Rehabilitation of Degraded Lands

Pravakar B. Shah[1], Hans E. Schreier[2] and Gopal Nakarmi[1]
[1]International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal,
[2]Institute for Resources and Environment, University of British Columbia, Vancouver, Canada

Abstract

Degraded sites are difficult to rehabilitate because of their adverse chemical and physical condition and the large inputs required to restore the physical properties and the soil nutrient pool. Experiments conducted in the Jhikhu Khola watershed showed that fodder trees could be successfully established in hedgerows on degraded non-red soils on quartzite, but that this was a significant challenge on degraded red soils (on phyllite), and extremely difficult on non-red soils on saprolite. Selected groundcover and grasses were established on red soils and the effect of adding various combinations of lime and manure tested. Lemon grass in particular was found to be a successful coloniser on these highly acid soils. Rehabilitation of the nutrient pool with litter additions alone was found to be very slow, but significant improvements were achieved in the carbon pool and soil structure following a two-year period of continuous addition of litter (once every six months). The incorporation of locally grown thetonia species improved the carbon content and soil structure, but had little affect on the soil pH or availability of phosphorus. It seems that addition of litter and lime is the best treatment to overcome the adverse chemical conditions of red soils.

Introduction

Natural instabilities are common in the middle mountains of Nepal. The main causes of slope failures are the excessively steep topography, the highly weathered and fractured bedrocks, the continuous tectonic uplift of the rock formations, and the monsoon climate. If to this is added the very intensive land use and the limited external inputs into the forested and agricultural systems, it is of little surprise that land degradation is evident in large areas, including in the two watersheds in the middle mountains of Nepal, the Jhikhu and Yarsha Khola watersheds, that are being studied as examples in the PARDYP project. Seven per cent of the Jhikhu Khola watershed was classified as degraded land on the basis of interpretation of aerial photos and GIS analysis. The definition used for degraded land included all areas with minimal permanent vegetation cover on landslides, rilled and gullied surfaces, areas subject to frequent sheet erosion, and continuously eroding riverbanks. The causes of the degradation are difficult to assess since many slope failures are likely to be the result of a combination of natural instabilities caused by uplift, excessive rainfall, and human-induced degradation resulting from overgrazing, deforestation, and insufficient inputs of organic matter and nutrients. While the overall extent of the degraded areas is small, the impact on the rest of the watershed system is magnified. The degraded areas in the watershed do not produce any biomass and because of the lack of protective vegetation cover much more sediment is produced from these source areas than from agricultural and forested land (Carver 1997). An estimated 30 to 40 per cent of the annual stream sediment load in the Jhikhu Khola watershed originates from degraded lands. This sediment causes many problems clogging irrigation channels and silting up reservoirs downstream from the source areas. A significant portion of the soils eroded from upland areas is recaptured via irrigation water in the lowlands, but whereas the soils eroded from agricultural fields provide a nutrient enrichment that is of significant benefit to the downstream rice farmers (Schreier *et al.* 1995, 1998), the sediments originating from degraded lands have a very low nutrient content and are of little benefit.

It is imperative that degraded sites are rehabilitated because the demand for agricultural land is high and the off-site impacts are substantial. Rehabilitating degraded sites is highly challenging, however, and in the current situation farmers have little incentive to initiate such projects because the human effort needed is large, there are widespread labour shortages in the watershed, and there are few short-term benefits because the initial biomass yields are very small. Rehabilitation experiments were performed to help improve our understanding of what processes are successful in stabilising the soils and how the soil fertility can be improved.

Characteristics of the Degraded Sites

A three hectare site at 900m elevation on quartzite, phyllite, and siltstone/saprolite parent material was selected for the rehabilitation experiment. The site is shown in Figure 39. It had marked gullies and was heavily eroded. About 60 per cent of the site consisted of red soils, which are particularly sensitive to degradation.

