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Soil, water and nutrient conservation in mountain farming systems: Case-study from the Sikkim Himalaya

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The Khanikhola watershed in Sikkim is agrarian with about 50% area under rain-fed agriculture representing the conditions of the middle mountains all over the Himalaya. The study was conducted to assess overland flow, soil loss and subsequent nutrient losses from different land uses in the watershed, and identify biotechnological inputs for management of mountain farming systems. Overland flow, soil and nutrient losses were very high from open agricultural (cropped) fields compared to other land uses, and more than 72% of nutrient losses were attributable to agriculture land use. Forests and large cardamom agroforestry conserved more soil compared to other land uses. Interventions, like cultivation of broom grass upon terrace risers, N_2-fixing Albizia trees for maintenance of soil fertility and plantation of horticulture trees, have reduced the soil loss (by 22%). Soil and water conservation values (>80%) of both large cardamom and broom grass were higher compared to other crops. Use of N_2-fixing Albizia tree in large cardamom agroforestry and croplands contributed to soil fertility, and increased productivity and yield. Bio-composting of farm resources ensured increase in nutrient availability specially phosphorus in cropped areas. Agricultural practices in mountain areas should be strengthened with more agroforestry components, and cash crops like large cardamom and broom grass in agroforestry provide high economic return and are hydroecologically sustainable.

Keywords: agroforestry, bio-composting, land use, N_2-fixing tree, nutrient loss, overland flow, soil erosion, watershed.

Introduction

The livelihood of the mountain people in the Himalayan region is mainly based on subsistence farming. These farming systems are managed traditionally, with practices having been evolved by the farmers through trial and error over long periods of time (Rai *et al.*, 1994). The farming systems are dependent on surrounding natural resources. In recent years, rapid population growth and fragmentation of farm-families have decreased the land holding size and increased the food demand (Sharma *et al.*, 1998). Agricultural land area has increased considerably over the past 40 years at the cost of other land uses, particularly forestry, causing depletion of natural resources in the Himalaya (Sharma *et al.*, 1992; Rai *et al.*, 1994). The forest-dominated watersheds are consequently converted into agrarian watersheds where sediment and nutrient losses are accelerated.

Eighty percent of the sediments to the world's oceans each year come from Asian rivers and amongst these the Himalayan rivers are the major contributors (Stoddart, 1969). The Himalaya contributes 500–1000 Mg/km^2/yr of sediment (Milliman and Meade, 1983) and Sikkim in the eastern Himalaya is no exception, contributing as much as 616 Mg/km^2/yr (Rai and Sharma, 1998a). Agricultural practices in areas without tree cover in steep uplands can lead to soil erosion and reduced soil fertility (Rai and Sharma, 1998b). Understanding the relationship between land use/cover and hydrology is critical to the prediction of nutrient budgets for the functioning of

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the watersheds. A holistic approach to the management of resources can be one of the effective methods of reversing the pace of environmental degradation (Sharma *et al.*, 1998).

There have been some attempts to manage natural resource in an integrated way in a few selected Himalayan watersheds (Dhurva Narayan *et al.*, 1991; Sharma *et al.*, 1992; Jally *et al.*, 1992; Arya and Samra, 1995; Grewal *et al.*, 1995; Misra, 1996). These studies have provided useful information that can help increase the socio-economic status of farmers. However, linkages of overland flow, soil erosion and nutrient losses with soil and water conservation potentials and biotechnological management in mountain farming systems are lacking. Therefore, based on land-use mapping of a watershed in Sikkim, this paper aims to assess overland flow, soil loss and subsequent nutrient losses from different land uses, their soil and water conservation potentials, and identify biotechnological inputs for management of mountain farming systems. The specific objectives of this study are to: (1) estimate runoff and erosion under different cropping practices and land-uses; (2) estimate the soil and water conservation values of different crop coverage; and (3) assess existing practices and provide management options using biotechnological tools. These estimations in agrarian watersheds are required for holistic management in view of the conversion of forestry to agriculture land in the Himalaya in recent years. This study bridges the information gap that collates hydrological parameters with conservation and biotechnological inputs in mountain farming system.

The study area

The Himalaya is a fragile mountain system. In its eastern part lies Sikkim, a small state in India (Figure 1), with an area of 7096 km^2 having a population of 405 505 in 1991 (Rai and Sundriyal, 1997). The state is a hotspot of biodiversity, with an altitudinal range of 300 to 8545 m above msl. There are mainly two livelihood options for the people namely, farming and tourism. The majority of people (>80%) depend primarily on subsistence farming.

The Khanikhola watershed located (88°24' 3"–88°26'30" E and 27°6'50"–27°7'10" N) in the southern part of the state has been selected for the present study (Figure 2). It has an elevational range of 300–1700 m, and the slope at the higher ridges exceeds more than 70%. The watershed is fairly representative of conditions of the middle-mountains in the Himalaya. It is a rain-fed agrarian watershed having two settlement blocks. There is one perennial stream bisecting the watershed that drains into River Tista, while other streams are seasonal. There is a strong traditional agroforestry base in the watershed, broadly classified into three types: (1) large cardamom; (2) mandarin; (3) tree-fodder-based systems. Large cardamom (*Amomum subulatum*) and mandarin (*Citrus reticulata*) are cash crops. Large cardamom is a shade-loving shrub grown under tree cover whose fruits (capsule) are used as spices/condiment. Mandarin is small tree yielding mandarin-orange fruits. The National Watershed Development Project for Rain-fed Areas (NWDPRA) provided broom grass (*Thysanolena*

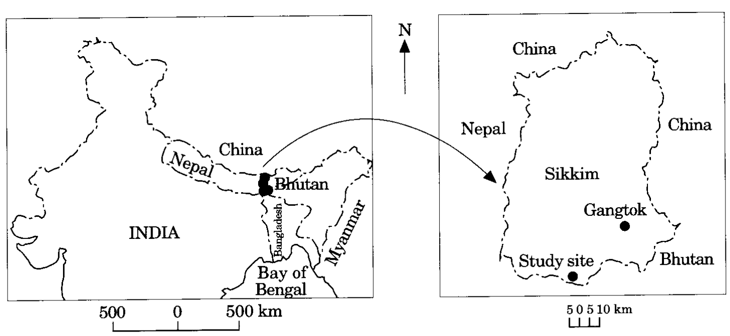

Figure 1. Location map showing study site in the Sikkim Himalaya.

