Environmentalist
DOI 10.1007/s10669-008-9164-6

Characterizing land-use diversity in village landscapes for sustainable mountain development: a case study from Indian Himalaya

K. Singh · R. K. Maikhuri · K. S. Rao · K. G. Saxena

Abstract This study aimed to analyze the ecological, socio-economic and policy implications of land-use diversity in a traditional village landscape (900–1,000 m *amsl.*) in the Garhwal region of Indian Himalaya. The village landscape was differentiated into three major land-use types viz., forests, settled agriculture and shifting agriculture. Settled agriculture was further differentiated into four agroecosystem types viz., homegarden system (HGS), rainfed agroforestry system (RAS), rainfed crop system (RCS) and irrigated crop system (ICS), and shifting agriculture system (SAS) was differentiated into different stages of a 4-year long cropping phase and a 7-year long fallow phase, and forests into Community Forests (CF) and Reserve Forests (RF). HGS is the most productive agroecosystem, with soil organic carbon and nutrient concentrations significantly higher than all other forest/agricultural land-uses. Farmers capitalize upon crop diversity to cope with the risks and uncertainties of a monsoon climate and spatial variability in ecological factors influencing productivity. The SAS, a land-use adopted as a means of acquiring inheritable rights over larger land holdings provided in the policies during the 1890s, is less efficient in terms of land productivity than the traditional RAS and HGS but is maintained for its high labour productivity coupled with availability of high-quality fuelwood from fallow vegetation. Dominance of fodder trees in the RAS seems to derive from policies causing shortage of fodder available from forests. Cultural norms have favoured equity by allowing hiring of labour only from within the village community and income from non-timber forest products only to the weaker section of the society. Conversion of rainfed to irrigated cropping, a change facilitated by the government, improves agricultural productivity but also increases pressure on forests due to higher rates of farmyard manure input to the irrigated crops. Existing forest management systems are not effective in maintenance of a large basal area in forests together with high levels of species richness, soil fertility and resistance to invasive alien species *Lantana camara*. Farmers have to spend huge amount of labour and time in producing manure, managing livestock and other subsidiary farm activities. Interlinkages among agriculture, forests and rural economy suggest a need of replacing the present policies of treating agricultural development, forest conservation and economic development as independent sectors by an integrated sustainable development policy. The policy should promote technological and institutional innovations enabling parallel improvements in agricultural productivity and functions of forest ecosystems.

Keywords Land-use/cover diversity · Himalaya · Resource use patterns · Sustainable development · Traditional knowledge

K. Singh · K. G. Saxena
School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India

R. K. Maikhuri
G.B. Pant Institute of Himalayan Environment and Development, Garhwal Unit, P. Box 92, Srinagar (Garhwal) 246174, India

K. S. Rao (✉)
Center for Inter-disciplinary Studies of Mountain and Hill Environment, University of Delhi, Delhi 110007, India
e-mail: srkottapalli@yahoo.com

1 Introduction

Himalaya is a vast mountain system covering partly/fully eight developing countries of south Asia including Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. India's recognition as a 'mega-diversity' country and as one of the ten largest forested areas in the world derives partly from the Himalaya. More than 90% people of the Indian Himalaya live in villages, which are organized as independent socio-ecological systems. Village landscapes are mosaics of a range of agricultural and forest ecosystem types managed by local communities surrounded by forests managed by government agencies. Traditional crop-livestock mixed farming, the backbone of livelihood of local people, is highly dependent on forests for livestock feed and manure. Changes in forest ecosystem structure and functions may be coupled with changes in quality and/or quantity of livestock feed and manure, which in turn may induce changes in agroecosystem structure and functions. Similarly, changes in manure input rates in farmland may alter grazing/lopping regimes in forests leading to changes in forest ecosystem structure and functions. Apart from the inputs that drive agricultural production process, forests provide a range of other products and services, which are crucial not only for sustainable livelihood of 115 million people living in the Himalaya, but also for a much larger population inhabiting the adjoining Indo-gangetic plains (Ives and Messerli 1989; Hurni 1999). An agricultural system will be considered to be sustainable if its productivity is maintained in the long run, natural resources driving agricultural production process are conserved and profitability of production and therefore financial incomes to farmers are guaranteed (Neher 1992; Kessler 1994). As agricultural production is directly linked to surrounding ecosystems, consideration of all interactions between the agricultural production system and natural ecosystems in cultivated landscapes is a critical requirement for developing sustainable land-use policies and programmes (Briggs and Twomlow 2002; Ghersa et al. 2002; Desbiez et al. 2004; Baijukya et al. 2005). Efforts have been made to analyze the structure, functions and management of selected agricultural and forestry land-uses in the Himalaya (Singh and Singh 1992; Sharma and Sharma 1993; Pilbeam et al. 2000) as well as other mountain regions in developing countries (Murage et al. 2000; Poudel et al. 2000; Clermont-Dauphin et al. 2005). However, a comprehensive analysis of ecological and socio-economic attributes of the full range of land-use/cover types within village landscapes is lacking. This deficiency in knowledge partly accounts for environmental degradation as an outcome of rural development programmes and farmers' negative attitudes towards environmental conservation programmes in the Himalaya (Rao et al. 2003). The present study aimed to characterize the diversity of land-use/cover, in terms of spatial variability in cropping patterns, agricultural inputs and productivity, vegetation structure, soil nutrient pools and management practices, in a traditional village landscape and its environmental, socio-economic and policy implications in the Himalayan region.

2 Materials and methods

2.1 Study area

The study was carried out in village Bacchelikhal, a typical mid-altitude (900–1,000 m *amsl.*) village of Garhwal region of Indian Himalaya (29°26′ to 30°28′ N latitude and 77°49′ to 80°06′ E longitude) (Fig. 1). The year consists of three seasons: warm rainy season (July to September), winter season (October to March) and dry summer (April to June). Mean annual rainfall is 1500 mm and temperature 21°C. The parent material consists of schistose, phyllite and biotitequartz, flaggy quartzite and sericite quartzs. Soils are 30–80 cm deep and can be classified as Dystric Cambisols. The village comprises 48 households, with average family size of 6 individuals, farm holding of 1.7 ha and livestock holding of 5 adult units of livestock comprising cattle, goats and mules/horses. Livestock are sustained partly by stall-feeding of crop by-products mixed with green fodder from farm/forest trees and partly by grazing in forests. Leaf litter collected from forests is used as bedding material in livestock-sheds. The mixture of litter and livestock excreta is used as manure in settled agriculture. The village community consists of two strata: the lower caste group and the higher caste group. The former group is characterized by a lower social status, smaller land holdings and lower incomes compared to the latter group (Table 1).

2.2 Policy interventions

Land-use practices were guided by the indigenous knowledge system until the 1890s. Policy interventions related to land-use/cover management and livelihood in the study area include: (i) grant of inheritable ownership rights on cultivated lands together with a legal ban on expansion of agricultural land-use in the 1890s, (ii) classification of traditional village forests into: (a) Community Forests (CF), where all subsistence resource uses were regulated by the Village Council (comprising 7 individuals elected by the village community) and commercial extractions by government agencies, and (b) Reserve Forests (RF), where all traditional resource uses were terminated, silvicultural practices favouring timber species *Shorea robusta* were applied during 1900–1976 period and all income from timber was appropriated by the Government Forest Department, (iii) suspension of cutting of green trees in forests or farms for timber trade since 1976, (iv) supply of chemical fertilizers, pesticides, seeds of high yielding

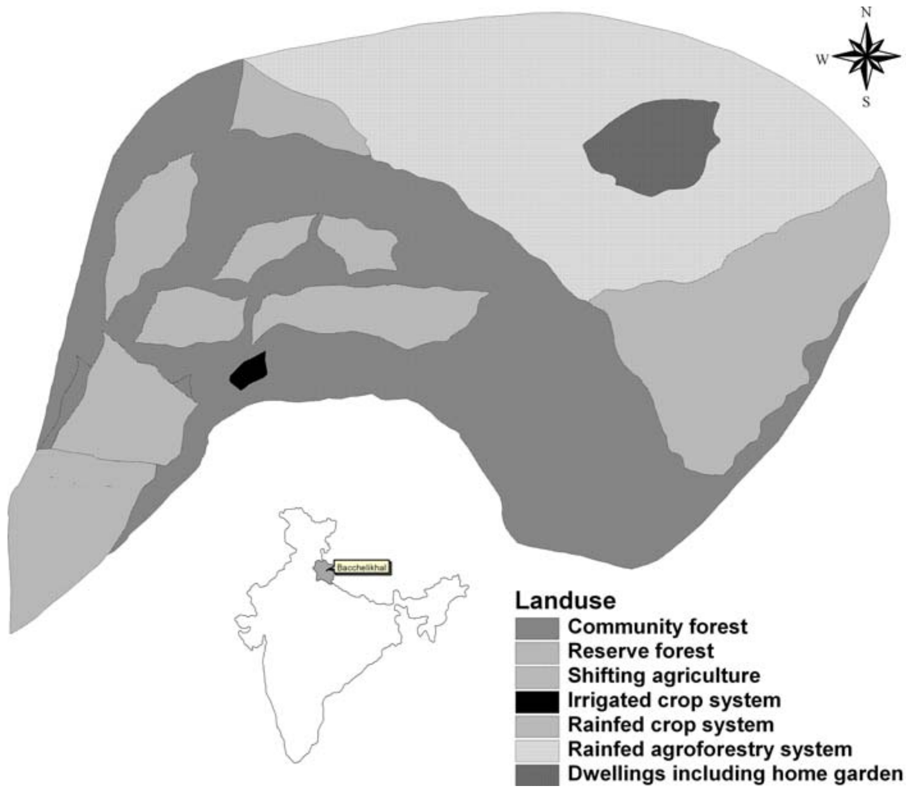

Fig. 1 Location and sketch map of land-use/cover types differentiated in village Bacchelikhal, Garhwal, India

varieties of maize, soybean and rice, saplings of multipurpose trees and a quota of staple food grains (25 kg of wheat and 30 kg of rice per family per month) at subsidized price by the government since 1980, (v) provision of government funds to meet 50% of the construction cost of tanks in farmlands for run-off harvesting for irrigating crops since 1985 and (vi) improvement in infrastructure by the government in whole of the Garhwal region after 1970.