The red soils in Nepal tend to develop on stable land forms and represent the oldest and most leached soils in the country. Once degraded they are difficult to rehabilitate. They have chemical and physical conditions that inhibit biomass production in many different ways. Red soils originate predominantly from phyllitic bedrock and are dominated by iron and aluminum oxides, with kaolinite as the dominant clay mineral. These soils have a relatively low cation exchange capacity and lack basic cations (Ca and Mg), they have low pH values, and because of the acidity and dominance of Al and Fe the availability of phosphorus is very limited (Schreier *et al.* 1999). As

Figure 39: **Degraded Red Soil Site**

degraded sites have no biomass cover the carbon and nitrogen contents are also very low. The values of some of the chemical parameters of the red and non-red soils in the watershed are given in Table 48. The physical structure of the red soils is also poor with low infiltration and percolation rates and frequent surface crusting. Rainfall intensity often exceeds the infiltration and percolation rates at these sites leading to accelerated surface erosion.

Table 48: **Contrast in Soil Chemistry between Red and Non-red Soils, Bela Subcatchment**

Variable	Red Soil (n=90)	Non-red Soil (n=110)
pH	4.9	4.8
CEC (cmol kg-1)	13.0	8.9
Exchange Ca (cmol kg-1)	3.97	3.56
Exchange Mg (cmol kg-1)	1.77	1.09
Exchange K (cmol kg-1)	0.37	0.21
Base Saturation (%)	46.8	55.8
Available P (mg kg-1)	9.8	22.1
Carbon (%)	0.99	1.00

Rehabilitation Experiments

Three different rehabilitation experiments were performed:

- a fodder tree hedgerow experiment;
- a grass cover experiment with different soil treatments; and
- an organic litter experiment to rehabilitate the soil nutrient status.

The first experiments were started in April 1996.

Fodder Tree Hedgerow Experiment

The degraded site was divided into sixteen 30x30 metre sections whose edges approximately followed the contour lines. Although the plan of the sections was regular, the sections were actually highly variable as the site was heavily gullied, sloping, and irregular. The edges of the sections approximately followed the contour lines across the site. The type of soil and parent material varied across the site and the sections were defined according to the major soil type/parent material in each. Essentially red (and pink) soils were found on phyllite parent material, and yellowish brown soils on quartzite, siltstone, and sandstone. There is very little (non-red) soil cover on saprolite parent material. Quartzite has the advantage that it tends to be deeply cracked, offering a secure hold for tree roots as well as potential caches of water. These characteristics are unevenly distributed, however, leading to a variation across any site in the potential for supporting tree growth.

In each section one of seven different types of six month-old fodder tree seedlings was planted along both sides of one metre wide strips down the length of the plot (with a two to three metre spacing between seedlings) in the form of a hedge (a total of approximately 60 trees per plot). The hedgerow form of planting was chosen as it is a particularly successful way of stabilising a slope and at the same time leaves a clear space that can be used to grow other crops. The tree species tested were *Dalbergia sissoo, Albizia lebbeck* (kalo siris) and *Albizia procera* (rato siris), *Litsea monopetala* (kutmiro), *Bauhinia purpurea* (tanke), *Melia azedarach* (bakaino), and *Acacia catechu* (khair). The constraints of the site meant that it was not possible to plan a strictly controlled experiment with single tests or replicates of each type of tree on each type of soil. Rather an attempt was made to discover whether a) fodder trees of the types preferred locally (and available) could be established successfully in hedgerow form on this degraded site, and b) any type of tree could be grown successfully in the most difficult parts of the site and the site successfully rehabilitated overall. Thus, for example, siris and sisso trees were not planted on saprolite parent material as previous experience indicated that these species would not grow successfully on such soil, and other potentially more promising species were tested on this particularly disadvantageous area. The experimental design is shown in Table 49 and shows the type of fodder trees planted on the three types of weathered parent materials: saprolite/siltsone (non-red soil), phyllite (red soils), and quartzite (non-red soil). One kilogram of manure was added with each seedling in order to increase tree survival rates.