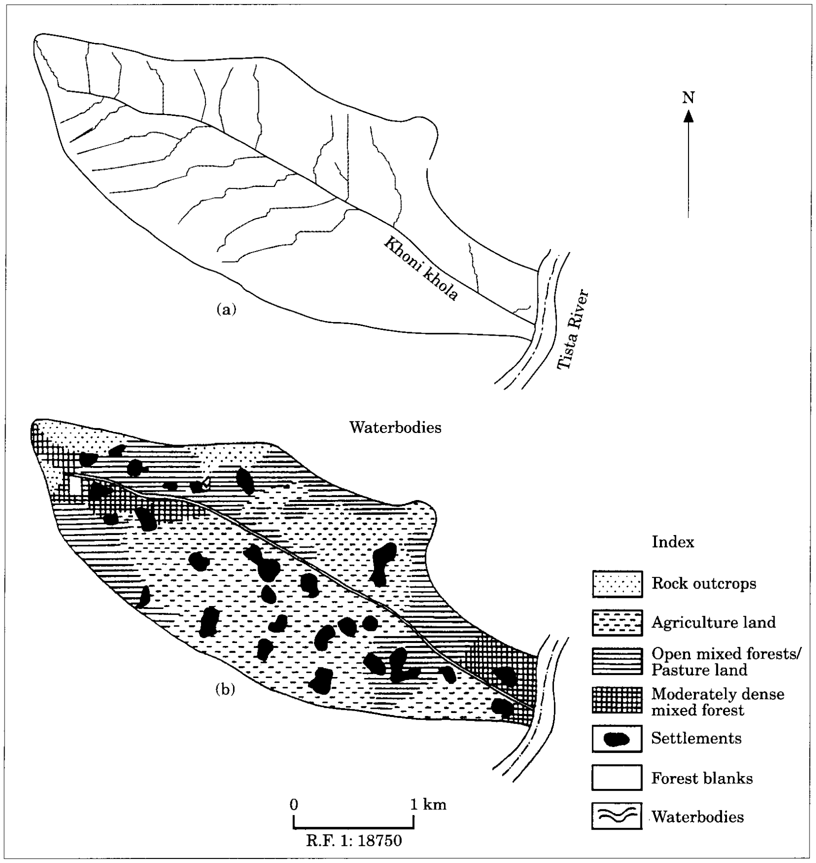

Figure 2. Khanikhola watershed showing (a) drainage and (b) land use/land cover.

maxima) which was grown to aid soil binding in terrace risers, the N_2-fixing *Albizia* tree for maintaining soil fertility on rain-fed slopes and fruit trees (guava and citrus varieties) for increasing economic benefits to the farmers (Sharma, E. *et al.*, 1997).

The total area of the watershed is 416 ha and six types of land-uses have been found (Figure 2). Cropping is the most predominant land-use, covering an area of 206 ha. This is followed by pasture land/open forest (111 ha), settlement (36 ha), and moderately dense mixed forest (35 ha). Forest-land by agriculture-land ratio is 0·88. The ratio is low for subsistence farming systems where dependency on forests for natural resources is high. Most soils in the watershed are acidic (pH ranged from 5·4 to 6·3). Average soil moisture levels ranged from 10–20% under different crop combinations, 20–30% under forest conditions, 7–11% under *Albizia* shade tree based cropped area and 25–36% under large cardamom agroforestry. The soil type of different land-uses in the watershed was similar (Sharma, E. *et al.*, 1997).

Precipitation was recorded using rain gauge at two locations (elevation 800 m and 1500 m) in the watershed during the study period (1995–1996). The average annual precipitation for the 2 years period was 1210 mm in the watershed. More than 80% of precipitation was received in monsoon during June to September.

Methodology

The land-use pattern of the Khanikhola watershed was determined using remote sensing techniques. The land-use data of the watershed was generated by a combination of surveys, satellite images (IRS 1A/1B, LISS II, FCC, Band 2 3 4) and a survey map of India on a 1:50 000 scale. Information on various features derived from the data sources were integrated and analyzed.

Overland flow, soil and nutrient loss

Overland flow, and soil and nutrient losses were estimated from 15 experimental plots under different land uses in 1995 and 1996 from three events each year during the rainy season. The rainfall events were spread to cover the entire monsoon, once each in July, August and September. These were estimated using natural shallow surface runoff channels and artificially delineated plots (Singh *et al.*, 1983; Rai and Sharma, 1998b). The delineated plot size was $3\,m \times 3\,m$ for estimation of overland flow and soil loss, and three plots were laid in each type of the land-use practice. These plots were delineated with aluminum sheets (inserted in soil for about 6 cm and remaining 15 cm exposed in air) from all sides to prevent water likely to enter from adjacent areas. The plots were selected with a 25–30° slope in all the land uses, as the majority of land in the watershed falls into this slope category. The overland flow and soil loss along the slope were estimated from the collecting tank after each rainfall event. Soil samples were collected from the surroundings of each of the delineated plots in replicates (N=5) up to 15 cm depth. These samples were collected just before the rainy season, at the time of plot delineation and designated as parent soil. The eroded soil was sampled in the form of bed-load sediment and suspended clay material from the collecting tank. The suspended clay material was separated by filtration. The losses were quantified on a unit area basis and extrapolated to determine total loss from each land-use type and the whole watershed. Soil nutrients from two depths (0–15 cm and 15–30 cm) under different land uses were estimated to determine the influence of land use on soil fertility and nutrient levels. The parent and eroded soil samples were analyzed for nutrients (organic carbon, total nitrogen and total phosphorus). The runoff water samples were analyzed for phosphate-phosphorus by stannous chloride method (Eaton *et al.*, 1995) and total nitrogen by AOAC method (Cunniff, 1995). The pH was measured by mixing 10 g of fresh soil in 50 ml distilled water for 30 min and using a glass electrode digital pH meter. Soil organic carbon was estimated using the modified Walkley-Black method and total nitrogen by modified Kjeldhal method (Anderson and Ingram, 1993). Total phosphorus was extracted using acidified ammonium fluoride after oxidation, employing 30% H_2O_2 and estimated by chlorostannous reduced molybdophosphoric blue colour method (Jackson, 1967). Available phosphorus was determined by the bicarbonate extractable method (Anderson and Ingram, 1993) and exchangeable potassium by flame photometer (Allen, 1989).

