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Factors affecting the nutrient status of forest sites in a mountain watershed in Nepal

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SUMMARY

Soil and foliage samples were collected from 136 sample sites in forested areas of the Dhulikhel Watershed, Nepal. Analyses showed that the soils have small values for pH, base saturation, total nitrogen, carbon and available phosphorus. Sample sites were stratified on the basis of aspect and elevation, soil type, forest type and management and the strata were compared to determine the influence of site factors on forest soil fertility.

Soils on south-facing slopes at low elevation contained significantly less total nitrogen and organic carbon compared with soils from north-facing slopes at high elevation. Foliage of both sal (*Shorea robusta* Gaertn.) and chir pine (*Pinus roxburghii* Sargent) growing on red soils (Rhodustults and Haplustults) contained significantly less phosphorus compared with non-red soils (Ustochrepts and Dystrochrepts). Soils under stands of sal have the poorest soil fertility levels in comparison with chir pine and hardwood sites. The continuous removal of base-rich litter from sal sites may account for the poor fertility conditions. Soil fertility levels are greater on sites which have been protected from biomass removal for at least 15 years relative to sites which have come under protection in the past 7 years.

INTRODUCTION

The forests in Nepal are a major source of animal fodder, agricultural compost, fuelwood and timber (Mahat *et al.*, 1987). There is generally a one-way flow of nutrients from the forest to the farm in the form of grass, green leaves and dry leaves. The growing population is placing increasing pressure on the forests and this may lead to declines in soil fertility, site productivity and the supply of forest products (Ives & Messerli, 1989). Thus, it is important that the fertility of the forest soils be maintained.

The forest soils of Nepal have not been widely studied and little information is available with regard to forest soil fertility in this region. Burton (1989) studied the soil quality under agriculture and forest in the Terai region of Nepal. Feigl (1989) studied soil properties under forest in the Jhikhu Khola Watershed in the Middle Mountain region.

Our objective was to investigate the influence of climate, soil type, forest type and management on forest soil fertility in the Dhulikhel Watershed in Nepal.

MATERIALS AND METHODS

Study area

The study was conducted in the Dhulikhel Watershed which covers an area of 1270 ha and lies in the Middle Mountain region of Nepal (Fig. 1). The climate is monsoonal and the average rainfall at Dhulikhel (1550 m elevation) is 1400 mm.

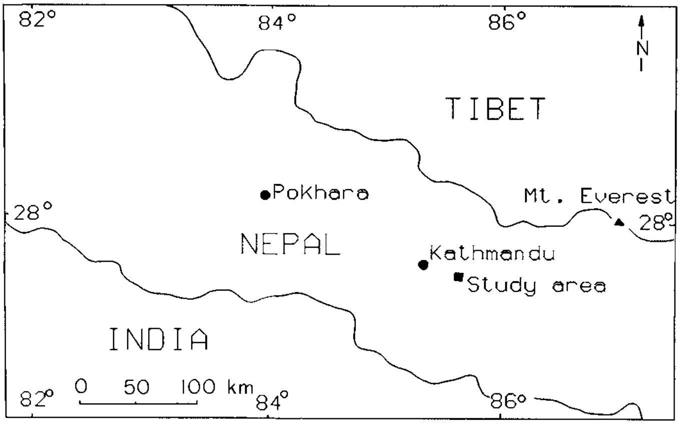

Fig. 1. The location of the study area.

Soil and foliage sampling

Measurements were taken at 136 sample plots, radius 3 m, randomly located within forest, plantation and shrub areas (Fig. 2). A soil profile (to a depth of 30 cm) was excavated in the centre of each plot, surface horizons described and soil type classified as red (hue of 7.5YR or redder) or non-red. Soil samples from a depth of 10 cm were collected from the central pit and two other excavations, and the samples were mixed on an equal volume basis to form one composite sample per site. From 72 of the sites, soil samples were taken at a depth of 10 cm to determine soil water content during the dry season.

