Assessment of Soil and Nutrient Losses from Rainfed Upland (Bari) Terraces in the Western Hills of Nepal

B.P. Tripathi, S.P. Shrestha, G.P. Acharya, R. Gardner, K. Mawdesley, S. Gaskin, and S. Adams
Lumle Agriculture Research Station, Lumle, Pokhara, Nepal

Introduction

Rainfed upland ('bari') in Nepal is increasingly becoming a concern due to declines in soil fertility and poor management. Soil erosion is directly linked to fertility decline because of the loss of nutrients associated with eroded soil. The rainfall that promotes soil loss also facilitates nutrient loss in solution as runoff and water leached through the root zone.

Radioactive fallout Caesium 137 (^{137}Cs) measurement offers a rapid technique to estimate soil erosion. Because of its 30-year half-life and ease of detection, ^{137}Cs is a useful tracer for determining long-term rates of soil erosion or deposition (Hasholt and Walling 1992; Ritchie et al. 1975). Oztas et al. (in press) proposed a time- and depth-dependent, third-order polynomial model relating soil depth to ^{137}Cs activity; this technique has been used to predict soil erosion with reasonable success in temperate areas and in terraced terrains in China (Quine et al. 1992; Zhang et al. 1994). The extension of the technique to provide quantitative estimates of loss, as opposed to indications of spatial patterns of relative loss and accumulation of soil, remains to be developed (Walling and Quine 1990). However, it is as a relative tool that the technique was used for the first time in Nepal as part of this study, to complement the plot-based work.

This study attempts to quantify soil and nutrient losses from bari with regard to timing and intensity of the monsoon and to understand the reasons for the spatial and temporal variability of soil and nutrient losses from bari in order to be able to target the areas most susceptible, and to assist management of soil and nutrient retention in these areas.

Materials and Methods

Measurement of runoff and soil loss

In the beginning of 1997, plots were established at three sites: Landruk (Kaski), Bandipur (Tanahun), and Nayatola (Palpa). The sites differ in altitude, rainfall, and soil characteristics, and to some extent farming practices. Landruk and Bandipur showed high and low responses of the qualitative indicators, respectively, suggesting less runoff and high infiltration. Nayatola was chosen because the farming system there is very different from the other sites and the response was unusual in that it was particularly dependent on the less frequent, higher magnitude, rain.

A total of 24 erosion plots (approximately 5 m X 20 m) were established at the three sites. The plots were bounded on both sides and at the top (except for four plots deliberately left open to run-on) by metal sheeting dug to a depth of 15 cm. Plots of approximately 100 m^2 were established, and runoff and eroded soil captured via runoff troughs and collection drums, from where it was sampled and filtered.

Monitoring of runoff and soil loss was done from April/May to October/November. Local recorders were trained and then recorded data at each site. Runoff from each plot was measured daily, soil samples were taken on all days when runoff was greater than 10 litres. Seasonal totals were calculated by adding daily totals.

Measurement of water leached through the root zone

Water leached through the root zone was measured using small, bounded, undistributed lysimeters, 40 cm long and 10 cm diameter, on the erosion plots. The recorders measured the volume of leachate each day at the same time as the runoff in the drums was sampled. These lysimeters were installed on 20 erosion plots during April and May, and recording continued at each site until 30 September.

Measurement of nutrients

The losses of macro-nutrients (N, P, and K) through runoff and leachate were measured. The nutrients dissolved in runoff and leachate water were measured using a portable spectrophotometer (Hach HR 2010) to analyse samples taken directly from the collection drums and lysimeters. The NPK in the topsoil was also monitored.

Analysis of Caesium-137

For the analysis of ^{137}Cs, soil samples were collected at 10 cm intervals up to 50 cm soil depth from 10 terraces spread over 200m on the hill slope. A grassland reference site was also selected to provide a local benchmark. The samples were analysed by S. Adams at Queen Mary Westfield College, University of London, UK.

Cryptogams

A study of cryptogamic soil crusts was carried out during the monsoon of 1996 on 168 terraces across five field areas, Bandipur, Chambas (Tanahun district), Nayatola (Palpa district), Kimchaur (Myagdi district), and Landruk (Kaski district), using a simple quadrat-based sampling methodology.

Results

Rainfall pattern over three years by manual gauge and automatic rain gauge

The average rainfall in 1997, 1998, and 1999 from March to November at the Bandipur, Landruk, and Nayatola sites was 1620 mm, 3524 mm, and 1591 mm respectively. Bandipur's highest monthly rainfall (526 mm) occurred in July, followed by August (428 mm), and the lowest in October (16 mm). The Landruk and Nayatola sites had their highest rainfall in August (978 mm and 532 mm, respectively) followed by July (940 mm and 530 mm respectively).