Water and soil conservation values

Soil conservation value of the land uses were calculated using the formula given by Ambasht (1970) and Ambasht *et al.* (1984): $CV = 100 - (S_{wp}/S_{wo} \times 100)$, where CV is conservation value, S_{wp} is the weight of soil eroded from the vegetated systems and S_{wo} is the weight of soil eroded from a bare plot under identical erosional stresses. The above formula was also used to determine the water conservation value. The S_{wp} and S_{wo} are replaced by W_{wp} and W_{wo} to denote, respectively, weights of water lost from vegetated and open (bare) plots, in this case CV refers to water conservation instead of soil conservation. Bare plot and vegetated plots were demarcated with similar aspect and slope ranging 25–30°. Runoff and soil loss from these plots were recorded. Bare plot was an undisturbed fallow land without any distinct plant cover. Mean values obtained from the three rainfall events were used in the above evaluation. Soil and water conservation values of four dominant crop covers (maize, finger-millet, mixed cropping, large cardamom) and terrace riser species were estimated. Species most commonly planted upon the terrace riser is the broom grass (*Thysanolena maxima*).

Agroforestry practice, N_2-fixation and bio-composting

In order to evaluate the influence of the symbiotic nitrogen fixing leguminous *Albizia stipulata* tree, sample plots of 30 m × 40 m were marked in each of the *Albizia*-cardamom, forest-cardamom, *Albizia*-cropland and mixed tree-cropland agroforestry stands. Plot replication was a constraint in this study, however homogeneity of stands were maintained and sampling replication within the plot was kept sufficient to adequately capture the variations. Root nodule biomass, nitrogenase activity, tree biomass, productivity and agronomic yields were determined in these plots. The root nodule biomass of *A. stipulata* was estimated by harvesting nodules from different sizes of trees and then pooling them to derive average tree biomass. Nitrogenase activity in the root nodules was estimated by using the acetylene reduction technique (Stewart *et al.*, 1967). The rates of N_2-fixation were calculated using a conversion ratio of 3:1 acetylene by nitrogen (Hardy *et al.*, 1973). Large cardamom and traditional crop production and yield were calculated using the harvest technique as specified by Sharma *et al.* (1994, 1995). Allometric relationships of component biomass on tree dimensions for *A. stipulata* and mixed tree species of similar elevation developed in Sikkim by Sharma *et al.* (1995) have been used in this study. The diameter at breast height (dbh) and height of the same trees from all the marked stands were measured in 1995 and 1996. Mean annual increments of components of the individual trees in the sample areas were obtained by dbh and height increment measurements and using the above mentioned allometric equations. The net change in the component biomass yielded annual biomass accumulation and the sum of the different components gave net biomass production of the tree strata.

Composting was tried at the farmer's field based on bio-resources available in the farms during the study period. Composts were prepared by using raw materials in different proportions and these raw material resources (such as *Eupatorium* weed, poultry wastes, soil, paper, cowbarn wastes, vegetable wastes, egg shells, other plants and old composts) were easily available in the village/farms. Pure *Eupatorium* weed composting required 32 days for maturity and other combinations matured between 18–33 days. Seven different combinations of composts were derived and their nutrient levels were examined. These composts were prepared based on the proportions of farm bio-resources used and nutrient availability in the compost. Nutrients of control soil were also estimated. The pH and nutrient values of composts in terms of organic carbon levels, total nitrogen, available phosphorus and exchangeable potassium were estimated using methods as specified above for soils.

Results

Soil nutrient status

In order to assess the effect of change in land-use on soil properties and fertility, the nutrient levels of soil at two depths (0–15 cm and 15–30 cm) from different land-uses were estimated (Table 1). Available phosphorus was low in large cardamom based agroforestry and wheat fields. As expected, all nutrients were higher in forest soils, except total nitrogen. The total nitrogen was higher in large cardamom agroforestry and wasteland. Nutrient concentration in parent soil and eroded soil was estimated during the rainy season in different land-uses (Figure 3). Concentrations of nitrogen were higher in eroded soils than the parent soils of forest, large cardamom, and orange orchard. However, concentrations are similar in both eroded and parent soils under maize cultivation, wheat and wasteland. Organic carbon content in parent soil was highest under forest, followed by wasteland, orange orchard, maize field, large cardamom agroforestry, and lowest in wheat field soils. An ANOVA test (SYSTAT, 1996) on total nitrogen concentration between eroded and parent soils, and between land uses shared a statistically significant variation (Figure 3). Organic carbon and total phosphorus showed significant differences with land use but not between the eroded and parent soil types.