2.3 Differentiation of land-use/cover in the village landscape

Bacchelikhal village landscape comprised three broad land-use/cover types viz., settled agriculture, shifting agriculture and forests, covering 35, 21 and 44% of the total area of the village (148 ha), respectively. Settled agriculture was further differentiated into (i) homegarden

Table 1 Selected attributes (standard deviation values given with the means) of Bacchelikhal village community, Garhwal, India

Attribute	Higher caste	Lower caste
Number of households	40	8
Population	252	51
Family size (number of individuals)	6.3 ± 0.8	6.4 ± 1.1
Number of individuals per family with employment outside the village[a]	0.65 ± 0.5	0.13 ± 0.36
Number of individuals per family with employment inside the village	0	0.16 ± 0.52
Land holding size (ha)		
Homegarden system	0.04 ± 0.01	0.11 ± 0.03
Rainfed agroforestry system	0.82 ± 0.11	0.42 ± 0.05
Rainfed crop system	0.27 ± 0.18	0
Irrigated crop system	0.02 ± 0.06	0
Shifting agriculture	0.76 ± 0.12	0.23 ± 0.05
Total land holding	1.92 ± 0.11	0.76 ± 0.08
Annual family income (as in the year 2000 in Indian Rupees) (US$ 1 = Indian Rupees 45 approx)	75,000 ± 25,000	39,000 ± 11,000

[a] Permanent outmigration is altogether lacking

system (HGS): a dense crown cover (>80%), dominance of fruit trees and understorey vegetable crops irrigated by domestic waste water, (ii) rainfed agroforestry system (RAS): rainfed cultivation of food crops and occurrence of scattered multipurpose trees (crown cover 10–20%), (iii) rainfed crop system (RCS): rainfed cultivation of food crops and absence of trees and (iv) irrigated crop system (ICS): cultivation of food crops irrigated by run-off accumulated in tanks in some parcels of land previously under the RCS. In all holdings, the HGS was nearest to the living place followed by the RAS. Settled agriculture was managed based on decisions of individual families and shifting agriculture on community decisions arrived through consensus. While the lower caste families practised only RAS, HGS and SAS and allocated larger proportions of available land to the HGS and RAS (15 and 55% of total land holding, respectively) compared to the higher caste families (2 and 43%, respectively), differences in management and productivity of these land uses common to both caste groups were neither reported by farmers nor perceived by us in our extensive surveys in the region (Rao and Saxena 1994; Maikhuri et al. 1996, 2000). Forests occurred on slopes varying from 30° to 50°. RF showed more luxuriant tree growth compared to CF (Table 2).

2.4 Participatory survey, crop yields and vegetation analysis

Information on land-use history, relative areas and farmers' perceptions on ecological and socio-economic attributes of different crops/agroecosystems, and selling/buying prices of agricultural inputs/outputs was obtained based on semi-structured interviews, using both open and probing questions, with the elders of each family separately ($n = 48$ families). Archival records related to land-use regulations were consulted. Absolute area of a given crop/agroecosystem type was computed from relative area values reported by the farmers and aggregate area values obtained from the village records.

Three plots for each of the five crops grown in the RCS and RAS ($n = 15$ plots in each land-use) and of the two crops grown in the ICS and SAS ($n = 6$ plots in each land-use) were randomly selected for monitoring agricultural inputs (seed, manure, bullock power and labour) and outputs (human food and fodder). Mean inputs/outputs of an agroecosystem type were derived from the relative areas under different crops grown in the system and input/output values of respective crops. Three random plots of HGS, where crop-wise disaggregation of inputs was not possible due to intermixing of a large number of crops, were also

Table 2 Selected features of land-use/cover types differentiated in Bacchelikhal village landscape, Garhwal, India

Land-use	Relative area (% of total village area)	Distance from dwellings (km)	General appearance	Ownership/management
Settled agriculture				
Homegarden system	1.7	0.01–0.3	5–8° outward sloping terraces; tree crown cover >80%; dominance of fruit trees	Land owned and managed by individual families; continuously irrigated by domestic waste water
Rainfed agroforestry system	24.7	0.2–1.0	5–8° outward sloping terraces; scattered multipurpose trees; crown cover: 10–20%	Land owned and managed by individual families
Rainfed crop system	7.7	2.0–3.0	5–8° outward sloping terraces; absence of trees	Land owned and managed by individual families
Irrigated crop system	0.6	2.5–3.0	5–8° outward sloping terraces; absence of trees	Land owned and managed by individual families; irrigated by run-off harvested in small tanks, with irrigation intensity markedly lower than that in homegarden
Shifting agriculture	21.4	2.5–4.0	10–15° outward sloping terraces; absence of trees	Privately owned but collectively managed
Forests				
Community forests	35.7	3.0–4.5	Natural 30–40° slopes; short trees (<10 m height) and crown cover 30–45%	Land owned by the government but forests are managed by the village community; regulated uses of non-timber forest products and absence of fire
Reserve forests	8.2	4.5–5.0	Natural 20–30° slopes; tall trees (>15 m) of *Shorea robusta* and crown cover of 45–60%	Both land and resources owned and managed by the government; unregulated uses of non-timber forest products and frequent ground fire

selected. Inputs and outputs were converted into energy equivalents following Mitchell (1979) and monetary equivalents based on wage rates and buying/selling prices in the village. Different crops and agroecosystems were compared in terms of land and labour productivity (food energy, fodder energy and monetary value of the produce per unit land area or per unit human energy input per unit time) and economic efficiency (net monetary return and output/input ratio).

Species-wise density and basal area of mature trees were measured in 20 random quadrats (10 × 10 m size) and of shrubs/tree saplings/seedlings in similar number of 5 × 5 m size quadrats in an ecosystem type. At the time of weeding, weed density was measured in 10 random quadrats (1 × 1 m size), sampled in each plot. These observations could not be made in the fields under fourth year of cropping in the SAS, which were not weeded, and in the HGS plots, which were so frequently weeded that we failed to track a few weeding events.

2.5 Soil analysis

Soil was sampled from 0 to 10, 10 to 20 and 20 to 30 cm depth from 15 random locations in each ecosystem type during summer season. Samples were mixed randomly such that three composite samples were obtained for each ecosystem type. Soil organic C was estimated by the Walkley–Black method, total N by the Kjeldahl method, available P (extracted in sodium bicarbonate solution at pH 8.5) by the molybdenum blue method, exchangeable Ca and Mg by atomic absorption spectrophotometer and exchangeable K by flame photometer (cation extraction in 1 M ammonium acetate at pH 7). Bulk density was estimated and soil stocks were calculated following Allen (1974).

2.6 Statistical methods

One-way analysis of variance and least significant difference ($P = 0.05$) were applied to compare mean values of agricultural inputs/outputs and soil properties in different ecosystem types (Snedecor and Cochran 1967).

3 Results

3.1 Crops and cropping patterns

Two crops, a warm rainy season crop (April/May–October) and a winter crop (November–April/May), were harvested in a year in settled agriculture and only rainy season crop in shifting agriculture. Of the six rainy season crop species, maize (*Zea mays*) and soybean (*Glycine max*) were confined to the RAS and horsegram (*Macrotyloma uniflorum*) to the shifting agriculture system (SAS), while sesame (*Sesamum indicum*) was common to the ICS and SAS and barnyard millet (*Echinochloa frumentacea*) and fingermillet (*Eleusine coracana*) to the RAS and the RCS. Of the two winter crops, both wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) were grown in the RAS and the RCS and only wheat in the ICS. In the SAS, sesame was grown during the first 2 years and horsegram (*M. uniflorum*) in the last 2 years of a 4-year long cropping phase (Table 3) alternating with a 7-year long fallow phase.

In the RAS, *Muatha* and *Bhagan* cultivars of barnyard millet and *Jhalarya* and *Chauras* cultivars of fingermillet were sown soon after the first monsoon showers in April/May, with each cultivar covering about 15% of farm area. Soybean was sown in gaps in fingermillet fields after 30–40 days after sowing of fingermillet. With the onset of the main monsoon in mid-June, maize was sown in the remaining fields and soybean was intercropped when maize plants were 20–25 days old. During participatory discussions, farmers reported that monsoon happened to be normal during the study period (2001–2002). If they observe poor growth of maize crop till 20–25 days after sowing due to low rainfall, they plough all maize fields afresh and sow *Mungerikuad* cultivar of fingermillet in these fields. If the main monsoon commences after mid-June, the maize area is sown with all cultivars of barnyard millet and fingermillet (Fig. 2).