Table 49: **Nitrogen Fodder Tree Experiments, 30 X 30m Plot Design**

A1 Siris Quartizite	Soil Rehabilitation Experiment			
B1 Sissoo Quartzite				
D1 Tanke Quartzite	D2 Siris Red Soil (phyllite)	D3 Kutmiro Mixed	D4 Bakaino Saprolite	D5 Sissoo Red Soil (phyllite)
E1 Siris Quartzite	E2 Bakaino Red/mixed	E3 Tanke Saprolite	E4 Kutmiro Saprolite	E5 Siris Red Soil (phyllite)
Soil Rehab. Experiments	F2 Sissoo Quartzite	F3 Khair Quartzite	F4 Bakaino Quartzite	F5 Sissoo Red Soil (phyllite)

Note: The name of the tree species planted, and the type of soil or parent material are shown for each plot. The 'soil rehabilitation' plot experiments are described in section c).

The number of hedgerow trees remaining and the average height after two and a half years are shown in Figures 40 and 41. The average tree heights on the three types of parent material are shown in Figure 42. The tree survival and growth varied considerably between the sections, but overall the establishment of hedgerows was significant. There were large differences in biomass production between parent materials. The best results were obtained on quartzite materials, while the red soils on phyllite showed less good and the saprolite/ siltstone very poor results, although even in these plots a small number of trees survived growing very slowly.