Overland flow, and soil and nutrient loss

Overland flow (percentage of rainfall during rainy season) was recorded to be highest in

Table 1. Soil pH and nutrients from two depths under different land use of Khanikhola Watershed in Sikkim

Land use	Soil depth (cm)	pH	Organic carbon (%)	Total nitrogen (%)	Total phosphorus (%)	Available phosphorus (%)	Exchangeable potassium (%)
Forest	0–15	5·44±0·25	3·94±0·09	0·28±0·05	0·163±0·009	0·007±0·0008	0·51±0·07
	15–30	5·62±0·34	3·32±0·14	0·19±0·04	0·150±0·013	0·007±0·0012	0·55±0·09
Large cardamom	0–15	5·53±0·18	1·73±0·09	0·30±0·07	0·093±0·011	0·002±0·0004	0·44±0·06
	15–30	5·86±0·31	2·13±0·13	0·22±0·06	0·096±0·008	0·002±0·0003	0·36±0·04
Orange orchard	0–15	5·81±0·41	2·75±0·06	0·23±0·03	0·108±0·013	0·007±0·0002	0·42±0·07
	15–30	6·17±0·36	2·04±0·05	0·21±0·04	0·119±0·009	0·006±0·0004	0·39±0·05
Maize	0–15	5·18±0·21	1·76±0·05	0·20±0·04	0·117±0·014	0·008±0·0010	0·41±0·07
	15–30	6·35±0·16	1·61±0·09	0·19±0·05	0·132±0·010	0·007±0·0008	0·38±0·03
Wheat	0–15	6·02±0·32	1·13±0·04	0·28±0·05	0·074±0·012	0·002±0·0004	0·18±0·03
	15–30	6·20±0·13	1·57±0·20	0·12±0·02	0·060±0·007	0·002±0·0003	0·20±0·05
Wasteland (scrub)	0–15	6·20±0·34	3·58±0·13	0·35±0·05	0·101±0·008	0·004±0·0005	0·41±0·05
	15–30	6·34±0·28	2·64±0·09	0·32±0·07	0·147±0·013	0·005±0·0007	0·64±0·08

large cardamom agroforestry (9·1%), due to the steep slope of the landscape where large cardamom has been cultivated, and lowest in wasteland (2·8%). Large cardamom cultivation started about 15 years ago in the watershed. Soil loss was highest from cropped land and smallest in wasteland (Table 2). The soil loss from the forest (3·04 Mg/ha/yr) and large cardamom agroforestry (3·92 Mg/ha/yr) was relatively low as compared to the cropped area (21·65 Mg/ha/yr) following traditional practices, and NWDPRA intervention has reduced the soil loss by 22% (Table 2). Overland flow, soil loss and nutrient loss through eroded soil from the total area of each land use and the entire watershed was estimated (Table 3). The overland flow was highest from cropped area and lowest from orange orchard. Total overland flow from the watershed was 268×10^6 l. Soil loss was 2937 Mg/yr from the watershed, the highest value (2481 Mg/yr) was recorded from the cropped area and the rest (456 Mg/yr) shared by the remaining land-uses including the NWDPRA intervened area. Total nitrogen loss through eroded soil was 6·92 Mg/yr, organic carbon 50·54 Mg/yr and total phosphorus 1·72 Mg/yr from the watershed (Table 3). The highest loss of total nitrogen through runoff was recorded from the cropped area while phosphate phosphorus from the forest land.

Water and soil conservation values

Five dominant crop/vegetation covers have been assessed to determine the *in situ* soil and water conservation values in the watershed. These were: (a) maize, (b) finger-millet, (c) mixed cropping, (d) large cardamom, and (e) broom grass. Water runoff, soil erosion, water conservation and soil conservation of the five are compared (Table 4). The highest runoff and soil loss was recorded in maize. Water runoff is reduced by less than one-third, and soil loss by two-fifths, in maize cultivation as compared to bare land (Table 4). Mixed cropping, large cardamom and broom grass showed fairly lower runoff compared to bare land and maize cultivation. Conservation value of water was high in mixed cropping, large cardamom and broom grass, while the soil conservation value was high only in large cardamom and broom grass plots. Soil loss was substantially lower in large cardamom and broom grass, and high water and soil conservation values suggest that they are of value both in economic and ecological terms. The beneficial role of terrace riser species on conservation is apparent to the upland farm communities in the study area. Broom grass is maintained and preferred by the farmers as this species provides fodder and broom, and also helps soil conservation on steep slopes.

N_2-fixation and Albizia

Albizia stipulata is a fast growing leguminous N_2-fixing tree that is planted to increase soil fertility levels. Nitrogenase enzyme activity, nodule biomass and nitrogen accretions