One hundred and sixty-eight foliage samples were collected from the dominant species on the site. Land ownership and degree of forest protection were evaluated by visual assessment and discussion with local villagers.

Laboratory analyses

The soil samples were air-dried and passed through a 2-mm mesh; the foliar samples were oven-dried at 70°C and then ground. Water content was determined gravimetrically. All samples were shipped to the University of British Columbia, Canada for laboratory analysis. The following soil properties were analysed: pH in H_2O and in $CaCl_2$ (McLean, 1982); cation exchange capacity (CEC), [$mmol_c$ kg^{-1}] (Rhoades, 1982); exchangeable Ca, Mg, Na and K [$mmol_c$ kg^{-1}] (Thomas, 1982); total C content [g kg^{-1}] (Nelson & Sommers, 1982); total N content [g kg^{-1}] (Bremner & Mulvaney, 1982); and available P [mg kg^{-1}] (Olsen & Sommers, 1982).

Total exchangeable bases, percentage base saturation and the C:N ratio were calculated for each sample. The foliage samples were analysed for the following nutrients: N, P, K, Ca, Mg, Fe, Al, Mn, Cu and Zn (Parkinson & Allen, 1975; Olsen & Sommers, 1982).

Stratification of sample plots

Factors expected to influence forest soil fertility in the Dhulikhel Watershed (climate, soil type, forest type and management) were used as a basis for stratifying the 136 sample sites. The lower slopes and south-facing slopes (hereafter 'south slopes') are generally hotter and drier, and the upper slopes and north-facing slopes (hereafter 'north slopes') are cooler and moister (Wymann, 1991). Five aspect/elevation classes were defined: 'south slopes' below 1200 m; 'south slopes' above 1200 m; 'north slopes' below 1200 m; 'north slopes' above 1200 m; and 'east and west slopes'.

There are two main soil types in the watershed: red soils (Rhodustults and Haplustults) formed on quartzitic phyllite, and non-red soils (Ustochrepts and Dystrochrepts) formed on phyllite, schist and quartzite (Jackson, 1987). Four forest types occur in the study area: chir pine (*Pinus roxburghii* Sargent) plantation, sal (*Shorea robusta* Gaertn.) forest, mixed hardwood forest and mixed forest (a combination of chir pine and sal, or chir pine and mixed hardwood).