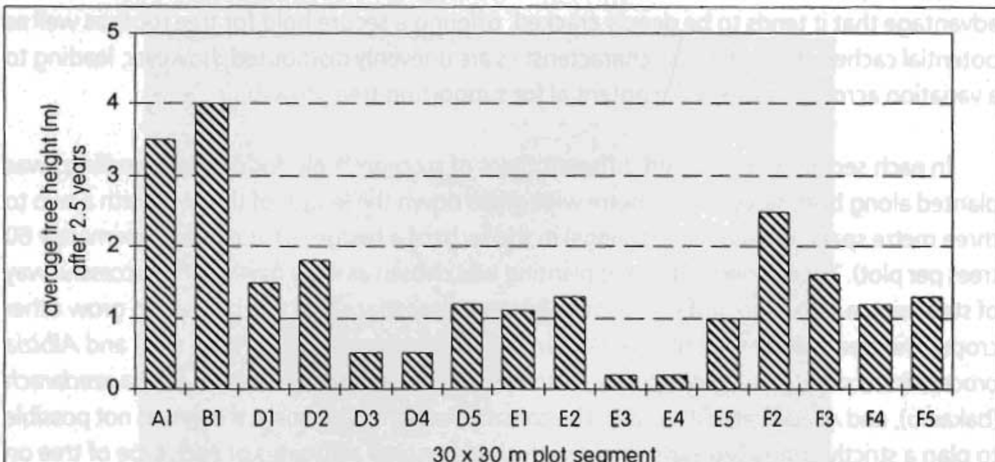


Figure 40: **Number of Hedgerow Trees after 2.5 Years**

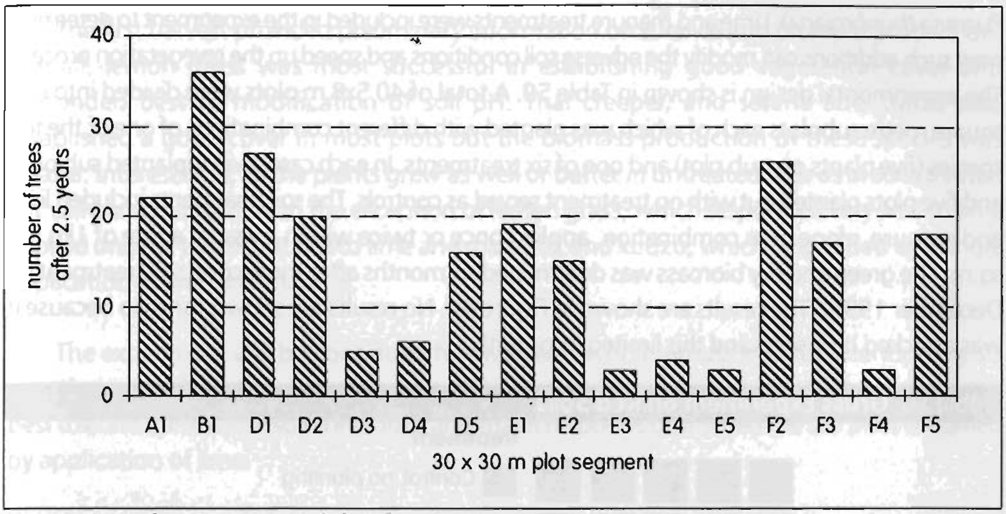


Figure 41: **Hedgerow Tree Height after 2.5 Years**

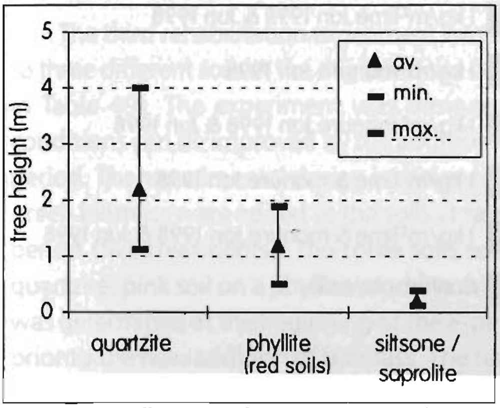


Figure 42: **Influence of Parent Material on Hedgerows**

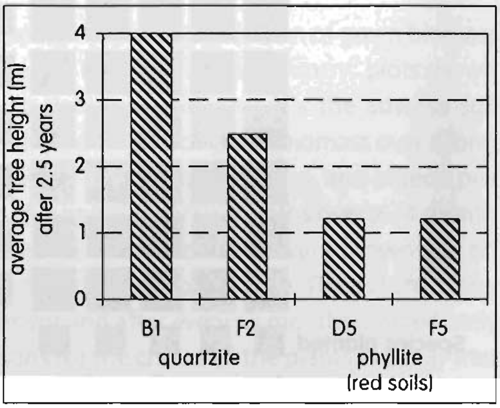


Figure 43: **Performance of *Dalbergia sisoo***

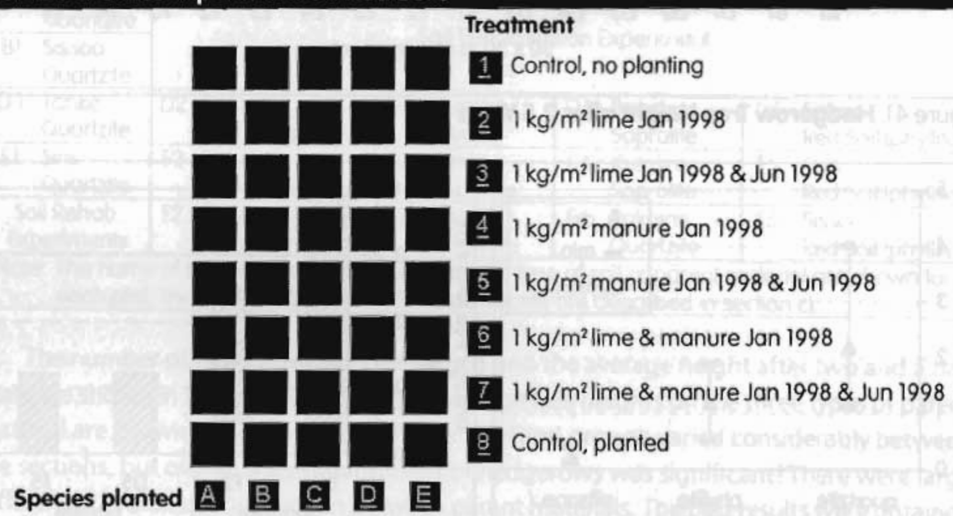
Of the seven fodder species, *Dalbergia sissoo* was the most successful with trees reaching average heights in the best sub-plots of up to 4 m within 2.5 years (Figure 43). The other successful species were *Albizia lebbeck* (kalo siris) and *Albizia procera* (rato siris). *Bauhinia purpurea* (tanke) and *Acacia catechu* (khair) survived well but grew only slowly on quartzite, *Melia azedarach* (bakaino) survived well but grew only slowly on red/mixed soil. As expected none of the three species tested on saprolite did well, although *Melia azedarach* (bakaino) showed fractionally better survival and growth rates than *Bauhinia purpurea* (tanke) and *Litsea monopetala* (kutmiro).