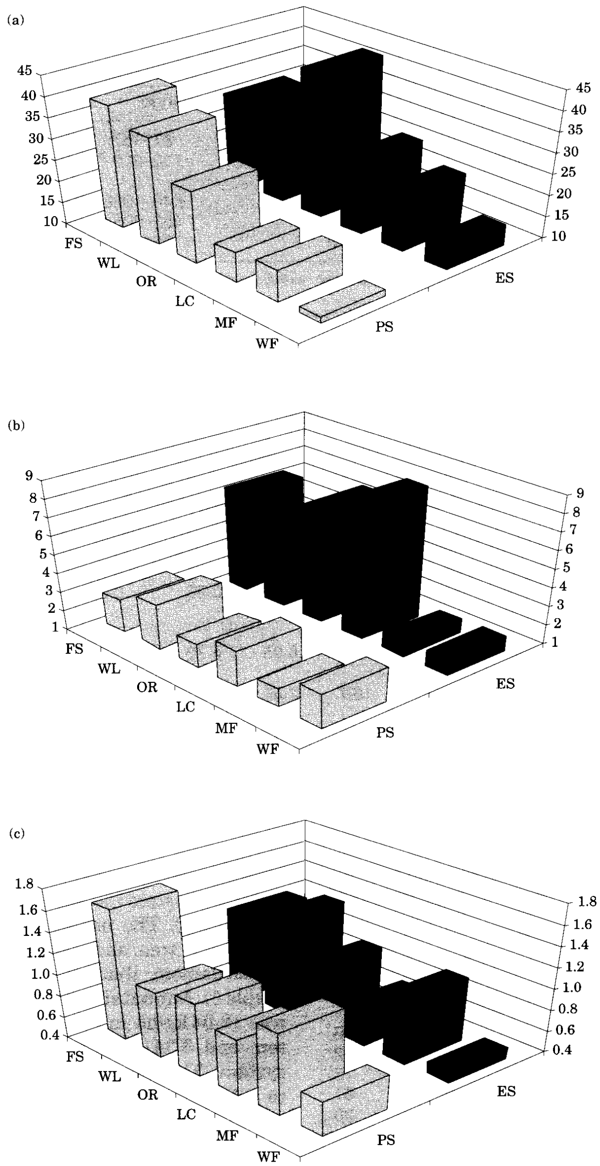

Figure 3. Nutrient concentration (mg/g soil) of parent (PS) and eroded (ES) soils under different land use (FS, forest stand; WL, wasteland; LC, large cardamom agroforestry; OR, orange orchard; MF, maize field; WF, wheat field) of the Khanikhola watershed. (a) Organic carbon; (b) total nitrogen; (c) total phosphorus. ANOVA: Organic carbon—land use $P<0{\cdot}005$, soil type NS, land use × soil type $P<0{\cdot}05$, $LSD_{(0{\cdot}05)}=8{\cdot}2$; Total nitrogen—land use $P<0{\cdot}005$, soil type $P<0{\cdot}005$, land use x soil type $P<0{\cdot}005$, $LSD_{(0{\cdot}05)}=0{\cdot}9$; Total phosphorus—land use $P<0{\cdot}005$, soil type NS, land use × soil type NS. Least significant difference (LSD) presented when interaction is significant.
NS, not significant.

Table 2. Overland flow and soil loss during the rainy season in selected sites under different land use of the Khanikhola watershed

Land-use	Overland flow (% of rainfall)	Soil loss (kg/ha)[a]		Soil loss (Mg/ha/yr)[b]
		Range	Mean	
Forest	6·89	87–157	116	3·04
Large cardamom agroforestry	9·09	110–210	150	3·92
Cropped area				
Traditional practice	4·87	640–1058	827	21·65
NWDPRA intervened	4·30	485–925	680	17·80
Wasteland (scrub)	2·76	35–97	68	1·78

Values of overland flow and soil loss are mean of the three rainfall events. Total rainfall recorded was 1210 mm in 1996 in the watershed.
NWDPRA, National Watershed Development Project for Rain-fed Areas.
[a]Mean of three rainfall events.
[b]Mg, megagram (tons).

Table 3. Overland flow, soil and nutrient loss from the watershed under different land uses (values calculated for total area basis under different land uses)

Land use	Area (ha)	Overland flow ($\times 10^6$ litre)	Soil loss[b] (Mg/yr)	Nutrient loss through eroded soil (Mg/yr)[b]			Soluble nutrient loss (kg/yr)	
				Organic carbon	Total nitrogen	Total phosphorus	Total nitrogen	Phosphate phosphorus
Forest	136·5	122·0	249	7·82	1·60	0·31	228·14	16·59
Large cardamom agroforestry	10·0	11·7	28	0·77	0·23	0·02	27·61	1·87
Cropped area								
Traditional practice	191·0	120·0	2481	38·95	4·72	1·29	392·40	16·08
NWDPRA intervention	15·0	8·3	160	2·51	0·31	0·08	24·40	1·07
Wasteland (scrub)	17·5	6·2	19	0·49	0·06	0·02	17·36	0·79
Total	370·0[a]	268·2	2937	50·54	6·92	1·72	689·91	35·33

NWDPRA, National Watershed Development Project for Rain-fed Areas.
[a]Does not include settlement and water-bodies (46 ha).
[b]Values are based on delivery ratio of 60% (Sharada *et al.*, 1992).

Table 4. Water and soil runoff quantities and conservation values. The average rainfall for three events was 107 litres/m^2

Plot type	Water runoff (litre)	Soil loss (kg)	CV for water (%)	CV for soil (%)
Maize	25±4	1·51±0·18	69	56
Finger-millet	18±3	1·32±0·14	78	62
Mixed cropping	12±3	0·95±0·12	85	73
Large cardamom	15±3	0·45±0·06	81	87
Broom grass	10±2	0·41±0·07	88	88
Bare land	80±11	3·46±0·35	—	—

Values for water and soil runoff are mean ±1 SE based on three rainfall events.
CV, Conservation value.

through fixation in *Albizia* were studied in cardamom and crop field systems (Table 5). Nitrogen fixation was higher in *Albizia* within the cardamom system (46·23 µmol N_2/g/nodule dry weight/day) compared to the crop field system (39·82 µmol N_2/g/nodule dry weight/day). The nodule biomass of *Albizia* both on a tree and area basis was higher in cardamom than the crop field system (Table 5). Annual stand N_2-fixation by *Albizia* was 12·04 kg/ha in the cardamom-based system and 3·34 kg/ha in the crop field based system. This tree substantially contributes to nitrogen accretion in nutrient poor systems and thereby contributes significantly in the maintenance of soil fertility. In the large cardamom based and crop based systems, the role of *Albizia* in increasing the biomass, productivity and agronomic yield has been assessed and presented in Table 6. Biomass, productivity, and yield under the influence of *Albizia* in both the systems increased by 9 to 13% which is a substantial increase in rain-fed condition.

Table 5. Nitrogenase activity, nodule biomass and nitrogen accretion through fixation in *Albizia stipulata* in cardamom based agroforestry and agriculture field

Function	*Albizia* in cardamom stand	*Albizia* in crop fields
Nitrogenase acitivity		
Acetylene reduction (μmol C_2H_4/g nodules dry weight/hour)	12·61±1·16	10·86±0·72
Nitrogen fixation (μmol N_2/g nodule dry weight/day)[a]	46·23±4·25	39·82±2·64
Nodule biomass		
g/tree	207±27	189±38
kg/ha	43·47	13·98
Annual tree N_2-fixation (g/tree/year)[b]	57·32	45·09
Annual stand N_2-fixation (kg/ha/year)	12·04	3·34

[a]Average active 11 hours of day and C_2H_2:N_2 ratio of 3:1 were used.
[b]Values are pooled for growing season, i.e. for the period April to October 1996.
Note: Albizia tree density in cardamom stand was 210 trees/ha; and Albizia tree density in agriculture field was 74 trees/ha.