In the HGS, vegetables viz., colocasia (*Colocasia esculenta*), pumpkin (*Cucurbita pepo*), bitter gourd (*Momordica charantia*), chili (*Capsicum annum*), ladies finger (*Abelmoschus esculentus*), onion (*Allium cepa*), ginger (*Zingiber officinale*), turmeric (*Curcuma domestica*), cucumber (*Cucumus sativus*), potato (*Solanum tuberosum*), mustard (*Brassica campestris*) and rye (*Brassica rugosa*) were grown as the major understorey crops mixed with a few individuals of all crops grown in other agroecosystem types. The HGS was thus a repository of domesticated crop diversity.

3.2 Inputs and outputs related to individual crops

In settled agriculture, maize–soybean mixed crop, a rainy season crop confined to the RAS, was the most productive as well as the most intensively cultivated crop. Productivity of barnyard millet in the RAS and RCS did not differ significantly ($P > 0.05$), even though farmers spent more of manure and labour on this crop in the former than in the latter system. Barley, a winter crop sown only in rainfed conditions, showed similar levels of productivity as well as manure/labour inputs in the RAS and RCS systems. In wheat, a winter crop grown in both rainfed and irrigated

Table 3 Crop-wise relative area (area of a crop as % of total cropped area in rainy season/winter season), inputs, land productivity (energy available from human food/fodder expressed in GJ or monetary value of the produce in Rs per ha of land) and labour productivity (food/fodder energy or monetary value of the produce per GJ human labour input) related to individual crops grown in different agricultural land-uses (1 US$ = Rs 45; monetary value of fodder is not given as it is not sold) in Bacchelikhal village landscape, Garhwal, India

Land-use/crop	Relative area (%)	Inputs							Edible yield				Fodder	
		Manure (Mg ha^{-1} yr^{-1})	Bullock power (GJ ha^{-1} yr^{-1})	Seed (GJ ha^{-1} yr^{-1})	Labour				Land productivity		Labour productivity		Land productivity (GJ ha^{-1} yr^{-1})	Labour productivity (GJ GJ^{-1} yr^{-1})
					Person days ha^{-1} yr^{-1}		Energy (GJ ha^{-1} yr^{-1})		Food energy (GJ ha^{-1} yr^{-1})	Monetary value (Rs ha^{-1} yr^{-1})	Food energy (GJ GJ^{-1} yr^{-1})	Monetary value (Rs GJ^{-1} yr^{-1})		
					Male	Female	Male	Female						
Rainfed agroforestry system														
Echinochloa frumentacea Link*	36	26^{b}	0.39^{d}	0.79^{d}	13^{d}	62^{b}	0.07^{d}	0.21^{d}	34^{b}	5219de	121^{a}	18639^{bcd}	59^{a}	213^{f}
Eleusine coracana (L.) Gaertner + *Glycine max* (L.) Merrill*	30	12^{cd}	0.71^{b}	1.29^{b}	19^{d}	65^{d}	0.10^{d}	0.22^{d}	33^{b}	11973^{bcd}	104^{ab}	37415^{b}	65^{a}	203^{f}
Zea mays L. + *Glycine max* (L.) Merrill*	34	42^{a}	0.87^{a}	2.41^{a}	23^{b}	98^{b}	0.12^{b}	0.33^{b}	49^{a}	33635^{a}	108^{ab}	74744^{a}	71^{a}	158^{cd}
Hordeum vulgare L.**	40	1^{e}	0.78^{b}	1.10^{c}	17^{e}	26^{e}	0.09^{e}	0.10^{e}	23^{b}	2858^{e}	120^{a}	15042^{cd}	36^{bc}	187^{bc}
Triticum aestivum L.**	60	8de	0.78^{b}	1.33^{b}	18^{e}	33^{e}	0.10^{e}	0.11^{e}	15^{c}	7021^{cde}	69^{bcd}	33433 ^{bc}	23^{cd}	111^{ef}
Rainfed crop system														
Echinochloa frumentacea Link*	50	1^{e}	0.32^{d}	0.99^{d}	10^{e}	47^{e}	0.05^{e}	0.16^{e}	27^{b}	4151^{e}	128^{a}	19766^{bcd}	62^{a}	296^{a}
Eleusine coracana (L.) Gaertner**	50	1^{e}	0.59^{c}	0.79^{d}	10^{e}	50^{e}	0.05^{e}	0.17^{e}	27^{b}	5076de	124^{a}	23072^{bcd}	40^{b}	184^{fc}
Hordeum vulgare L.**	14	1^{e}	0.35^{d}	1.05^{c}	10^{e}	36^{e}	0.05^{e}	0.12^{e}	21^{b}	2571^{e}	121^{a}	15124^{cd}	18de	103^{ef}
Triticum aestivum L. + *Hordeum vulgare* L.**	57	1^{e}	0.29^{d}	1.17^{c}	8^{f}	27^{f}	0.04^{f}	0.07^{f}	4^{d}	2032^{e}	40^{cd}	18472^{bcd}	13de	117^{ef}
Triticum aestivum L.**	29	1^{e}	0.32^{d}	1.38^{b}	6^{f}	18^{f}	0.03^{f}	0.06^{f}	3^{d}	1159^{e}	38^{d}	12878^{d}	6^{e}	62^{g}
Irrigated crop system														
Sesamum indicum L.*	100	21^{bc}	0.99^{a}	0.91^{c}	25^{d}	50^{d}	0.13^{d}	0.17^{d}	12^{c}	8201^{cde}	41^{cd}	27337^{bcd}	Nil	Nil
Triticum aestivum L.**	100	12^{cd}	0.98^{a}	1.34^{b}	44^{c}	47^{c}	0.23^{c}	0.16^{c}	27^{b}	12546 ^{bcd}	69^{bcd}	32169^{bc}	36^{bc}	83^{fg}
Shifting agriculture														
Sesamum indicum L.-first year crop*	25	Nil	Nil	1.22^{b}	78^{a}	124^{a}	0.41^{a}	0.42^{a}	28^{b}	17796^{b}	33^{d}	21440^{bcd}	Nil	Nil
Macrotyloma uniflorum (Lam.) Verdc.-fourth year crop*	75	Nil	Nil	1.06^{c}	13^{e}	27^{e}	0.07^{e}	0.09^{e}	14^{c}	13032^{bc}	87^{abc}	81450^{a}	Nil	Nil

Values with different letters within a column are significantly ($P < 0.05$) different

* Crops grown in rainy season

** Crops grown in winter season

conditions, the highest levels of productivity and labour/manure inputs were observed in the ICS followed by RAS and RCS. In the SAS, labour input drastically decreased from the first to the fourth year of cropping partly because energy spent in clearing/burning of vegetation was accounted in the first year crop. Labour productivity of horsegram grown in the fourth year of cropping was about four-times higher than that of sesame grown in the first year but the two crops did not differ significantly ($P > 0.05$) in terms of land productivity. Land productivity of sesame, a crop common to the SAS and ICS, was two-times higher in the former compared to the latter system, while labour productivity in the two systems did not differ significantly ($P > 0.05$) (Table 3).

3.3 Inputs and outputs related to different agroecosystem types

As the agroecosystem types differed in terms of crop composition and number of crops harvested from a plot in a year, it seemed useful to compare inputs and outputs in different agroecosystems on an annual time scale (Tables 4 and 5). Women spent more time (person days ha^{-1} yr^{-1}) than men in all agroecosystems, with their contribution to total labour input varying from 86% in the HGS to 60% in the ICS and SAS. Total labour input (0.31 GJ ha^{-1} yr^{-1}) in shifting agriculture was significantly ($P < 0.05$) lower compared to settled agriculture (0.53–0.74 GJ ha^{-1} yr^{-1}). Comparing the three types of settled agroecosystems evolved based on indigenous knowledge, the highest rates of manure and labour inputs were observed in the HGS followed by the RAS and RCS. The HGS was the most productive system followed by the RAS and RCS in terms of land or labour productivity of human food, while the RAS was the most productive system followed by the RCS and HGS in terms of land productivity of fodder.

The ICS, a land-use facilitated by the government, required 33-times higher manure input and 2-times higher human labour and bullock power inputs as compared to the RCS. Labour input to the ICS was 1.4-times higher compared to the RAS but the two systems did not differ in respect of other inputs. Land and labour productivities of the ICS were 3.1-times and 1.4-times, respectively, higher compared to the RCS. The ICS was less efficient than the HGS and RAS in terms of all measures of productivity, except that it was as productive as the RAS in terms of monetary value of land productivity. The SAS was as efficient as the RAS and more efficient than the RCS and ICS in terms of labour productivity (in monetary terms), but less efficient than all settled agroecosystems except the RCS in terms of land productivity (Table 4).

Only HGS and SAS showed positive annual net monetary returns and output/input ratio values higher than one, with monetary return from the former system being 354% higher but output/input ratio 13% lower compared to the latter system (Table 5).