Grass Cover Experiment with Different Soil Treatments

A second experiment was started in 1998 on red soils (parent material phyllite) using perennial ground cover species such as lemon grass (*Cymbopogon flexousus*), *Setaria ancep*, stylo (*Stylosantes quianensis*), Thai creeper (Golden Button), and Chinese creeper (kudzu or

Pueraria thunbrgiana). Lime and manure treatments were included in the experiment to determine how such additions can modify the adverse soil conditions and speed up the revegetation process. The experimental design is shown in Table 50. A total of 40 5x8 m plots were divided into one square metre subplots each of which was planted with different combinations of one of the five species (five plants per sub plot) and one of six treatments. In each case, five unplanted sub plots and five plots planted but with no treatment served as controls. The soil treatments included lime and manure, alone or in combination, applied once or twice within a year at a rate of 1 kg per sq.m. The green and dry biomass was determined six months after the second soil treatment (in December 1998). The results are shown in Figure 44. No results are shown for stylo because it was attacked by insects and this limited its growth.

Table 50: **Grass Experiment on Red Soils**



A = Lemon Grass (*Cymbopogon flexousus*) 5 plants/m²
B = Setaria (*Setaria ancep*) 5 plants/m²
C = Stylo (*Stylosanthes quianensis*) 5 plants/m²
D = Chinese Creeper Kodzu (*Pueraria thunbrgiana*) 5 plants/m²
E = Thailand Creeper - Golden Button 5 plants/m²

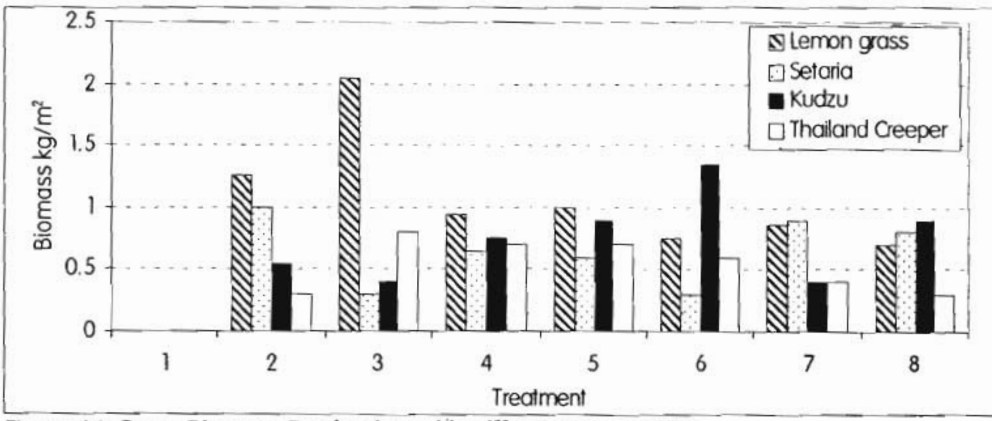


Figure 44: **Grass Biomass Production with Different Treatments**

The first harvest provided preliminary information on survival and biomass production. Overall, lemon grass was most successful in establishing good vegetation cover and responded best to modification of soil pH. Thai creeper, and setaria and kudzu also established a good cover in most plots but the biomass production of these species was smaller. Interestingly, all the plants grew as well or better in untreated soils as in soils treated with all combinations, with the exception of lemon grass, which responded very well to lime applied once or twice (but not to lime and manure), and kudzu, which responded to a single application of lime and manure.