Table 6. Biomass, productivity and yield (1995–1996) in N_2-fixing tree based systems compared to non-N_2-fixing stand

Agriculture system	Biomass (kg/ha)	Productivity (kg/ha/year)	Agronomic yield (kg/ha/year)
Large cardamom			
Albizia-cardamom			
Albizia-tree	21364	6341	–
Cardamom	10482	5273	342
Stand total	32846	11614	342
Forest-cardamom			
Mixed tree	26491	5362	–
Cardamom	7824	4718	267
Stand total	34315	10080	267
Cropland			
Albizia-cropland			
Albizia tree	8426	3215	–
Crops	4018	4018	1322
Stand total	12544	7233	1322
Mixed tree-cropland			
Mixed tree	9872	3462	–
Crops	3859	3859	1186
Stand total	13731	7283	1186

In cardamom stand *Albizia* density was 210 trees/ha; mixed tree density was 232 trees/ha; and in cropland *Albizia* density was 74 trees/ha; mixed tree density was 86 trees/ha. Age of trees in the above stands ranged between 15–20 years.

Bio-composting

Bio-composting was tried and seven different combinations were prepared based on the resources available in the farms. Soil without compost was used as the control. Their pH and nutrient levels such as organic carbon, total nitrogen, available phosphorus and exchangeable potassium were determined (Table 7). Available phosphorus in composts was higher by nine to 75 times, compared to the control soil, but in the case of organic carbon, total nitrogen and exchangeable potassium increased by only two to seven times compared to the control (Table 7). C/N ratio is a good indicator of net nitrogen mineralization while N/P ratio is a indicator of net phosphorus mineralization in soil and composts. In the control soil and different composts, net nitrogen mineralization did not seem to be a constraint, but phosphorus mineralization was limiting in the control soil and composts based solely on plant wastes (Table 7). The N/P ratio is

Table 7. Nutrient levels of composts

Compost type[a]	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (%)	Exchangeable potassium (%)	pH	C/N ratio	N/P ratio
A	1·33±0·07	0·20±0·01	0·002±0·001	0·191±0·005	6·31	6·65	100·00
B	5·30±0·03	1·49±0·02	0·034±0·002	0·840±0·003	7·46	3·56	43·80
C	4·05±0·05	0·64±0·02	0·018±0·003	0·573±0·001	7·41	6·33	35·56
D	5·06±0·05	0·99±0·02	0·038±0·002	0·761±0·001	8·16	5·11	26·05
E	4·05±0·12	1·18±0·06	0·061±0·002	0·666±0·017	7·03	3·43	19·34
F	3·02±0·03	0·73±0·02	0·083±0·002	0·726±0·004	7·50	4·14	8·80
G	5·37±0·07	0·95±0·02	0·120±0·003	0·716±0·020	7·12	5·65	7·92
H	5·22±0·06	0·76±0·01	0·150±0·003	0·946±0·002	8·40	6·87	5·07

Values are mean ±1 SE (N=3).
[a]Ingredients: A (control), soil (100%); B, *Eupotarium* sp. weed (100%); C, *Eupotarium* sp. (11·5%), poultry wastes (57·7%), other plants (7·7%), cowbarn waste (19·2%) and kitchen waste (3·9%); D, *Eupotarium* sp. (19·1%), poultry wastes (38·2%), soil (38·2%) and paper (4·5%); E, *Eupotarium* sp. (8·6%), poultry wastes (25·9%), soil (25·9%), paper (5·5%), other plants (18·5%), cow-barn wastes (10·2%) and vegetable wastes (5·5%); F, *Eupotarium* sp. (16·9%), poultry wastes (16·9%), soil (33·8%), paper (7·9%), cow-barn wastes (16·9%), vegetable wastes (6·8%) and egg shells (1·0%); G, *Eupotarium* sp. (14·7%), poultry wastes (29·3%), soil (29·3%), paper (5·87%), old compost (14·7%), vegetable wastes (4·4%) and egg shells (1·8%); and H, poultry wastes (47·2%), soil (47·2%) and paper (5·5%).

known as a better indicator of phosphorus availability, with phosphorus mineralization at or below N/P ratios of 20. The N/P ratio was below 20 where the proportion of poultry wastes and egg-shells contributed substantially to higher phosphorus values and lower N/P ratios. Total nitrogen and exchangeable potassium contents also increased considerably in the composts.

Discussion

Differences in soil nutrient status of different land-uses support the hypothesis that conversion of land from forest to agriculture reduces the fertility of soils. Total nitrogen in eroded soil was higher than parent soil in forest and agroforestry systems, while it did not vary much between soil types at the cultivated sites. Total phosphorus concentration of parent and eroded soils was no different in all land uses, a finding also reported by Rai and Sharma (1998b), indicating lower loss of phosphorus compared to nitrogen and organic carbon.