The highest daily rainfall recorded at Bandipur was on 28 August 1999 while that at Landruk (140mm) and Nayatola (>250 mm) was on 12 June 1999. The high rainfall at the beginning of the rainy season at the Landruk and Nayatola sites might have significantly affected the runoff loss of soil and nutrients. By August, site ground cover might have developed, and this would have minimised soil and nutrient losses by runoff at Bandipur.

Runoff and infiltration of water

Water runoff and infiltration differed among different terraces and sites. Water runoff ranged from 30.1 to 443.5 l/m^2 with a mean of 112.9 l/m^2 at Bandipur, 36.7 to 302.2 l/m^2 with a mean of 112.2 l/m^2 at Landruk, and 1.3 to 14.6 l/m^2 with a mean of 7.1 l/m^2 at Nayatola. When compared with total rainfall, water runoff was the lowest (0.6%) at Nayatola, followed by Landruk (3.1%) and Bandipur (5.7%) .

Water infiltration at 40 cm depth in the lysimeter was 589.8, 1122.2, and 1027.6 l/m^2 at Bandipur, Landruk, and Nayatola, respectively. In other words 30, 31, and 85% of the total rainwater leached down to a depth of 40cm at Bandipur, Landruk, and Nayatola, respectively, indicating higher leaching losses than runoff losses .

Soil loss due to runoff water

Mean soil losses at the three sites are shown in Table 1. The losses in individual plots ranged from 0.5 t/ha to 15.4 t/ha, 0.6 to 5.9 t/ha, and 0.1 to 10.4 t/ha with overall mean soil losses over the three years of 3.4 t/ha, 2.5 t/ha and 2.6 t/ha at the Bandipur, Landruk, and Nayatola sites, respectively. The actual largest soil loss of 35.4 t/ha (at the Bandipur site) in 1998 was due to a high volume of water that caused the collapse of a terrace riser in the infertile soil under a maize-fingermillet system.

These soil losses are not very alarming in the western hills. Water run-on, slope angle, soil type, ground cover, and soil fertility status play important roles for soil losses from these hill slopes, however, and values for one site cannot be taken as typical for others.

Table 1: Mean soil and nutrient losses (1997-1999)

	Bandipur	Landruk	Nayatola
Mean soil losses (t/ha)			
1997	1.5	4.2	4.4
1998	7.3	2.3	3.1
1999	1.3	1.0	0.2
Mean	3.4	2.5	2.6
Mean losses (kg/ha)			
NO_3-N	1.2	0.6	0.2
P	3.5	1.5	0.9
K	7.4	7.5	3.0
Leaching losses (kg/ha)			
NO_3-N	10.2	53.0	34.0
P	21.1	8.7	9.7
K	44.9	114.5	70.0

Loss of nutrients

The mean losses in 1997-1999 of NO_3-N, P, and K dissolved in runoff water and in leachate at the Bandipur, Landruk, and Nayatola sites are shown in Table 1. The leaching losses were far higher than the runoff losses.

Caesium-137 analysis

The benchmark sample of (undisturbed) forest soil showed the typical pattern of exponential decrease in ^{137}Cs activity down the soil column, with most of the ^{137}Cs contained in the upper 20 cm. The total ^{137}Cs inventory, determined as the sum of ^{137}Cs content in each of the five 10 cm layers in the core, was 54.1 mBq/g.

In the cultivated terraces, the total ^{137}Cs inventories ranged from 29.6 to 156 mBq/g. With the exception of one extreme terrace (156 mBq/g), the values were generally within ±50% of the benchmark value. This suggests that there has been little if any net loss of topsoil from the terrace surfaces on the hillslope as a whole over the past 40 years of cultivation, although considerable redistribution has taken place among terraces, with some net losers and some net gainers.

The worst cases (Terrace 7 and Terrace 22) indicated losses roughly equivalent to 40 - 50% of the top 10 cm of soil over the 40-year period (average 1 mm/yr). These rates are excessive and would be unacceptable if they were the norm across all terraces.

The high spatial differences in net loss and accumulation suggest that where possible farmers should aim to manage surface runoff on the hillslope communally so as to minimise and spread risk.

Cryptogamic soil crusts

Several environmental variables, operating at regional and local scales, were correlated with cryptogam distribution. These included altitude (negative), rainfall (negative), soil sealing (positive), soil sand content (negative), pH (positive), microtopography (positive), and, to a lesser extent, weed cover (positive). Under the existing crop cycle, cryptogams developed within a few weeks during the main monsoon and reduced runoff and soil losses by about 50%. While recognising that the size of the plots restricts our ability to extrapolate to larger areas, cryptogams appeared to offer a substantial benefit in reducing soil erosion on bench terraces. They remained effective during the entire period studied.