The experiment will be continued for two years with biomass measurements every six months and soil chemical analysis every 12 months. So far it seems that lemon grass can best tolerate the adverse soil conditions and that it responds best when the soil pH is modified by application of lime.

Soil Fertility Rehabilitation through Additions of Organic Litter

The third rehabilitation experiment was based on continuous addition of green biomass to three different soils at the degraded site (in the 'soil rehabilitation experiment' plots shown in Table 49). The experiment was designed to determine how rapidly the adverse soil conditions can be improved by the addition of different types of green biomass over a long period. The experimental design is shown in Table 51. Thetonia, sunhemp, and pigeon pea green biomass were added to the soils at rates of 2 kg/m^2 every six months over a 24 month period (five treatments). The three soils selected for the experiment were brown soil on quartzite, pink soil on a phyllite/saprolite mixture, and red soil on phyllite. The soil chemistry was determined at the beginning of the experiment and after every six months, immediately prior to the new addition of biomass. The reasons for the choice of the plants were: a) that sunhemp and pigeon pea both grow fairly well on degraded red soils so that sufficient green biomass could be grown locally for the experiment; and b) that thetonia, which originates from the Philippines, can be grown on quartzite dominated sites and has been used successfully as an organic matter soil amendment in the Philippines and in Kenya. Locally established sites served as the continuous source of biomass for the experiment.

The green biomass was incorporated into the 0-15 cm surface layer of the soil. After six months a well-mixed bulk soil sample was collected for each plot by combining 20 sub-samples taken in the plot at the same depth. No plants were grown at the site and occasional

Table 51: **Restoration Using Organic Matter, Experimental Design**

Brown Soil	**Red-Pink Soil**	**Red Soil**
Plot 1 Thetonia litter 2 kg/m^2	Plot 1 Thetonia litter 2 kg/m^2	Plot 1 Thetonia litter 2 kg/m^2
Plot 2 Sunhemp litter 2 kg/m^2	Plot 2 Sunhemp litter 2 kg/m^2	Plot 2 Sunhemp litter 2 kg/m^2
Plot 3 Pigeon Pea litter 2 kg/m^2	Plot 3 Pigeon Pea litter 2 kg/m^2	Plot 3 Pigeon Pea litter 2 kg/m^2
Additions: April 96, October 96, April 97, October 97, April 98 Soil sampling: before each new addition		

weeds invading the site were removed. The soils were analysed for pH, carbon, available phosphorus, and exchangeable cations using standard methods as described by Page *et al.* (1982).

Typical results are shown in Figures 45 and 46. The three soils reacted differently and, as expected, the changes in soil conditions took place at a relatively slow rate. There was a natural fluctuation in the values, but a clear trend could be observed after 24 months at which time addition of thetonia biomass had resulted in a tripling of the soil carbon content, and the other two treatments had doubled the soil carbon content. None of the treatments influenced the soil pH significantly, and while the available P increased in brown soil, no effect was observed in the red and pink soils. It seems possible that the high concentrations of extractable Al and Fe (ammonium oxalate and citric dithionite-bicarbonate) are responsible for fixing any available P that is released from the decomposition of the organic litter. The soil structure in the red soils became gradually more granular following the addition of organic matter, thus improving the soil structure and water infiltration capacity.

