

Nutrient erosional losses in sub montaneous tract of northern India under simulated rainfall

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Abstract

Soil erosion is believed to be a major cause of nutrient depletion from soils, but there exists substantial variability and uncertainty among various estimates. We conducted simulated rainstorm studies on soils packed to field measured levels of bulk densities to determine nutrient removal with the eroded sediments for some soils of the sub-montaneous tract of northern India. Results demonstrated a positive correlation between the soils and the sediment concentrations of soil organic matter, and N, and a negative correlation for K, Ca, Mg, S, Cu and Mn. Enrichment ratios greater than unity for organic matter, N, K, Mg, Cu and Zn indicated preferential removal of these elements with the eroded sediments and the enrichment ratios lower than unity for P, S, Ca and Mn indicate preferential retention of these elements in the soil matrix under erosive rainstorms. This pattern will be significant for shaping the future fertility regimes of soils exposed to erosive rainstorms.

Key Words

Nutrient enrichment, soil erosion, rainfall simulator, soil fertility

Introduction

Nutrients lost through erosion have substantial on-site impacts affecting fertility and productivity of soil and off-site impacts through pollution of waterways. Soil erosion is one of the several processes contributing to onsite nutrient depletion. Nutrient depletion can also be a contributing cause of soil erosion because when nutrients are limiting, there is lower production of above and below ground biomass that protects the soil against erosion (Hashim *et al.* 1998). This is less frequently recognised than the fact that erosion causes nutrient depletion. In fact this makes up a cyclic relationship – erosion leading to nutrient depletion leading to increased susceptibility to erosion and further more erosion and so on. Most of the nutrient losses occur with the sediment fraction. The amount of nutrient loss per unit soil varies with soil type and is a function of the inherent nutrient status of the soil (Hargrave and Shaykewich 1997). Runoff enrichment studies quantify the effect of erosion on soil fertility and productivity. Enrichment ratios (ER) are calculated as the ratio of the nutrient content of sediment (eroded soil) to that of source soil. An ER >1 denotes that the sediment is richer in that nutrient than in the source soil, and an ER <1 denotes impoverishment of the sediment in that nutrient compared to the source soil. In the present study an evaluation has been made of the erosional losses of available nitrogen and ABDTPA extractable macro and micro-nutrients along with the eroded sediments from some soils of the submontaneous tract of northern India using laboratory scale simulated rainstorms under controlled conditions.

Methods

The soils selected for this study represent an area lying between 30° 40' to 32° 30' N latitude and 75° 30' to 76° 40' E longitude and comprising an ecologically fragile agro economic zone that poses serious environmental problems including land degradation. An assembly of soil boxes and a micro sprinkler based rainfall simulator was used for simulating rainfall and inducing erosion for the present study. The experimental soil boxes, 0.50 x 0.50 x 0.20 m³, were fabricated from galvanized iron sheets in an arrangement for collecting infiltration. The base of the soil boxes was overlaid with a sieve sheet to enable separation of soil from the collected infiltration. The borders, on all sides of the soil boxes, were surrounded with a 20 cm wide horizontal sheet. The down slope end of the soil boxes was in the shape of a V-notch to enable the flow of runoff and sediments to the attached sediment collector which directed the flow of runoff and sediments through a funnel to the collecting vessels. The base of the soil boxes was also connected to a funnelled outlet to direct infiltrating water to the collecting vessels. Soil boxes were placed on iron stands of similar dimensions in length and breadth and a height of 0.5 m with a provision of adjusting the height of each side to level the soil boxes or to incline them to desired slopes. The empty soil boxes were placed on iron stands and levelled using the levelling screws. The sieved base was covered with a sheet of filter paper and overlaid with approximately 2 cm of a coarse gravel bed. The experimental soil sieved to pass through

an 8 mm sieve was filled in the soil boxes above the gravel bed in 2 cm depth increments; hand levelled and compacted to the level of field measured bulk density. The top five cm of the soil in the boxes was harrowed with hand up and down the slope and left uncompacted to replicate the conditions of cultivated fallow prescribed for universal soil loss equation measurements. The depth of the soil overlying the gravel bed was approximately 12-cm. The soil boxes initially set flat and packed with soil, were wetted from the bottom and allowed to saturate overnight. The soil in the boxes was then allowed to drain freely for 24 hours and inclined to a slope of 9% by raising the upstream end of the soil boxes by 4.5 cm. Triplicate packed samples of each soil were prepared for simulated rainfall studies using a rainfall simulator (Kohli and Khera 2008). This assembly was operated continuously to collect about 60 L of runoff. The sediment in the runoff collected in the final run was allowed to settle for 24 h and separated from runoff water by decantation followed by filtration of the remaining puddle. The sediment collected was then air dried and stored for further laboratory analysis for organic C by the Walkley and Black method (Allison 1965), available nitrogen by alkaline KMnO₄ method (Subbiah and Asija 1956) and Ammonium Bicarbonate-Diethylene Triamine Penta Acetic Acid (ABDTPA) extractable P, K, Ca, Mg, S, Fe, Cu, Mn and Zn by plasma emission spectroscopy using ICAP (Jones 1977).