Conclusions and Implications

In general, soil losses were surprisingly and consistently low, except for extreme events early in the pre-monsoon season or where there were high volumes of run-on. The high losses of nutrients are probably due to the shallow soil depth and light textured soils typical in the hills of Nepal, which encouraged leaching of nutrients. These losses can be minimised by following appropriate cropping systems and planting cover crops. The seasonal pattern of soil loss in relation to agricultural cycles has been confirmed. The importance of weed and crop cover in diminishing soil loss is paramount.

Although high rainfall in all areas can potentially lead to substantial losses of NO_3- N, P, and K nutrients through leaching, losses due to runoff are low. Those adsorbed to soil particles have yet to be determined.

Caesium 137 showed limited net soil losses through erosion from the hillside but highlighted the various processes of redistribution of soil between terraces. Caesium 137 has been shown to be largely immobilised and trapped on clay, organic matter and fine micaceous particles within the upper layers of the soil. Mixing resulting from ploughing is a probable explanation for the greater homogeneity of ^{137}Cs content within the upper 20 to 25 cm.

Cryptogams are as effective as weed cover for minimising runoff and soil erosion. They reduced runoff and soil erosion by about 50%. As long as the farmers' practice of allowing weed growth in the main monsoon continues, the greatest potential benefits of cryptogam cover may be in the early season when the soil is most exposed and vulnerable. The propensity for cryptogams to form at this time needs to be examined, as it was not part of the study.

Typically, cryptogams exist on the soil surface beneath the weed cover, and thus farmers should be encouraged to cut weeds rather than to pull them by their roots to minimise disturbance to both the soil surface and the cryptogam cover.

The potential role of cryptogams in fixing nitrogen in the Nepalese setting also needs further investigation.

Sustainable crop production requires balanced resource use, and the management decisions at a household level determine nutrient fluxes and the economic viability of enterprises. Traditionally, the agricultural systems of the mid-hills of Nepal have a close integration of forestry, livestock husbandry, and crop production, but increasing population and other social changes are straining these systems.

Acknowledgements

The authors are grateful to Dr P. E. Harding, former Director; Dr W. Stewart-Jones, HARP Research Adviser; and Dr R. P. Sah, Chief, ARS Lumle for their continued support and encouragement . We sincerely acknowledge the contribution of team members, Soil Fertility Research, and ARS Lumle for their inputs, especially Mr R.C. Tripathi, technical assistant, for his continuous effort in the project. The cooperation of the recorders and farmers at the three sites in Kaski, Tanahun, and Palpa districts in implementing the field study is gratefully acknowledged. The funding support to this study provided by Queen Mary (Westfield) College, University of London, and Hill Agriculture Research Project (HARP) of the British Government, UK, is gratefully acknowledged.

References

Hasholt, B. ; Walling, D.E. (1992) 'Use of Caesium-137 to Investigate Sediment Sources and Sediment Delivery in a Small Glacierised Mountain Drainage Basin in Eastern Greenland'. In *Erosion, Debris Flows and Environment in Mountain Regions, Proceedings of the Chengdu symposium.* IAHS Publication. No. 209, pp 87-100. Chengdu: IAHS

Oztas, T.; Jones, A.J.; Millke, L.N.; Grossman, R.B. (in press) 'Parabolic Method to Predict Soil Erosion from Caesium-137 Activity', In *Nebraska Agric. Exp. Stn. J. Series*

Quine, T.A.; Walling, D.E.; Zhang, X.; Wang, Y. (1992) 'Investigation of Soil Erosion on Terraced Fields Near Yanting, Sichuan Province, China, Using Caesium -137'. In Walling, D.E.; Davies, T.; and Hasholt, B. (eds.) *Erosion, Debris Flows and Environment in Mountain Regions, Proceedings of the Chengdu symposium.* IAHS Publication. No. 209. Chengdu: IAHS

Richie, J.C.; Hawks, P.H.; McHenry, R.J. (1975) 'Deposition Rates in Valleys Determined Using Fallout Caesium-137'. In *Geol. Soc. Am. Bull,* 86: 1128-1130

Walling, D.E.; Quine, T.A. (1990) 'Calibration of Caesium-137 Measurements to Provide Quantitative Erosion Rate Data'. In *Land Degradation and Rehabilitation*, 2: 161-175

Zhang, X.; Quine, T.A.; Walling, D.E.; Zhouli. (1994) 'Application of the Caesium 137 Technique in a Study of Soil Erosion on Gully Slope in a Yuan Area of the Loess Plateau Near Xifeng, Gansu Province, China'. In *Geografiska Annaler*, 76A (1994): 1-2