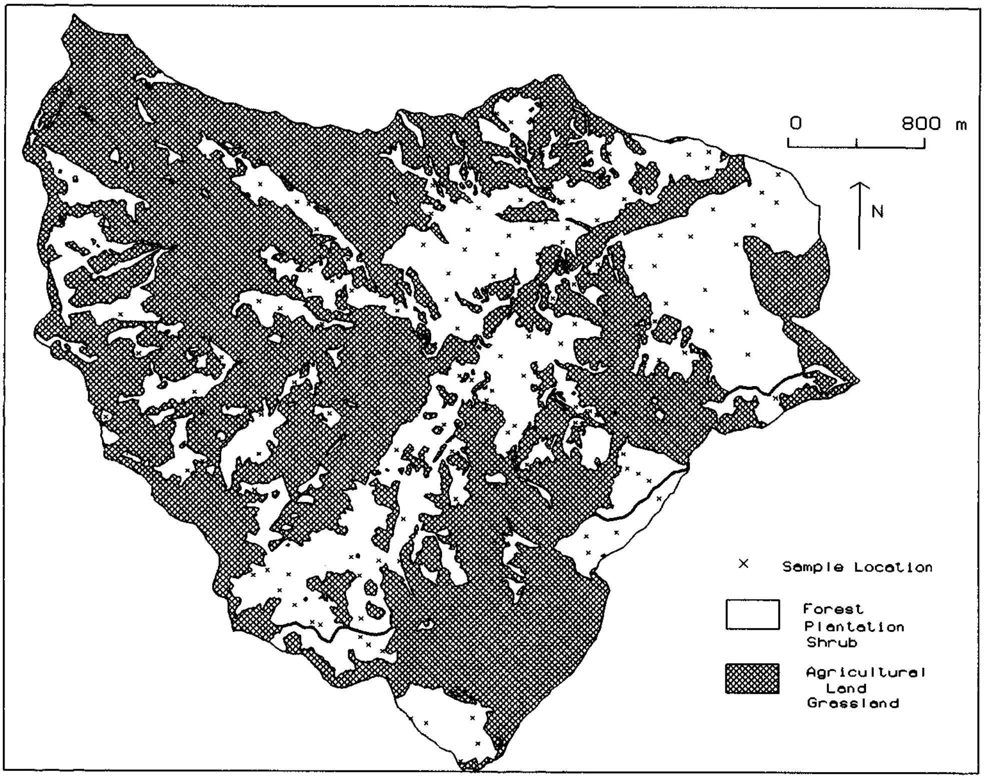

Fig. 2. The location of sample points within the study area.

The sites were divided into four management classes: private (owned by individuals), government-owned and guarded, government-owned but unguarded, and 'panchayat'. Private forest land is generally well protected by the owner and use is controlled. Some government forest is protected by guards and use has been restricted for at least 15 years. Panchayat forest is previously degraded government forest which has recently (<7 years) been handed over to local communities to be managed.

Statistical analysis

Descriptive statistics were calculated for all parameters. Soil parameters were compared with values listed by Landon (1990). Relationships were tested among soil, foliar, site and forest parameters by computing Pearson correlations for pairs of properties (Wilkinson, 1988). The results of multivariate analyses (multiple regression, cluster analysis and discriminant analysis) were not very revealing and will not be presented in this paper. The Mann–Whitney *U*-test (Siegel, 1956) was used to test for significant differences in soil and foliar nutrient parameters between classes of aspect/elevation, soil type, forest type and management.

For a more detailed description of the methods see Schmidt (1992).

RESULTS AND DISCUSSION

Soil, foliar, forest and topographic parameters

Compared with values listed by Landon (1990) the forest soils of the study area have small values for CEC, total exchangeable bases, base saturation, total N, organic C and available P (Table 1). All of the sites have total N and organic C levels below the critical range and 76% of the sites have available P levels below the critical range.

Significant correlations occur between several soil and topographic variables: in particular, there are strong positive correlations between pH (in H_2O), pH (in $CaCl_2$), Ca, Mg, K, total exchangeable

Table 1. Properties of soils

Soil property	Mean[a]	Standard deviation	Minimum	Maximum
pH (in H_2O)	5.3	0.3	4.4	6.3
pH (in $CaCl_2$)	4.3	0.3	3.7	5.5
CEC ($mmol_c\ kg^{-1}$)	140.0	50.0	57.0	305.0
Exchangeable Ca ($mmol_c\ kg^{-1}$)	18.0	11.0	10.0	59.0
Exchangeable Mg ($mmol_c\ kg^{-1}$)	6.0	4.0	1.0	24.0
Exchangeable K ($mmol_c\ kg^{-1}$)	3.0	1.0	1.0	6.0
Exchangeable Na ($mmol_c\ kg^{-1}$)	0.1	0.1	0.0	0.4
Exchangeable bases ($mmol_c\ kg^{-1}$)	27.0	14.0	3.0	74.0
Base saturation (%)	21	10	1.7	48
Total N ($g\ kg^{-1}$)	0.90	0.40	0.10	2.20
Available P ($mg\ kg^{-1}$)	3.5	2.9	0.4	13.6
C ($g\ kg^{-1}$)	6.0	2.5	0.9	12.6
C:N	7.1	1.3	2.9	10.5
Water content ($g\ kg^{-1}$)[b]	130	70	40	360

[a]$n = 136$.
[b]$n = 72$.