Results and Discussion

The organic matter content of the sediments (mean = 4.53 %, se = 0.23) was much higher than that of the original soil (mean = 0.57%; se = 0.08). The mean enrichment ratio of organic matter was 9.86 (se = 1.28). Organic matter enrichment was significantly correlated with soil organic matter content and soil organic matter content accounted for 90 per cent of the variation in organic matter enrichment when fitted as a logarithmic function. Available nitrogen in the soils ranged from 8 ppm to 34.67 ppm and in the eroded sediments from 18.67 ppm to 51.33 ppm. The average enrichment ratio for available nitrogen was 2.61 (se = 0.23). Teixeira and Misra (2005) have also reported from simulated rainfall erosion experiments that N concentration was greater in the sediments than in the un-eroded soil (signifying ER >1). Sediment enrichment of available N was significantly and negatively correlated ($r = -0.73$) with available soil N. Teixeira and Misra (2005) have also reported that the soil with highest fertility in terms of N concentration, was not only less susceptible to erosion but also to loss of fertility. Available soil N explained up to 67 per cent of the variation in the N enrichment ratio (ERN) of sediments when enrichment ratio was fitted as an exponential function of available soil N.

$$\text{ERN} = 4.316 e^{-0.0339 \times (\text{Available soil N})} \quad (r^2 = 0.67) \quad (1)$$

The concentration of ABDTPA extractable P in the soils and the eroded sediments ranged from 6.12 ppm to 55.00 ppm and 2.30 ppm to 19.25 ppm, respectively. The average enrichment ratio for ABDTPA extractable P was 0.46 (se = 0.07). However, no significant correlation was found between sediment enrichment of ABDTPA extractable P and the ABDTPA extractable soil P.

The concentration of ABDTPA extractable K in the soils and the sediments ranged from 25.18 ppm to 258.98 ppm and 27.44 ppm to 98.64 ppm respectively. The average enrichment ratio for ABDTPA extractable K was 1.21 (se = 0.18). Sediment enrichment of ABDTPA extractable K was significantly and negatively correlated ($r = -0.65$) with ABDTPA extractable soil K. ABDTPA extractable soil K accounted for 84 per cent of the variation in the K enrichment ratio (ERK) of sediments when enrichment ratio was fitted as an exponential function of ABDTPA extractable soil K.

$$\text{ERK} = 2.09 e^{-0.0118 (\text{ABDTPA extractable soil K})} \quad (r^2 = 0.84) \quad (2)$$

The role of soil structure and soil aggregates, which was not been investigated in this study, could also be a potential controlling factor for N losses in erosion. For soils with a more stable structure, the increased concentration of N-rich aggregates, in the sediment probably results from the presence of plant residues and an N-rich outer layer removed from larger aggregates by raindrop stripping (Ghadiri and Rose 1991a, b). Notwithstanding these, Teixeira and Misra (2005) have asserted that for a wide range of soils and erosion conditions, loss of N by erosion could be reasonably estimated from the knowledge of soil loss alone. The micaceous minerals in the silt and clay fractions (Catt 2001) could have enriched the sediment in K. Most of the nutrient losses occur with the sediment fraction and the amount of nutrient loss per unit soil varies with soil and is a function of the inherent soil nutrient status (Hargave and Shaykewich 1997). The selective removal of N, P and K in runoff will reduce soil fertility and productivity. The transport of N, P and C is primarily associated with clay sized minerals and organic particles (Foster *et al.* 1980). Zhang and Shao (2001) have shown that enrichment of clay results in the enrichment of organic matter and total nitrogen.

Sediment bound nutrients may account for up to 90 per cent of the total amount transported in runoff (Schuman *et al.* 1973 a & b). Alberts *et al.* (1983) reported that much of total N was transported by the larger aggregates (> 50µm) which would be expected because organic N is primarily associated with the clay fraction of the soil (Frere 1976). They also suggested that smaller aggregates have a higher capacity to buffer soluble P levels because of a larger number of accessible sorption sites. So at a common equilibrium phosphorus concentration, smaller aggregates will transport greater quantities of labile P per gram. Although P transport in runoff is associated with clay-sized particles, the preferential transport of Brays I P or Labile P increased during erosion compared to the source soil. This increase may result from a selective erosion of certain clay minerals and fine clays having an increased Brays I P and Labile P content and / or a decrease in particle aggregation compared to the surface soil.