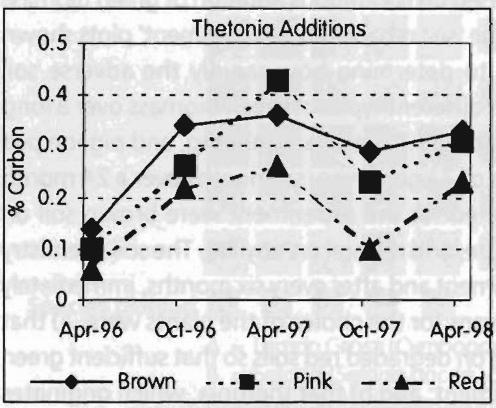


Figure 45: **Changes in %C Following Thetonia Incorporation**

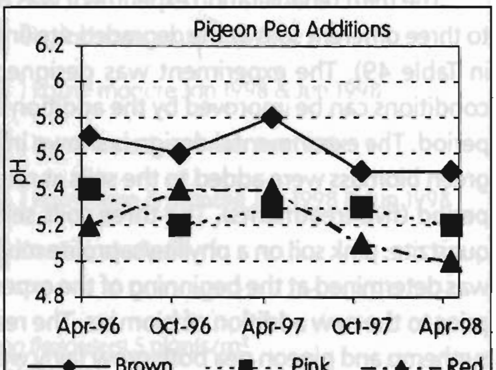


Figure 46: **Changes in pH Following Pigeon Pea Incorporation**

Conclusions

Degraded soils are difficult to rehabilitate. The experiments conducted in the Jhikhu Khola watershed showed that it was not easy to establish fodder trees in hedgerows on red soils, but the results were sufficiently encouraging to prompt further attempts. *Dalbergia sisoo* performed particularly well on the degraded sites on non-red soils on quartzite, reaching tree heights of up to four metres over a 2.5 year period. Various species of perennial ground cover were successfully established on red soils but biomass production was low. Addition of lime improved the survival and biomass production of lemon grass considerably, resulting in the production of more than two kg/m^2 of dry biomass over a six-month period. Setaria, Thai creeper, and Chinese creeper also survived well in amended red soil and untreated red soil but produced lower biomass. Addition of locally grown green litter (thetonia, sunhemp, pigeon pea) to red, red-pink, or brown soils improved the soil carbon pool but had little effect on soil pH. Available P was improved in the degraded brown soils but not in the red soils. Extractable Al and Fe probably fixes any P released from the organic fraction. Additions of thetonia elicited the most significant soil improvement, but even after four additions of green biomass over a 24 month period, the increase in soil carbon was small (from 0.1 to 0.3%). Improving the overall soil nutrient pool is a slow and tedious process.

References

Carver, M. (1997). 'Diagnosis of Headwater Sediment Dynamics in Nepal's Middle Mountains: Implications for Land Management'. Ph D Thesis. Vancouver: University of British Columbia.

Page, A.L.; Miller, R.H. and Keeney, D.R. (eds) (1982). *'Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*. Madison: American Society of Agronomy.

Schreier, H.; Brown, S.; Carver, M. and Shah, P.B. (1998). 'Linking Land Degradation to Nutrient and Sediment Transport in a Middle Mountain Watershed', In Haigh, M.; Krecek, J.; Rajwar, G.S. and Kilmartin, M. (eds) *Headwaters: Water Resources and Soil Conservation,* Proceedings of Headwater 1998-4th International Conference on Headwater Control, IAHC, WASWC, Merano, Italy, pp 315-327. Rotterdam: A.A. Balkema,

Schreier, H.; Brown, S.; Lavkulich, L.M. and Shah, P.B. (1999). 'Phosphorus Dynamics and Soil P-Fertility Constraints in Nepal'. In *Soil Science,* 164(5): 1-10.

Schreier, H.; Shah, P.B. and Brown, S. (1995). 'Challenges in Mountain Resource Management in Nepal'. In Schreier, H.; Shah, P. B. and Brown, S. (eds) *Challenges in Mountain Resource Management in Nepal: Processes, Trends and Dynamics in Middle Mountain Watershed*. Kathmandu: ICMOD.