Mean per capita annual production of cereals/millets was 545 kg, of pulses 101 kg and of oilseeds 30 kg, indicating food self-sufficiency in the village. On-field activities in the whole village absorbed 8,750 person days per year of the total available labour of 33,250 person days per year. Subsidiary farm activities (including stall-feeding/herding of livestock, preparation of farmyard manure and transport of farm inputs/outputs between homesteads and crop fields) combined with other domestic tasks (including collection of fuelwood, wild edibles and medicinal plants and maintenance of natural springs providing drinking water) involved labour input (24,500 person days per year) 3.8-times higher than the labour spent for on-field activities. Children contributed 26% of the total labour input to subsidiary farm activities and only 2% of that to on-farm activities. Lower caste families provided 24% of the total labour input to the farms of higher caste families. If both on-field and subsidiary activities were considered together, the labour available in the village was fully occupied.

3.4 Natural vegetation in the village landscape

The HGS was dominated by fruit trees *Psidium guajava, Punica granatum* and *Carica papaya*, RAS by high-quality fodder trees *Boehmeria rugulosa* and *Grewia optiva*, CF by moderate quality fodder/fuelwood species *Adina cardifolia* and *Gmelina arborea* and RF by high-quality timber species *S. robusta*. The RAS showed the highest tree species richness and the RF the highest basal area. Most tree species of the CF were regenerating in 7-year-old shifting cultivation fallow fields (Table 6). *Murraya koenigii* was the most dominant shrub in forests and was followed by *Lanatana camara*, an invasive alien species, in the RF and *Rhus parviflora* in the CF. *R. parviflora* was the most dominant species in 1-year old and *L. camara* in 7-year old fallow fields (Table 7). People valued *M. koenigii* and *R. parviflora* stems as high-quality fuelwood and removed them before burning the slash in the SAS. *Ageraturm conyzoides* was the most abundant herbaceous species in fourth year cropping/1-year old fallow fields of the SAS and RAS, *Commelina erecta* in the RCS and first year of cropping under the SAS, *Stellaria media* in the ICS, *Oxalis corniculata* in 7-year old fallow fields and *Tridax procumbens* in forests (Data not presented here).

3.5 Soil chemical properties

Soil organic C, total N and exchangeable cations decreased with increase in depth in all land-uses except the ICS

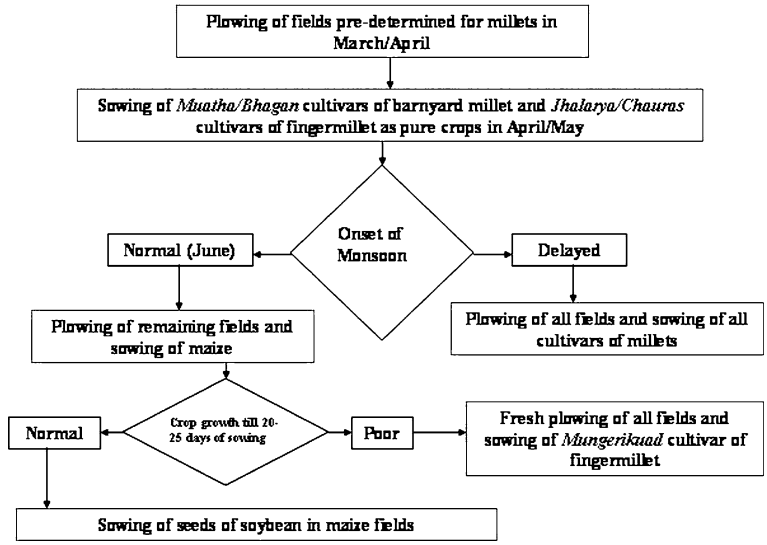

Fig. 2 Farmers' decision making on cropping pattern during rainy season in rainfed agroforestry system in village Bacchelikhal, Garhwal, India

showing the largest organic C pool in 20–30 cm soil layer. Among settled agroecosystems, soils of the HGS had 4-times larger organic C and nutrient pools compared to the RCS and 2-times larger pools as compared to the ICS and RAS, with insignificant differences ($P > 0.05$) between the latter two systems. In the SAS, soil organic C and nutrient pools during first year of cropping after burn were almost 2-times larger compared to those in 7-year old fallow fields. Further, soil nutrient pools decreased with the progress of cropping phase, a trend that was most pronounced for available P. There was no significant ($P > 0.05$) change in soil properties over 7 years of fallow development. All soil pools, except exchangeable Ca, were significantly ($P < 0.05$) larger in the CF compared to the RF (Figs. 3a–c and 4a–c).

3.6 Farmers criteria of distinguishing crops/cultivars and religious beliefs related to farm/forest management

Participatory discussions with farmers led to following deductions:

- Farmers distinguished crops/cultivars based on their economic values and adaptations to various stresses determining risks to productivity (Table 8). The crops could be classified into three groups: (a) maize, soybean and wheat, which have high economic values but are highly susceptible to soil moisture stress arising from low rainfall conditions or nutrient stress under low manure input conditions, stresses in compact soils in untilled agroecosystems and to shade caused by agroforestry trees and weeds, (b) fingermillet, barnyard millet and barley, which have low economic values and are less susceptible to soil moisture/nutrient stresses and (c) sesame and horsegram, which have high economic values and are able to grow in untilled soils and to compete with weeds.
- Farmers determined cropping patterns based on costs/benefits and opportunities/constraints associated with the available options of minimizing the risks to crop productivity. Farmers perceived two major risks to crop productivity: (a) the risk of water stress arising from climatic uncertainty and (b) the risk of spending huge labour and time in travel and transport by cultivating fields far away from homesteads. They viewed the HGS as the least risky agroecosystem because it did not experience water stress due to continuous irrigation by domestic wastewater and was most close to the dwellings.
- Farmers understood conversion of rainfed to irrigated agriculture to be a more efficient way of coping with the climatic risks and uncertainties than the traditional way of adapting crops/cultivars to the monsoon trends. However, they did not like the present tank-based irrigation system because it was costly to maintain and was unable to meet water requirements of highly profitable crops like paddy and vegetables.
- Farmers realized that nutrient stresses derived not from any inherent soil constraint but from low manure input rates. They did not use chemical fertilizers for two reasons: (a) they found benefits of fertilizers insignificant in rainfed agriculture or present irrigated agriculture based on the tank system and (b) they were to keep a stock of this input because of uncertainty of its availability at subsidized price from the government agencies.
- Farmers were aware of some loss of crop yields due to shading and depredation of crops by birds perching on agroforestry trees in the RAS but reconciled this loss with the availability of tree fodder near dwellings.

Table 4 Annual mean inputs, land productivity and labour productivity of different agricultural land-use types in Bacchelikhal village landscape, Garhwal, India

	Inputs			Labour				Edible yield				Fodder	
	Manure (Mg ha^{-1} yr^{-1})	Bullock power (GJ ha^{-1} yr^{-1})	Seed (GJ ha^{-1} yr^{-1})	Person days ha^{-1} yr^{-1}		Energy (GJ ha^{-1} yr^{-1})		Land productivity		Labour productivity		Land productivity (GJ ha^{-1} yr^{-1})	Labour productivity (GJ GJ^{-1} yr^{-1})
				Male	Female	Male	Female	Food energy (GJ ha^{-1} yr^{-1})	Monetary value (Rs ha^{-1} yr^{-1})	Food energy (GJ GJ^{-1} yr^{-1})	Monetary value (Rs GJ^{-1} yr^{-1})		
Homegarden system	50^{a}	1.55^{b}	0.73^{c}	22.7^{c}	139.1^{a}	0.13^{c}	0.47^{a}	102^{a}	63340^{a}	171^{a}	105567^{a}	36^{c}	60^{c}
Rainfed agroforestry system	30^{b}	2.36^{a}	2.62^{a}	33.2^{b}	100.6^{b}	0.19^{b}	0.34^{b}	55^{b}	20362^{b}	103^{b}	38419^{b}	99^{a}	187^{a}
Rainfed crop system	1^{c}	0.77^{c}	2.14^{a}	15.7^{d}	74^{c}	0.09^{d}	0.25^{c}	34^{c}	6674^{d}	99^{b}	19629^{d}	73^{b}	216^{a}
Irrigated crop system	33^{b}	1.95^{ab}	2.26^{a}	66.3^{a}	106.5^{b}	0.38^{a}	0.36^{b}	39^{c}	20747^{b}	53^{c}	28036^{c}	36^{c}	49^{d}
Shifting agriculture	Nil	Nil	1.08^{b}	26.2^{c}	47.3^{d}	0.15^{c}	0.16^{d}	19^{d}	12170^{c}	61^{c}	39258^{b}	Nil	Nil

Similarly, they reconciled the loss in current yields due to less intense weeding in the SAS with the contribution made by weeds in terms of soil conservation and rapid growth of fallow vegetation required for sustainability of the SAS.

- Farmers viewed settled and shifting agriculture as complementary land-uses. They valued shifting agriculture for high labour productivity (in terms of income) and availability of high-quality fuelwood and settled agriculture for high land productivity, food security and fodder availability.
- There was a religious belief that catastrophic events would follow if any family adopted timber trade as a means of livelihood, abandoned agriculture and hired labour from outside the village for farming. Further, cultural norms restrained sale of non-timber forest products by higher caste families and ploughing by women.