Overland flow and soil loss was greatest from the open cropped area because of intensive cultivation on the mountain slopes. Soil loss from the watershed was high (794 Mg/km^2/yr), however within the range of 500–1000 Mg/km^2/yr for the Himalaya reported by Milliman and Meade (1983). Soil losses as high as 3005 Mg/km^2/yr, were recorded in an agro-ecosystem under 5 years of shifting cultivation (Toky and Ramakrishnan, 1981). Therefore, land-use practices such as agroforestry (280 Mg/km^2/yr) and stabilized cultivation (1298 Mg/km^2/yr) in the present study, were found better in terms of reducing soil losses compared to shifting cultivation. According to an estimate made by Shah (1982), nearly 85% of all agricultural land already suffers from severe erosion problems. Overland flow and soil loss from the wasteland was low compared to agricultural land as it was not disturbed and was covered by ground vegetation. Toky and Ramakrishnan (1981) also made similar observations on fallow lands in a shifting agriculture system in northeast India. In spite of more overland flow from the large cardamom based agroforestry system in the present study, soil loss was low because of good canopy coverage and complete ground cover by perennial cardamom bushes. Nutrient releases from forests are generally less than from croplands, as soil erosion rates are smaller. Nutrient discharge from watersheds increases as percentage of cropland increases (Jordan *et al.*, 1986; Likens and Bormann, 1974) and high nutrient loss from the cropped area in the present study is consistent to this finding. More than 72% of nutrient loss from the watershed was attributed to agricultural land uses and therefore, intervention should focus upon these land uses with emphasis on how to reduce the soil loss and measures to increase soil fertility.

Soil and water conservation values of perennial bushes such as large cardamom and broom grass were much higher than annual crops. Conservation of soil and water by these perennials was almost comparable to thick cushion forming perennial grasses as reported by Ambasht *et al.* (1984). This suggests that in the mountain farming systems use of perennial species would be beneficial.

Agroforestry, with species like large cardamom and mandarin, is a traditional practice in the region that is also profitable. The use of N_2-fixing *Albizia* in the cardamom fields, croplands and mandarin-orange orchards can help in achieving sustainable agriculture practice in mountain watersheds. Such agroforestry support soil, water and nutrient conservation and enhance soil fertility and crop productivity. *Albizia* grows well up to 1500 m altitude and its combination with large cardamom, mandarin-orange and traditional crops will be beneficial. Above 1500 m elevation another N_2-fixer, *Alnus nepalensis*, has been extensively used (Sharma *et al.*, 1994). Mandarin-orange is nutrient exhaustive (Sharma *et al.*, 1995), therefore nutrient input could be increased by planting *Albizia* in the orchard. Use of *Albizia* in agroforestry is emphasized as it accelerates nutrient cycling (Sharma *et al.*, 1995).

Nutrient losses were high in agricultural fields and their replenishment slow causing the degradation in soil fertility. In such a situation bio-composting was found to be highly useful. Phosphorus availability is limited in highly acidic soils because of secondary fixation (Sharma, R. *et al.*, 1997). Composts prepared in the current study were all alkaline which when mixed with acidic soil can increase the pH levels and phosphorus availability. The lower N/P ratios bearing composts provide both nitrogen and phosphorus quite readily for plant uptake. Use of N_2-fixing *Albizia* and bio-composts could be indispensable for soil fertility maintenance in the mountain farming systems.

Conclusions

The Khanikhola watershed presents a mid-hill habitation zone in the eastern Himalaya. A major proportion of the land cover is rain-fed agriculture involving intensive cropping practice on open, unterraced slopes and agroforestry systems. Overland flow, soil and nutrient losses were very high from open agricultural (cropped) fields compared to other land-uses in the watershed. More than 72% of nutrient losses were attributable to agriculture land-use. Large cardamom agroforestry and forests conserved more soil compared to open agricultural fields under traditional practices. This suggests an increase of agroforestry systems from the existing open agricultural practice. Such a practice would help in soil and nutrient conservation consequently enhancing the soil fertility status and productivity. Interventions, like cultivation of broom grass upon terrace risers, use of N_2-fixing *Albizia* trees for maintenance of soil fertility on rain-fed slopes and plantation of horticulture trees, have reduced the soil loss by 22% which is quite substantial in steep slopes. Soil and water conservation values of both large cardamom and broom grass were higher compared to other crops. These are perennial cash crops of greater conservation potential that could be more useful for extensive plantation in the event of large-scale land use change from forestry to agriculture.

Use of N_2-fixing *Albizia* tree in large cardamom agroforestry and croplands contributed to soil fertility, and increased productivity and yield by 9–13% in rain-fed land. The annual nitrogen fixation by *Albizia* was higher in large cardamom agroforestry compared to crop fields. Wider use of this species in agroforestry is recommended. Soil fertility loss resulting from soil erosion is common phenomenon in the mountains, and soils being acidic phosphorus availability is limited. In such a situation, use of farm resources based bio-composts in open agricultural land increases nutrient availability specially phosphorus. Plantation of N_2-fixing *Albizia* tree as associate and use of bio-composts in open agricultural fields could be indispensable for soil fertility maintenance in mountain farming systems.

The conversion of forests to agricultural land has been quite conspicuous in the last few decades (this is a general trend in most of the areas in the Himalaya) and it has to be reversed immediately. Agricultural land in mountains should be strengthened with more agroforestry components logically with multipurpose species like *Albizia*. The agroforestry systems with cash crops like large cardamom and broom grass provide high economic return and are hydroecologically sustainable.

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References

Allen, S. E. (1989). *Chemical Analysis of Ecological Materials*. London: Blackwell Scientific Publications.

Ambasht, R. S. (1970). Conservation of soil through plant cover of certain alluvial slopes in India. In *Proceedings of IUCN XI Technical Meeting, Morges*. Switzerland.

Ambasht, R. S., Singh, M. P. and Sharma, E. (1984). Soil, water and nutrient conservation by certain riparian herbs. *Journal of Environmental Management* **18**, 99–104.

Anderson, J. M. and Ingram, J. S. I. (1993). *Tropical Soil Biology and Fertility: A Handbook of Methods*. Wallingford, UK: CAB International.

Arya, S. L. and Samra, J. S. (1995). *Socio-Economic Implications and Participatory Appraisal of Integrated Watershed Management Project at Bunga*. Chandigarh: Central Soil and Water Conservation Research and Training Institute, Research Centre.

Cunniff, P. (1995). *Official Methods of Analysis of AOAC International*. Arlington, Virginia.

Dhruva Narayan, V. V., Sastry, G. and Patnaik, U. S. (1991). *Watershed Management*. Pusa, New Delhi: Indian Council of Agricultural Research.