Table 2. Correlation matrix for significantly correlated soil and topographic variables[a]

	pH (H_2O)	pH ($CaCl_2$)	Ca	Mg	K	EB[b]
pH (in $CaCl_2$)	0.69					
Ca	0.55	0.82				
Mg	0.44	0.60	0.61			
K				0.49		
EB[b]	0.57	0.82	0.97	0.78	0.44	
BS[c]	0.51	0.67	0.77	0.65	0.35	0.80
Elevation	-0.41			−0.46		

	C	N	WC[d]	Aspect
N	0.88			
Water content	0.72	0.77		
Aspect	0.61	0.60	0.63	
Elevation	0.50	0.59	0.48	0.42

[a]$n = 136$, $P < 0.05$.
[b]Exchangeable bases.
[c]Base saturation.
[d]Water content.

bases and base saturation (Table 2). Elevation is significantly related to pH (in H_2O), pH (in $CaCl_2$), Mg, K, total exchangeable bases and base saturation. Soil carbon content and N are both positively correlated with elevation and negatively correlated with aspect class (small value = 'south slopes', large value = 'north slopes').

Table 3. Pearson correlation coefficients for pairs of soil and foliar variables

Variable 1	Variable 2	r^a	n
P in soil	P in sal foliage	0.39	43
P in soil	P in pine foliage	0.32	33
Mg in soil	Mg in pine foliage	0.46	33
K in soil	K in pine foliage	0.35	33

[a]r values significant at $P<0.05$.

Table 4. Mean values of soil parameters for aspect/elevation classes[a]

	S <1200 m $n=33$	S >1200 m $n=11$	N <1200 m $n=25$	N >1200 m $n=47$
CEC (mmol$_c$ kg^{-1})	125.0a	138.0ab	130.3a	161.7b
Mg (mmol$_c$ kg^{-1})	8.6a	6.2ab	6.4ab	5.3b
Base saturation (%)	24.6a	18.9a	21.7a	18.5a
N (g kg^{-1})	0.5a	0.7ab	0.9b	1.2c
C (g kg^{-1})	4.0a	4.5a	6.3b	7.9c
Water content (g kg^{-1})	80a	60a	150b	200c

[a]Significant differences ($P<0.05$) between aspect/elevation classes are indicated by different letters following the mean value.

Correlations calculated between soil and foliar variables (Table 3) indicate that measurements of P, Mg and K in chir pine foliage and P in sal foliage are related to what is available in the soil.

Comparison between aspect/elevation classes

A number of soil variables are related to the aspect/elevation classes (Table 4). The soil on 'south slopes' at low elevation has smaller contents of N, C and water. The input of organic matter is probably greater and the decomposition rate smaller on the cooler, wetter 'north slopes' at high elevation. This would account for the larger values of C and the corresponding larger values of soil N. CEC is related to organic matter content and thus the values of CEC are greatest on the 'north slopes' at high elevation.

The amount of precipitation increases with increasing elevation in the watershed (Wymann, 1991) and consequently higher elevations experience stronger leaching conditions. This would explain the smaller values of Mg and base saturation at higher elevations. The growing conditions are severe on the 'south slopes' at low elevations, in terms of soil contents of N, C, water content and CEC.

Comparison between soil types

Total N, available P, and C content are smaller in the red soils (Table 5) indicating that, in relation to these variables, the red soils are less fertile than the non-red soils. However, the red soils have greater clay content, pH (in H_2O), Mg, total exchangeable bases and base saturation. With adequate amounts of organic matter and P input, these soils may have the potential to be quite productive.