4 Discussion

4.1 Land-use diversity: patterns and driving factors

Traditional subsistence farming in the Garhwal and adjoining regions of Himalaya is characterized by settled rainfed agriculture as the major and homegarden as a minor land-use highly dependent on forests for inputs required to produce manure and maintain livestock. Land management objectives have changed with time with changing socio-economic conditions, technological innovations and policy interventions, leading to changes in traditional land-use practices in the Himalaya (Singh et al. 1997; Sherchan et al. 1999; Pilbeam et al. 2000) as also elsewhere (Plieninger and Wilbrand 2001; Zhang et al. 2004; Baijukiya et al. 2005). Farmers of the Garhwal Himalaya believe that yield depressing effects of trees on understorey crops outweigh their yield enhancing effects in tree-crop mixed farming, an element of traditional knowledge also supported by scientific evidences (Narain et al. 1997; Semwal et al. 2002). Though income from wood of farm trees can compensate for crop yield losses due to them, marketing of wood is restrained by religious faith as well as policies. It has been estimated that 4 ha of forest land would be the minimum requirement for providing fodder and manure needed for maintaining soil fertility and sustainable yields in one ha of traditional settled rainfed agriculture (Hrabovzsky and Miyan 1987; Ashish 1993). Absence of agroforestry trees in village landscapes with forests dominated by multipurpose trees covering areas 4- to 5-times larger than the area under agriculture (Rao and Saxena 1996; Semwal et al. 2004) suggests that farmers adopt tree-crop mixed farming when

Table 5 Annual monetary input, output, net return and output/input ratio related to different agricultural land-use types in Bacchelikhal village landscape, Garhwal, India[a]

Land-use system	Input				Output (Rs ha^{-1} yr^{-1})	Net return (Rs ha^{-1} yr^{-1})	Output/input ratio
	Labour (Rs ha^{-1} yr^{-1})	Manure (Rs ha^{-1} yr^{-1})	Seed (Rs ha^{-1} yr^{-1})	Total (Rs ha^{-1} yr^{-1})			
Homegarden	10841^{a}	22500^{a}	381^{c}	33722^{a}	63340^{a}	29618^{a}	1.88^{b}
Rainfed agrorofestry system	8965^{c}	13500^{b}	1332^{a}	23797^{b}	20362^{b}	-3435^{c}	0.86^{c}
Rainfed crop system	6010^{d}	450^{c}	625^{b}	7085^{c}	6674^{d}	-411^{d}	0.94^{d}
Irrigated crop system	11578^{b}	14850^{b}	1118^{a}	27546^{b}	20747^{b}	-6799^{c}	0.75^{c}
Shifting agriculture	4925^{e}	Nil	719^{b}	5644^{d}	12170^{c}	6527^{b}	2.16^{a}

[a] Local people did not attach any monetary value to bullock power and fodder available from crop fields and hence these two components are not accounted

Table 6 Density (individuals ha^{-1}) of mature trees (MT) and regeneration (seedlings + saplings) (SS) and basal area (BA) (m^2 ha^{-1}) in different land-use/cover types in Bacchelikhal village landscape, Garhwal, India

	Homegarden			Rainfed agro-forestry system			Community forest			Reserve forest			1-Year fallow			7-Year fallow		
	MT	SS	BA	MT	SS	BA	MT	SS	BA	MT	SS	BA	MT	SS	BA	MT	SS	BA
Acacia catechu (L.f.) Willd.	–	–	–	–	–	–	36	–	4	–	–	–	–	–	–	–	–	–
Adina cordifolia (Roxb.) Hook.f.ex Brandis	–	–	–	31	13	3	157	100	8	13	–	2	–	–	–	30	143	8
Anogeissus latifolius (Roxb. ex DC.) Wallich ex Richard	–	–	–	5	2	<1	–	7	–	53	–	5	–	–	–	–	–	–
Boehmeria rugulosa Wedd.	27	–	2	121	18	8	–	–	–	–	–	–	–	–	–	–	–	–
Carica papaya L.	53		3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Celtis australis L.	9	–	1	23	16	2	–	–	–	–	–	–	–	–	–	–	–	–
Citrus medica L.	45		3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Diospyros montana Roxb.	–	–	–	–	–	–	–	14	–	20	33	2	–	–	–	–	30	–
Ficus roxburghii Wallich ex Miq.	–	–	–	10	25	1	–	–	–	–	–	–	–	–	–	–	–	–
Gmelina arborea Roxb.	–	–	–	–	–	–	86	371	3	20	40	1		153		10	116	1
Grewia optiva J.R. Drummond ex Burret	24	–	2	120	83	9	–	–	–	–	–	–	–	–	–	–	–	–
Lannea coromandelica (Houttuyn) Merrill	–	–	–	–	5	–	–	–	–	87	0	11	–	–	–	–	–	–
Mallotus phillipensis (Lam.) Muell.-Arg.	–	–	–	2	25	<1	64	314	1	27	813	1	–	1153	–	–	187	–
Nyctanthes arbo-tristis L.	–	–	–	–	–	–	50	–	2	–	–	–	–	–	–	–	30	–
Psidium guajava L.	81	–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Punica granatum L.	51	–	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Shorea robusta Roxb. ex Gaertner f.	–	–	–	–	–	–	–	–	–	93	53	16	–	–	–	–	–	–
Others	138	–	10	50	54	2	42	285	2	42	421	5	–	20	–	–	107	–
Total	428	–	32	362	241	26	435	1091	20	355	1360	43	–	1326	–	40	613	9

'–' refers to absence

their livelihood is threatened by scarcity of forest resources. Density and species composition of farm tree community would vary depending on the nature and magnitude of forest resource scarcity, indigenous silvicultural knowledge and policies and ecological factors influencing costs/benefits of growing trees on farmland (Gilmour and Nurse 1991; Nautiyal et al. 1998; Pilbeam et al. 2000; Semwal et al. 2004). Crop productivity in settled agriculture seems to be constrained by shortage of fodder and manure in Bacchelikhal village landscape where only one ha of community forest land is available against the minimum requirement of about 4 ha. Maintenance of high-quality fodder trees *Grewia optiva* and *Boehmeria rugulosa* in the RAS could be viewed as an indigenous way of adaptation to shortage of fodder and manure arising from timber-centered forest policies. Farmers, however, do not maintain trees in the rainfed or irrigated crop system (RCS or ICS) located far away from

Table 7 Density (individuals ha^{-1}) of shrub species in different land-use/cover types[a] in Bacchelikhal village landscape, Garhwal, India

	Community forest	Reserve forest	1-Year fallow	7-Year fallow
Carissa opaca Stapf. ex Haines.	257	213	1733	2065
Lantana camara L.	114	567	932	2132
Murraya koenigii (L.) Sprengel	1500	1080	999	666
Rhus parviflora Roxb.	300	27	1930	1937
Others	93	106	1463	90
Total	2264	1993	7057	6890

[a] Settled agricultural land-uses had negligible shrub component and hence not shown here

homesteads because of huge labour and time required for managing trees, transporting fodder (Gilmour and Nurse 1991) and protecting crops from birds perching on agro-forestry trees.

Unlike the north-eastern Himalaya and many other mountain regions where shifting agriculture evolved in ancient times is a major land-use system at present (Ramakrishnan 1992; Cairns and Garrity 1999), this land-use is a relatively recent and minor land-use in the central Himalaya including the present village landscape (Rawat 1994; Negi et al. 1997; Bohle and Adhikari 1998). Archival records and oral history accounts suggest that the policy of granting inheritable rights on all cultivated lands together with restrictions on traditional uses of forest resources introduced during the 1890s prompted farmers to practise