Eaton, A. D., Clesceri, L. S. and Greenberg, A. E. (1995). *Standard Methods for the Examination of Water and Wastewater*, 19th edn. Washington DC: American Public Health Association.

Grewal, S. S., Samra, J. S., Mittal, S. P. and Agnihotri, Y. (1995). *Sukhomajri Concept of Integrated Watershed Management*. Chandigarh: Central Soil and Water Conservation Research and Training Institute, Research Centre.

Hardy, R. W. F., Burns, R. C. and Holsten, R. D. (1973). Application of the acetylene-ethylene assay for measurement of nitrogen fixation. *Soil Biology and Biochemistry* **5**, 47–81.

Jackson, M. L. (1967). *Soil Chemical Analysis*. New Delhi: Prentice-Hall.

Jally, M. K., Marothia, D. K. and Agrawal, D. K. (1992). Socio-economic evaluation of Nartara watershed project. In *Proceedings of Workshop on Watershed Management*, pp. 65–70. IIFM, Bhopal, India.

Jordan, T. E., Correll, D. L., Peterjohn, W. T. and Weller, D. E. (1986). Nutrient flux in a landscape: the Rhode river watershed and receiving waters. In *Watershed Research Perspectives* (D. L. Correll, ed.), pp. 57–76. Washington DC: Smithsonian Institution Press.

Likens, G. E. and Bormann, H. F. (1974). Linkages between terrestrial and aquatic ecosystems. *BioScience* **24**, 447–456.

Milliman, J. D. and Meade, R. H. (1983). World-wide delivery of river sediments to the oceans. *Journal of Geology* **91**, 1–21.

Misra, B. (1996). A successful case of participatory watershed management at Ralegaun Sidhi Village in district Ahmadnagar, Maharastra, India. In *Case Studies of Peoples' Participation in Watershed Management in Asia, Part I. Nepal, China and India* PWMTA-WMTUH-FARM Field Document No. 4., (P. N. Sharma and M. P. Wagley, eds), pp. 35–47. Kathmandu, Nepal.

Rai, S. C. and Sharma, E. (1998a). Comparative assessment of runoff characteristics under different land use patterns within a Himalayan watershed. *Hydrological Processes* **12**, 2235–2248.

Rai, S. C. and Sharma, E. (1998b). Hydrology and nutrient flux in an agrarian watershed of the Sikkim Himalaya. *Journal of Soil and Water Conservation* **53**, 235–243.

Rai, S. C., Sharma, E. and Sundriyal, R. C. (1994). Conservation in Sikkim Himalaya: traditional knowledge and land-use of the Mamlay watershed. *Environmental Conservation* **21**, 30–34, 56.

Rai, S. C. and Sundriyal, R. C. (1997). Tourism and biodiversity conservation: the Sikkim Himalaya. *Ambio* **26**, 235–242.

Shah, S. L. (1982). Ecological degradation and future of agriculture in the Himalaya. *Indian Journal of Agriculture Economics* **37**, 1–22.

Sharada, D. L., Venkataratnam, B. R. M., Rao, K. V. and Raju, A. S. (1992). Characterization and prioritization of watersheds of part of Musi river catchment using LAND SAT, TM data. In *Remote Sensing Applications and GIS: Recent Trends* (I. V. Muralikrishna, ed.), pp. 180–186. Delhi, India: McGraw Hill Publication Company Ltd.

Sharma, E., Sundriyal, R. C., Rai, S. C., Bhatt, Y. K., Rai, L. K., Sharma, R. and Rai, Y. K. (1992). *Integrated Watershed Management*. Nainital, India: Gyanodaya Prakashan.

Sharma, E., Sundriyal, R. C., Rai, S. C., Sharma, R., Sundriyal, M., Pradhan, P. and Rasailey, B. (1997). *Soil, Water and Nutrient Conservation in Upland Farming Systems of a Watershed in Sikkim*. Final Technical Report, NWDPRA, Department of Agriculture, Government of Sikkim, Gangtok, India.

Sharma, E., Sundriyal, R. C., Rai, S. C. and Krishna, A. P. (1998). Watershed: a functional unit of management for sustainable development. In *Modern Trends in Ecology and Environment* (R. S. Ambasht, ed.), pp. 171–185. Leiden: Backhuys Publishers.

Sharma, R., Sharma, E. and Purohit, A. N. (1994). Dry matter production and nutrient cycling in agroforestry systems of cardamom grown under *Alnus* and natural forest. *Agroforestry Systems* **27**, 293–306.

Sharma, R., Sharma, E. and Purohit, A. N. (1995). Dry matter production and nutrient cycling in agroforestry systems of mandarin grown in association with *Albizia* and mixed tree species. *Agroforestry Systems* **29**, 165–179.

Sharma, R., Sharma, E. and Purohit, A. N. (1997). Cardamom, mandarin and nitrogen-fixing trees in agroforestry systems in India's Himalayan region II. Soil nutrient dynamics. *Agroforestry Systems* **35**, 255–268.

Singh, J. S., Pandey, A. N. and Pathak, P. C. (1983). A hypothesis to account for the major pathways of soil loss from Himalaya. *Environmental Conservation* **10**, 343–345.

Stewart, W. D. P., Fitzgerold, G. P. and Burris, R. H. (1967). *In situ* studies on N_2-fixation using the acetylene reduction technique. *Proceedings of the National Academy of Sciences, USA* **58**, 2071–2078.

Stoddart, D. R. (1969). World erosion and sedimentation in water. In *Water, Earth and Man* (R. J. Chorley, ed.), pp. 43–64. London: Methuen.

SYSTAT (1996). *Statistics*. SYSTAT 6·0 for windows. Chicago: SPSS Inc.

Toky, O. P. and Ramakrishnan. (1981). Run-off and infiltration losses related to shifting agriculture (jhum) in north-eastern India. *Environmental Conservation* **8**, 313–321.