship among rainfall, runoff, soil loss and nutrient losses from the twelve experimental plots of various characteristics located at Roorkee, Uttarakhand, India. The experimental plots were constructed to have four different land uses (sugarcane, maize, blackgram and fallow), soil type and slopes. The highest grade plot was found to yield the highest magnitude of runoff (i.e. runoff coefficient) for a given land use and soil type. The soil loss from the experimental plots of various characteristics shown that for given rainfall input, on average the plots with sugarcane land use were found to produce high amount of soil loss followed by Maize, fallow land and Blackgram. The nutrients losses were very low in the sediment as compared to the dissolved losses. Nutrients concentration in runoff water and sediment were found to be more during the critical period. The soil loss observed from the experimental plots was under tolerance limit. The seasonal loss of TP varied between 0.689 and 27.291 kg/ha and TK recorded from different plots ranged between 3.368 and 10.423 kg/ha. The land uses and land treatment greatly influenced the sediment yield as well as total nutrients losses which were lower for good canopy coverage and vice versa.

Notations

TK= Total Potassium
TN= Total Nitrogen
TP= Total Phosphorus
kg/ha/yr= Kilogram per hectare per year
t/ha= tonne per hectare

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