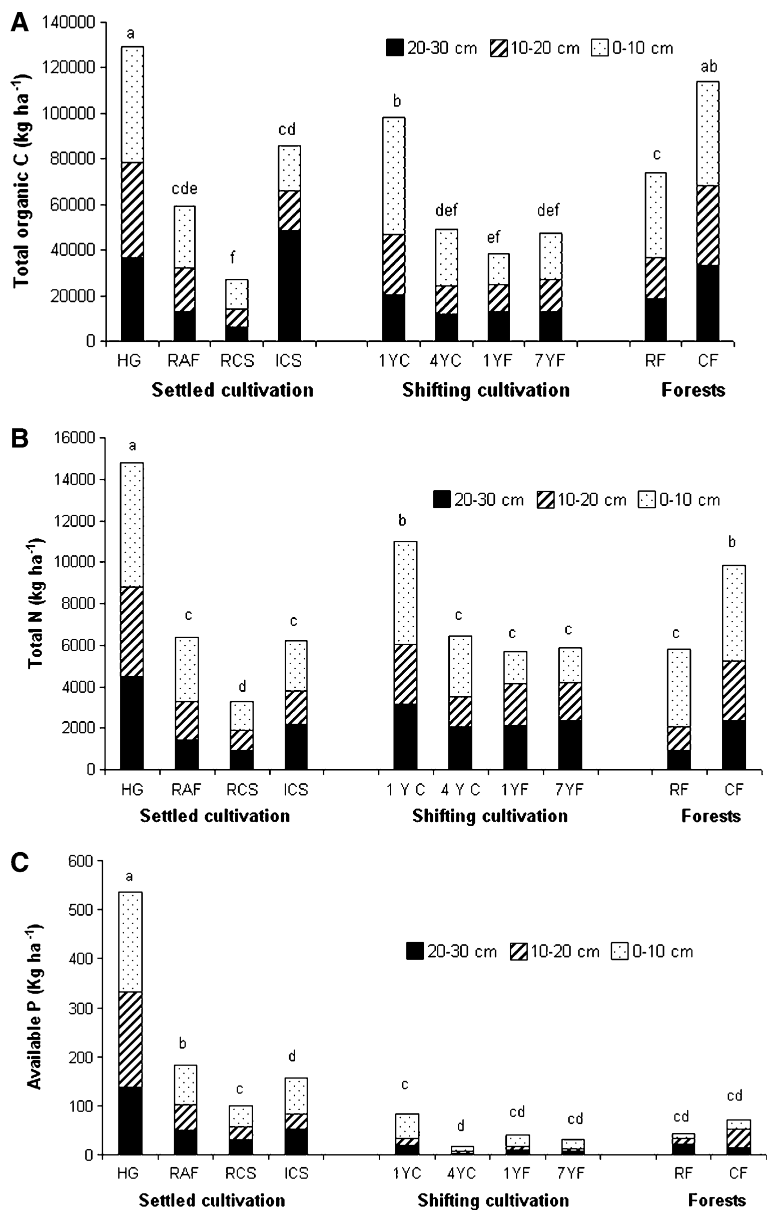

Fig. 3 (**A**) Organic C, (**B**) total N, (**C**) available P pools in soil under different land-use/cover types. HG, homegarden system; RAF, rainfed agroforestry system; RCS, rainfed cropping system; ICS, irrigated cropping system; 1YC and 4YC, first and fourth (last) year of cropping, respectively, after slash-burn in shifting agriculture; 1YF and 7YF, 1- and 7-year old fallow field, respectively, under shifting agriculture; RF, Reserve Forests; CF, Community Forests. Different letters denote significant ($P < 0.05$) differences in total soil organic C, total N, available P pools in 0–30 cm soil layer between various land-use/cover types

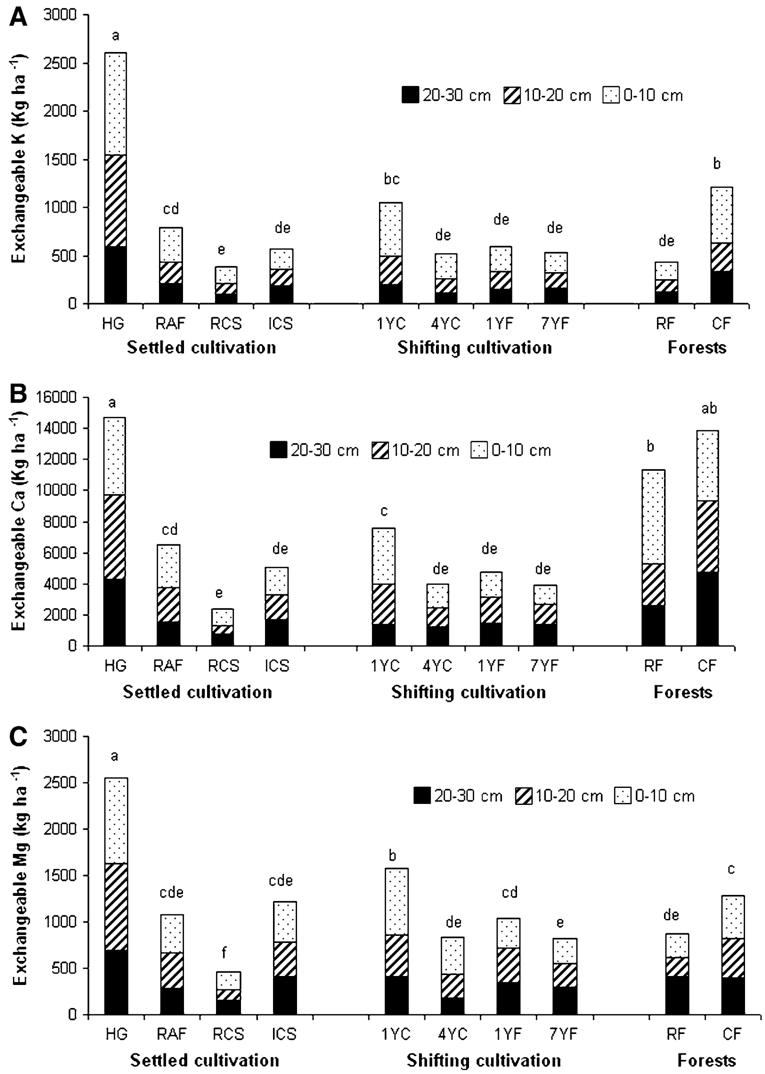

Fig. 4 (**A**) exchangeable K, (**B**) exchangeable Ca and (**C**) exchangeable Mg pools in soil under different land-use/cover types. HG, homegarden system; RAF, rainfed agroforestry system; RCS, rainfed cropping system; ICS, irrigated cropping system; 1YC and 4YC, first and fourth (last) year of cropping, respectively, after slash-burn in shifting agriculture; 1YF and 7YF, 1- and 7-year old fallow field, respectively, under shifting agriculture; RF, Reserve Forests; CF, Community Forests. Different letters denote significant ($P < 0.05$) differences in exchangeable K, Ca and Mg pools in 0–30 cm soil layer between various land-use/cover types

Table 8 Farmers' criteria of distinguishing crops grown in Bacchelikhal village landscape, Garhwal Himalaya, India

Crops	Adaptation to stress due to					Economic value
	Moisture[a]	Nutrients[a]	Agroforestry trees[a]	Absence of tillage[a]	Weeds[a]	
Echinocloa frumentacea[b]	High	High	Low	Low	Low	Low
Eleusine coracana[b]	High	High	Low	Low	Low	Low
Zea mays	Low	Low	Low	Low	Low	High
Glycine max	Low	Low	Low	Low	Low	High
Macrotyloma uniflorum	High	High	Low	High	High	High
Sesamum indicum	High	Low	Low	High	High	High
Triticum aestivum	Low	Low	Low	Low	Low	High
Hordeum vulgare	High	High	Low	Low	Low	Low

[a] Farmers explained moisture stress as the conditions arising from delayed onset and/or lower amounts of monsoon rainfall, nutrient stress as the conditions arising from lower rates of farmyard manure input in settled agriculture or prolonged cropping in shifting agriculture, stress caused by agroforestry trees as shading of crops by tree canopy and crop depredation by birds perching on farm trees, stress caused by absence of tillage as poor aeration and highly compact nature of soil and stress caused by weeds as suppression of crop due to competitive superiority of weeds

[b] In rainfed conditions, *Muatha* and *Bhagan* cultivars of barnyard millet and *Jhalarya* and *Chauras* cultivars of fingermillet require longer growing periods as compared to *Mungerikuad* cultivar of fingermillet

shifting agriculture for two reasons: (i) establishment of shifting agriculture in previously uncultivated lands was an efficient way of staking claims over larger land holdings as it required less energy and time compared to the establishment of settled agriculture and (ii) restrictions on forest resources did not pose any threat to crop yields in shifting agriculture as it did not depend on forest-based farm inputs (i.e., fodder and manure) required for maintenance of soil fertility in traditional settled agriculture (Rawat 1994; Negi et al. 1997). Since the 1930s, policies do not provide for any agricultural expansion but have facilitated partial restoration of traditional forest resource use rights and access to alternatives to forest-based farm inputs (i.e., chemical fertilizers in place of traditional manure and livestock feed concentrates in place of traditional feeds), leading to conversion of shifting to settled agriculture when livelihood is threatened by food shortage (Gilmour and Nurse 1991; Saxena et al. 1993). There seem several reasons for absence of such a land-use change in the present village landscape. First, as the village is self-sufficient in terms of its food requirements, farmers have so far not realised the need of raising land productivity by converting shifting to settled agriculture. Second, forest resources accessible to people are inadequate to provide fodder and manure needed for obtaining optimal yields from the present area under settled agriculture restraining its further expansion. Use of chemical fertilizers can reduce dependence on manure but seems not practical partly because farmers consider the capacity of the present tank-based irrigation system too low to realize the potential benefits of fertilizers and partly because they have to stock this input due to uncertainty of its availability. Third, labour shortage arising from migration of rural people to urban areas favours maintenance of shifting agriculture characterized by low levels of labour inputs but high labour productivity. Fourth, availability of high-quality fuelwood from *Rhus parviflora* and *Murraya koeningii*, the dominant species of fallow vegetation, resolves the problem of shortage of fuelwood arising from timber-centred forest policies. Comparison of small holders/lower caste families and large holders/higher caste families (Table 1) suggests that the former tend to maximize food production by allocating higher proportions of available settled agricultural land to the highly productive HGS and RAS rather than by converting shifting to settled agriculture.