Table 5. Mean values of soil, foliar, topographic and site parameters for two soil types[a]

Parameters	Non-red soil $n=122$	Red soil $n=14$
pH (in H_2O)	5.28	5.49
pH (in $CaCl_2$)	4.29	4.46
Mg ($mmol_c\ kg^{-1}$)	5.80	12.30
EB[b] ($mmol_c\ kg^{-1}$)	26.20	36.60
BS[c] (%)	20.13	27.68
N ($g\ kg^{-1}$)	0.90	0.40
P ($mg\ kg^{-1}$)	3.71	1.81
C ($g\ kg^{-1}$)	6.40	3.20
Water content ($g\ kg^{-1}$)[d]	140	90
P in sal ($mg\ kg^{-1}$)	2100	1400
P in pine ($mg\ kg^{-1}$)[f]	1600	1300
Fe in pine ($mg\ kg^{-1}$)[f]	120	180
Al in pine ($mg\ kg^{-1}$)[f]	330	360
Aspect[g]	4.4	1.4
Elevation (m)	1280	1075
Slope (%)	67	46

[a]All listed differences between soil types are significant at $P<0.05$.
[b]Exchangeable bases.
[c]Base saturation.
[d]$n=58, 14$.
[e]$n=35, 8$.
[f]$n=25, 8$.
[g]Ranges from 1 to 8, 1 = south (180°) and 8 = north (360°).

The small P availability in the red soils is probably associated with large concentrations of hydrous oxides of Fe, Al and Mn which fix P and render it unavailable. Oxide contents were not measured in this study, but previous work by Shah & Schreier (1991) showed that red soils in Nepal have large contents of oxides of Fe and Al. The foliar analysis supports the finding of small soil-P availability, since P concentrations in the sal and chir pine foliage are significantly smaller on the red soils compared with non-red soils.

It is possible that differences in fertility found between red and non-red soils are partially due to differences in topography, species or management and not completely due to soil type. Thus various comparisons were made on subsets of the plots holding these three variables constant. In most cases N, P, C and Mg are signficantly different for red and non-red soils. However, values for total exchangeable bases and base saturation are not greater on the red soils when topographic class is held constant. The red soils may have greater total exchangeable bases and base saturation because these soils occur largely on 'south slopes' at low elevations.

Comparison between forest types

Sal forests have the smallest values for most of the soil parameters whereas pine forests have the largest values and mixed hardwood sites are intermediate (Table 6).

Various comparisons of soil fertility parameters were made between the forest types having as many environmental factors constant as possible. For example, the three forest types were compared for government and panchayat red soils on 'south slopes' below 1200 m. For most of the comparisons, sal sites have the lowest pH (in $CaCl_2$), Ca, Mg and total exchangeable bases, pine sites

Table 6. Mean values of soil, topographic and site parameters for three forest types[a]

Parameter	Sal $n=36$	Hardwood $n=71$	Pine $n=15$
pH (in $CaCl_2$)	4.17a	4.31b	4.44b
CEC ($mmol_c\ kg^{-1}$)	118.30a	148.30b	149.40b
Ca ($mmol_c\ kg^{-1}$)	12.80a	18.50b	25.80c
Mg ($mmol_c\ kg^{-1}$)	7.10ab	5.70a	7.20b
EB[b] ($mmol_c\ kg^{-1}$)	23.00a	26.90a	36.00b
BS[c] (%)	20.32a	19.95a	24.80a
N ($g\ kg^{-1}$)	0.60a	1.00b	1.10b
C ($g\ kg^{-1}$)	4.60a	6.60b	7.20b
Aspectd	2.10a	4.90b	4.90b
Elevation (m)	1125a	1305b	1350b

[a]Significant differences ($P<0.05$) between forest types are indicated by different letters following the mean value.
[b]Exchangeable bases.
[c]Base saturation.
[d]Ranges from 1 to 8, 1 = south (180°) and 8 = north (360°).

have the largest values and hardwood sites are intermediate. It is unlikely that these differences are due to a species effect, since sal and other hardwood foliage is greater in base content than chir pine foliage.

The smaller values of pH, Ca, Mg and exchangeable bases found under sal and hardwood forest may be partially explained by the removal of bases in base-rich hardwood leaves during fodder and litter collection. Feigl (1989) made similar findings in a study of chir pine plantations in the lower Jhikhu Khola Watershed, Nepal.