ABDTPA extractable calcium in the soils ranged from 227 ppm to 344 ppm and in the eroded sediments from 223 ppm to 301 ppm. The average enrichment ratio for ABDTPA extractable calcium (ERCa) was 0.937 (*se* = 0.05). Sediment enrichment of ABDTPA extractable calcium was significantly and negatively correlated (*r* = -0.89) with ABDTPA extractable soil calcium. ABDTPA extractable magnesium in the soils ranged from 6.9 ppm to 112.6 ppm and in the eroded sediments from 129.0 ppm to 235.3 ppm. The average enrichment ratio for ABDTPA extractable magnesium (ERMg) was 5.82 (*se* = 1.48). Sediment enrichment of ABDTPA extractable magnesium was significantly and negatively correlated (*r* = -0.82) with ABDTPA extractable soil magnesium. The concentration of ABDTPA extractable S in the soils and the sediments ranged from 11.2 ppm to 39.3 ppm and 4.9 ppm to 10.2 ppm respectively. The average enrichment ratio for ABDTPA extractable S (ERS) was 0.36 (*se* = 0.04). Sediment enrichment of ABDTPA extractable S was significantly and negatively correlated (*r* = -0.80) with ABDTPA extractable soil S. The ABDTPA extractable contents of Ca, Mg and S in the soil matrix accounted for 83, 90 and 68 per cent of the variation in their respective enrichment ratios when fitted as exponential functions.

$$\text{ERCa} = 3.6444e^{-0.005 (\text{Available soil Ca})} \quad (r^2 = 0.83) \quad (3)$$

$$\text{ERMg} = 14.727e^{-0.0241 (\text{Available soil Mg})} \quad (r^2 = 0.90) \quad (4)$$

$$\text{ERS} = 0.7309e^{-0.0327 (\text{Available soil S})} \quad (r^2 = 0.68) \quad (5)$$

The enrichment ratios less than unity for calcium and sulfur indicate that there is actually an impoverishment of calcium and sulfur in the eroded sediments in comparison to the matrix soil. This leads us to believe that there will be an actual enrichment of the matrix soil in Ca and S and an impoverishment in Mg with continued erosion over a period of time.

ABDTPA extractable Fe in the soils ranged from 5.3 ppm to 100.4 ppm and in the eroded sediments from 3.8 ppm to 61.0 ppm. The average enrichment ratio for ABDTPA extractable Fe (ERFe) was 0.98 (*se* = 0.20). This little enrichment of iron in the eroded sediments in comparison to the matrix soil did not show any significant correlation with the available Fe content of the matrix soil. ABDTPA extractable Cu in the soils ranged from 0.3 ppm to 2.8 ppm and in the eroded sediments from 0.8 ppm to 4.3 ppm. The average enrichment ratio for ABDTPA extractable Cu (ERCu) was 2.32 (*se* = 0.34). Sediment enrichment of ABDTPA extractable Cu was significantly and negatively correlated (*r* = -0.66) with ABDTPA extractable soil copper. The concentration of ABDTPA extractable Mn in the soils and the sediments ranged from 20.5 ppm to 97.0 ppm and 2.9 ppm to 19.7 ppm respectively. The average enrichment ratio for ABDTPA extractable Mn (ERMn) was 0.30 (*se* = 0.06). Sediment enrichment of available Mn was significantly and negatively correlated (*r* = -0.56) with available soil Mn. The low enrichment ratio for Mn indicates that there is actually an impoverishment of Mn in the eroded sediments in comparison to the matrix soil with erosion over time. The concentration of ABDTPA extractable Zn in the soils and the sediments ranged from 1.5 ppm to 3.2 ppm and 12.6 ppm to 63.6 ppm respectively. The average enrichment ratio for available Zn (ERZn) was 14.51 (*se* = 2.00) which indicates high preferential removal of Zn along with the eroded sediments. However, the sediment enrichment of Zinc did not show any significant correlation with ABDTPA extractable Zn concentration in the soil. These results suggest that continued erosion over time could lead to a soil matrix that is almost similar in available Fe, relatively enriched in Mn and impoverished in Cu and Zn as compared to the original soil matrix. The ABDTPA extractable contents of Cu and Mn in the soil accounted for 63 and 35 per cent of the variation in their enrichment in the eroded sediments when fitted as logarithmic functions.

$$\text{ERCu} = -1.3017\text{Ln}(\text{Available soil Cu}) + 2.1731 \quad (r^2 = 0.63) \quad (6)$$

$$\text{ERMn} = -0.2281\text{Ln}(\text{Available soil Mn}) + 1.1482 \quad (r^2 = 0.35) \quad (7)$$

Conclusions

Significant positive correlation was found for organic matter and available N soil contents with their enrichment in eroded sediments as compared to the parent soil. However, a significant negative correlation was found for the respective contents of ABDTPA extractable K, Ca, Mg, S, Cu, and Cu and Mn in the soil, with their enrichment in the eroded sediments as compared to the parent soil. Phosphorus, Fe and Zn concentration in the soil did not show any significant correlation with the enrichment ratios of the eroded sediments as compared to the original soil matrix. The enrichment ratios greater than unity for OM, N, K, Mg, Cu and Zn, and lower than unity for P, Ca, S and Mn signify the preferential removal in the eroded sediments and retention by the soil matrix, respectively. This has significance in shaping future fertility regimes for soils exposed to erosive rainstorms.

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