The input and output values at crop or agroecosystem level reported in the present study are within the range of values reported from the region (Singh et al. 1997; Rao et al. 2005b). Agricultural land-use diversity reflects farmer's ways of meeting their diverse needs, coping with the risks of climate arising from uncertainty of monsoon rainfall and of cultivating distant fields arising from huge labour and time spent in travel/transport. In settled agriculture, the lowest manure input to the RCS characterized by both climatic- and distance-related risks, medium level inputs to the RAS characterized by only climatic risk or the ICS by only distance-related risk and the highest input to the HGS devoid of the two risks (Table 2) suggests that farmers tend to apply more of inputs available in limited quantities to the perceived low risk agroecosystems as compared to the more risky ones (Carter and Murwira 1995). Further, farmers tend to reduce the risks to productivity by choosing crops/cultivars based on indigenous knowledge about their performance under varied ecological conditions. Cultivation of a range of local millet cultivars differing in respect of their performance under varied monsoon conditions is an indigenous strategy of coping with the climatic variability and uncertainty as also reported by Bardsley (2003). Fingermillet, barnyard millet and horsegram are always grown in rainfed conditions on residual soil fertility or with manure inputs substantially lower than those to maize and soybean (Maikhuri et al. 1996; Singh et al. 1997; Sherchan et al. 1999; Pilbeam et al. 2000) as farmers view the former crops less sensitive to climatic variability as well as soil moisture/nutrient stresses compared to the latter crops. This perception of farmers is partly supported by an insignificant difference in barnyard millet yields in the RAS and RCS differing in manure input rates and soil nutrient levels reported in this study and 17-fold variation in maize yield compared to 2-fold variation in fingermillet yield over a range of manure/fertilizer input rates in a given year and 2.1-fold variation in maize yield compared to 1.6-fold variation in fingermillet yield over a period of 8 years with no change in fertilizer/manure input rates (Sherchan et al. 1999). Further research is needed to validate farmers' perceptions about crop-environment relationships and their scientific rationale.

Local people view fingermillet and barnyard millet as less-delicious staple food compared to maize (Maikhuri et al. 1996) but grow them on a significant scale to cope with the unpredictability and variability of monsoon climate and nutrient stress in distant rainfed fields receiving lower quantities of farmyard manure. Conversion of rainfed to irrigated farming reduces the risks of climatic uncertainty and improves productivity (Bhatnagar et al. 1996; Maikhuri et al. 1997). However, changes in cropping patterns coupled with this conversion result in an increase in farmyard manure input, which may cause some loss of forest biodiversity and ecosystem services (Semwal et al. 2004). Conversion of rainfed to irrigated farming seems to be confined to a limited area in the present village landscape for two reasons. First, the procedures of drawing government grants for construction of irrigation tanks are so complex and grants available for the purpose so low that only a few households have been able to establish tanks.

Second, labour productivity/net economic returns from the tank-based ICS is lower than the other traditional land-uses like the HGS. Government support to canal-based irrigation systems innovated by local communities in other regions of the Indian Himalaya (Rao and Saxena 1994; Chandrasekhar et al. 2007) are likely to be more useful than that to the present tank-based irrigation system.

Replacement of traditional crops by altogether new cash crops as a means of economic development (Midmore et al. 1996; Semwal et al. 2004) is not visible in the study village possibly because farmers are likely to turn to modern inputs only when they have exhausted the potential of their traditional methods (Abdoulaye and Lowenberg-DeBoer 2000). Though farmers of the study area have been exposed to market economy since last couple of decades only, they have gained some understanding about the risks and uncertainties related to market prices/demands (Jodha 2000). They grow cash crops to an extent that there are no risks to local food security. Food self-sufficiency in the absence of any modern agricultural inputs under normal monsoon scenario observed in this study cannot be generalized too far in view of significant food shortage reported by others (Bohle and Adhikari 1998).

4.2 Soil fertility in relation to land-use

Soil organic carbon and nutrient concentrations in different land-uses in Bacchelikhal village landscape are within the range of values reported in other studies (Rao et al. 2005a). Irrigation coupled with high rates of manure input, low ratio of harvested biomass/standing biomass and a high tree density enabled a markedly higher level of organic C and nutrients in the HGS (Elias et al. 1998). Our results differ from those of Schreier et al. (1994) who observed soils of irrigated agroecosystems in Nepal Himalaya to be more depleted than those of rainfed agroecosystems and Singh et al. (1988) who observed agricultural soils to be more depleted than forest soils in Indian Himalaya. The RAS close to dwellings had higher soil organic C and nutrient levels compared to the RCS away from the dwellings, a trend also observed in other traditional rainfed farming systems (Murage et al. 2000; Tittonell et al. 2005).

Decline in soil fertility with progress of cropping phase in shifting agriculture reported here is a common trend (Ramakrishnan 1992; Juo and Manu 1996; Salcedo et al. 1997). A 7-year fallow period is too short to improve soil organic C and nutrient stocks except available P, as also observed by Sirios et al. (1998). Improvement in soil fertility after fire seems to stem from the release of minerals through ash, stimulation of activity of beneficial microbes and mulching effect of partially burnt slash (Andriesse and Schelhaas 1987). There is a need of evaluating the impact of fallowing on soil biological processes and concentration of available forms of nitrogen.

Frequent ground fire adopted by local people as a tool to improve quality and productivity of herbaceous fodder coupled with unregulated grazing may be attributed to lower soil organic C and nutrients in the RF compared to the CF. Disturbances of fire and grazing in the present RF are due to limited capacity of government agencies to protect these forests. If management plans are properly implemented, RFs have been found to be richer in soil fertility in comparison to CFs (Thadani and Ashton 1995). Contribution of species specific differences in organic matter partitioning and nutrient cycling patterns to the differences in soil chemical properties of the two forest types cannot be ruled out (Schmidt et al. 1993; Montagnini and Sancho 1994). A small sample size ($n = 15$), however, warrants generalizations of the conclusions related to spatial variability in soil fertility within highly heterogeneous mountain village landscapes.

Availability of litter and livestock feed from forests to produce farmyard manure is a form of environmental service to local inhabitants from natural forests. Coupled with this locally valued service are the globally valued environmental services from forests viz., recharge of springs, soil conservation and carbon sequestration. Excessive removal of litter from forest floor and over-grazing are likely to reduce these global benefits from the Himalayan forests (Rawat and Rawat 1994). Further research is needed to define precisely the nature and intensity of disturbances that do not pose any threat to both global and local benefits from forest ecosystems.

4.3 Vegetation

Extensive shifting agriculture, with cultivation cycles shorter than 10 years, may result in a severe loss of forest regeneration potential (Uhl 1987; de Rouw 1995). However, if shifting agriculture is a minor land-use interspersed with other tree-rich land-use/cover types, tree regeneration during fallow phase may be significant as reported in this study. Land-use variability brings in habitat heterogeneity resulting in a high level of biodiversity in village landscapes (Smeding and Joenjeb 1999; Iiyama et al. 2005). However, both shifting agriculture and forests in the present study area provide niche for an invasive alien species *Lantana camara* posing threats to indigenous biodiversity and ecosystem functions in future (Duggin and Gentle 1998). Basal area of trees in the present village landscape (20–43 m^2 ha^{-1}) is indeed substantially lower than the value of 72 m^2 ha^{-1} reported in well managed forests in comparable biophysical conditions (Singh et al. 1995).

Perceptions on traditional subsistence agriculture as a major threat to environmental degradation in the

Himalaya led to policies prohibiting cultivation of agricultural or horticultural crops in forest lands. Such policies did succeed in checking agricultural expansion at the cost of loss of forest area but not in enhancing functions of degraded forest lands. Higher species richness, basal area and soil organic C and nutrient stocks in the HGS compared to the CF suggest that policies allowing cultivation of cash crops on a limited scale in forest land will serve not only the economic interests of local people but will also conserve/restore globally significant biodiversity and ecosystem services (Wiersum 2004).

5 Conclusions

While the need of socio-economic development of local communities coupled with environmental conservation in the Himalaya is being increasingly realized, knowledge on ways and means of meeting this need is limited. This study suggests that (i) traditional HGS is economically the most efficient production system, with soil organic carbon and nutrient stocks significantly higher than other land-uses, (ii) farmers capitalize upon crop genetic diversity to cope with the environmental risks and uncertainties, (iii) farmers practise shifting agriculture system (SAS), a land-use adopted as a means of acquiring inheritable rights over larger land holdings provided in the policies during the 1890s, for its high labour productivity and availability of high-quality fuelwood from fallow vegetation, (iv) cultural norms favour integration of different socio-economic classes by discouraging hiring of labour for farming from outside the village and favouring economic benefits from marketing of non-timber forest products to the weaker section of the society, (v) dominance of fodder tree species in RAS derives from the policy interventions causing reduction in fodder available from forests, (vi) existing forest management systems are not effective in maintenance of a large basal area together with high levels of species richness, soil fertility and resistance to invasion by alien species, (vii) irrigation facilities supported by the government improves agricultural productivity, but also increases pressure on forests due to higher rates of farmyard manure input to irrigated crops and (viii) farmers have to spend huge amount of labour and time in producing manure, managing livestock and other subsidiary activities. Interlinkages among agriculture, forests and rural economy suggest a need of replacing the present policies of treating agricultural development, forest conservation and economic development as independent sectors by an integrated sustainable development policy. Such a policy should promote innovative technologies and institutional arrangements enabling improvement in traditional soil fertility management practices, maintenance of an ecologically sound agroforestry system on private farmlands, economic benefits to local people from sustainable utilization of forest resources and more productive utilization of human labour. Further studies are needed to improve the scientific knowledge required for developing sustainable development policies and programmes in the Himalayan region.