Sal is found mostly on hot and dry 'south slopes' at lower elevations and pine and hardwood are found on cooler and moister 'north slopes' at higher elevations (Table 6). This may account for the smaller values of C, N and CEC on the sal sites.

Comparison between management classes

Comparison between management classes was restricted to one topographic class ('north slopes' above 1200 m) in order to limit site variability (Table 7). The government and private sites have similar soil fertility conditions, but fertility is significantly poorer at the panchayat sites.

The differences in soil fertility are probably related to varying levels of exploitation. The government sites have been protected for at least 15 years by forest guards, and private sites have been protected by their owners. Panchayat sites on the other hand were unguarded until recently (< 7 years). It is thus likely that the amount of biomass and nutrients removed from the panchayat sites has been greater than that removed from the government and private sites. This may explain the significantly smaller values of pH (in H_2O), pH (in $CaCl_2$), Ca, Mg, total exchangeable bases and base saturation found on the panchayat sites compared with the government and private sites. These results agree with those of Feigl (1989) who found greater values of pH, total exchangeable bases and base saturation under well protected as compared with unprotected chir pine plantations.

It is anticipated that soil conditions at panchayat-managed sites will improve with time, if use continues to be effectively regulated. However, the process of soil fertility rehabilitation is expected to be slow.

Table 7. Mean values of soil, topographic and site parameters for management classes on 'north slopes' above 1200 m[a]

Parameter	Government, guarded $n=9$	Private $n=27$	Panchayat $n=10$
pH in (H_2O)	5.43a	5.36a	4.80b
pH (in $CaCl_2$)	4.52a	4.38a	3.88b
Ca ($mmol_c\ kg^{-1}$)	27.20a	23.30a	3.80b
Mg ($mmol_c\ kg^{-1}$)	7.70a	6.10a	1.60b
K ($mmol_c\ kg^{-1}$)	2.40ab	2.80a	2.00b
EB[b] ($mmol_c\ kg^{-1}$)	37.30a	32.20a	7.60b
BS[c] (%)	23.19a	22.01a	6.39b
C ($g\ kg^{-1}$)	9.20a	7.50a	7.50a
P ($mg\ kg^{-1}$)	5.03a	3.81a	1.56b
N ($g\ kg^{-1}$)	1.30a	1.10a	1.10a
Aspectd	6.3a	6.2a	6.1a
Elevation (m)	1410ab	1340a	1560b
Pine (%)	54a	3b	21a

[a]Significant differences ($P<0.05$) between management classes are indicated by different letters following the mean value.
[b]Exchangeable bases.
[c]Base saturation.
[d]Ranges from 1 to 8, 1 = south (180°) and 8 = north (360°).

CONCLUSIONS

This study has shown that forest soil fertility in the Dhulikhel Watershed is generally poor and varies with microclimate, soil type, forest type and management. Forest soil fertility is poorer on 'south slopes' and low elevations compared with 'north slopes' and high elevations. Red soils have significantly smaller contents of available soil P compared with non-red soils. Sal stands are the least fertile compared with hardwood and pine stands.

The better protected private and government-guarded forests have better soil fertility compared with recently (<7 years) protected panchayat forests. This is reassuring in that it suggests that a recovery in soil fertility is possible if active management is carried out in the heavily used forest areas. It also indicates that there may be an optimal level of forest use which will maintain or increase soil fertility in the long run while still providing an output of forest products.

The intensive use of forest which occurs in the Dhulikhel Watershed of Nepal is typical of other developing areas. Growing populations put increasing pressure on the forest of these areas potentially leading to decreased site fertility and declining supplies of forest products. This study has implications for other developing areas in that it indicates that it may be possible to break the vicious cycle of declining soil fertility associated with intensive forest use. It is of critical importance that forests in developing areas, such as the Dhulikhel Watershed, be actively managed to prevent soil fertility decline.

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