Acknowledgements We are grateful to the Director, G.B. Pant Institute of Himalayan Environment and Development for the facilities, to the CSIR, New Delhi and TSBF-CIAT, Nairobi for partial financial support and to the two anonymous reviewers for their comments/suggestions leading to improvement of the manuscript.

References

Abdoulaye T, Lowenberg-DeBoer J (2000) Intensification of Sahelian farming systems: evidence from Niger. Agric Sys 64:67–81
Allen SE (1974) Chemical analysis of ecological materials. Blackwell Scientific Publications, Oxford
Andriesse JP, Schelhaas RM (1987) A monitoring study of nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. III. The effects of land clearing through burning on fertility level. Agric Ecosyst Environ 19:311–332
Ashish M (1993) Decentralized management of natural resource in the U.P. Hills. Econ Polit Weekly XXVII:1793–1796
Baijukya FP, de Ridder N, Masuki KF, Giller KE (2005) Dynamics of banana-based farming systems in Bukoba district, Tanzania: changes in land-use, cropping and cattle keeping. Agric Ecosyst Environ 106:395–406
Bardsley D (2003) Risk allevation via in situ agrobiodiversity conservation: drawing from experience in Switzerland, Turkey and Nepal. Agric Ecosyst Environ 99:149–157
Bhatnagar PR, Srivastava RC, Bhatnagar VK (1996) Management of runoff in small tanks for transplanted rice production in the mid-hills of northwest Himalaya. Agric Water Manage 30:107–118
Bohle H, Adhikari J (1998) Rural livelihoods at risk. How Nepalese farmers cope with food insecurity. Mountain Res Dev 18:321–332
Briggs L, Twomlow SJ (2002) Organic material flows within a smallholder highland farming system of South West Uganda. Agric Ecosyst Environ 89:191–212
Cairns M, Garrity DP (1999) Improving shifting cultivation in Southeast Asia by building on indigenous fallow management strategies. Agroforest Syst 47:37–48
Carter SE, Murwira HK (1995) Spatial variability in soil fertility management and crop response in Mutoko communal area, Zimbabwe. Ambio 24:77–84
Chandrasekhar K, Rao KS, Maikhuri RK, Saxena KG (2007) Ecological implications of traditional livestock husbandry and associated land-use practices: A case study from the trans-Himalaya, India. J Arid Environ 69:299–314
Clermont-Dauphin C, Cabidoch YM, Meynard JM (2005) Diagnosis on the sustainability of an upland cropping system of southern Haiti. Agric Ecosyst Environ 105:221–234
de Rouw A (1995) The fallow period as a weed-break in shifting cultivation. Agric Ecosyst Environ 54:31–43
Desbiez A, Matthews R, Tripathi B, Ellis-Jones J (2004) Perceptions and assessment of soil fertility by farmers in the mid-hills of Nepal. Agric Ecosyst Environ 103:191–206

Duggin JA, Gentle CB (1998) Experimental evidence of the importance of disturbance intensity for invasion of *Lantana camara* L. in dry rain forest-open forest ecotones in north-eastern NSW, Australia. For Ecol Manage 109:279–292

Elias E, Morse S, Belshaw DGR (1998) Nitrogen and phosphorus balances of Kindo Koisha farms in southern Ethiopia. Agric Ecosyst Environ 71:93–113

Ghersa CM, Ferraro DO, Omacini M, Martinez-Ghersa MA, Perelman S, Satorre EH, Soriano A (2002) Farm and landscape level variables as indicators of sustainable land-use in the Argentine Inland-Pampa. Agric Ecosyst Environ 93:279–293

Gilmour DA, Nurse MC (1991) Farmer initiatives in increasing tree cover in central Nepal. Mountain Res Dev 11:329–337

Hrabovzsky J, Miyan K (1987) Population growth and land use in Himalaya. Mountain Res Dev 7:264–270

Hurni H (1999) Sustainable management of natural resources in African and Asian mountains. Ambio 28:382–389

Iiyama N, Kamada M, Nakagoshi N (2005) Ecological and social evaluation of landscape in a rural area with terraced paddies in southwestern Japan. Land Urban Plan 70:301–313

Ives JD, Messerli B (1989) The Himalayan dilemma: reconciling development and conservation. Routledge, London

Jodha NS (2000) Globalisation and fragile mountain environments: Policy challenges and choices. Mountain Res Dev 20:296–299

Juo ASR, Manu A (1996) Chemical dynamics in slash and burn agriculture. Agric Ecosyst Environ 58:49–60

Kessler JJ (1994) Usefulness of human carrying capacity concept in assessing ecological sustainability of land-use in semiarid regions. Agric Ecosyst Environ 48:273–284

Maikhuri RK, Rao KS, Saxena KG (1996) Traditional crop diversity for sustainable development of Central Himalayan agroecosystems. Int J Sust Dev World Ecol 3:8–31

Maikhuri RK, Semwal RL, Rao KS, Saxena KG (1997) Rehabilitation of degraded community lands for sustainable development in Himalaya: a case study in Garhwal Himalaya, India. Int J Sust Dev World Ecol 4:192–203

Maikhuri RK, Nautiyal S, Rao KS, Chandrasekhar K, Gavali R, Saxena KG (2000) Analysis and resolution of protected area-people conflicts in Nanda Devi Biosphere Reserve. Environ Conserv 27:43–53

Midmore DJ, Jansen HGP, Dumsday RG (1996) Soil erosion and environmental impact of vegetable production in Cameron Highlands, Malaysia. Agric Ecosyst Environ 60:29–46

Mitchell R (1979) The analysis of Indian agro-ecosystems, Inter print, New Delhi, India

Montagnini F, Sancho F (1994) Net nitrogen mineralization in soils under six indigenous tree species, an abandoned pasture and a secondary forest in the Atlantic lowlands of Costa Rica. Plant Soil 162:117–124

Murage EW, Karanja NK, Smithson PC, Woomer PL (2000) Diagnostic indicators of soil quality in productive and non-productive smallholders' fields of Kenya's Highlands. Agric Ecosyst Environ 79:1–8

Narain P, Singh RK, Sindhwal NS, Joshie P (1997) Agroforestry for soil and water conservation in the western Himalayan valley region of India. 1. Runoff, soil and nutrient losses. Agroforest Syst 39:175–189

Nautiyal S, Maikhuri RK, Semwal RL, Rao KS, Saxena KG (1998) Agroforestry systems in the rural landscape—a case study in Garhwal Himalaya, India. Agroforest Syst 41:151–165

Negi AK, Bhatt BP, Todaria NP, Saklani A (1997) The effect of colonialism on forests and the local people in the Garhwal Himalaya, India. Mountain Res Dev 17:159–168

Neher D (1992) Ecological sustainability in agricultural systems: Definitions and measurements. J Sustain Agric 2:51–61

Pilbeam CJ, Tripathi BP, Sherchan DP, Gregory PJ, Gaunt J (2000) Nitrogen balances for households in the mid-hills of Nepal. Agric Ecosyst Environ 79:61–72

Plieninger T, Wilbrand C (2001) Land-use, biodiversity conservation, and rural development in the dehesas of Cuatro Lugares, Spain. Agroforest Syst 51:23–34

Poudel DD, Midmore DJ, West LT (2000) Farmer participatory research to minimize soil erosion on steepland vegetable systems in the Philippines. Agric Ecosyst Environ 79:113–127

Ramakrishnan PS (1992) Shifting agriculture and sustainable development—an inter-disciplinary approach from north-eastern Himalayas. UNESCO and Parthenon Publishing Group, UK

Rao KS, Saxena KG (1994) Sustainable development and rehabilitation of degraded village lands in Himalaya. Bishen Singh Mahendra Pal Singh, Dehradun, India

Rao KS, Saxena KG (1996) Minor forest products' management—problems and prospects in remote high altitude villages of Central Himalaya. Int J Sust Dev World Ecol 3:60–70

Rao KS, Semwal RL, Maikhuri RK, Nautiyal S, Sen KK, Singh K, Chandrasekhar K, Saxena KG (2003) Indigenous ecological knowledge, biodiversity and sustainable development in the central Himalayas. Trop Ecol 44:93–111

Rao KS, Maikhuri RK, Sen KK, Semwal RL, Singh K, Das AK, Saxena KG (2005a) Soil fertility management in settled farming systems of Himalaya. In: Ramakrishnan PS, Saxena KG, Swift MJ, Rao KS, Maikhuri RK (eds) Soil biodiversity, ecological processes and landscape management. Oxford & IBH, New Delhi, pp 243–276

Rao KS, Nautiyal S, Maikhuri RK, Saxena KG (2005b) Resource flows of villages with contrasting lifestyles in Nanda Devi Biosphere Reserve, Central Himalaya, India. J Mountain Sci 2:271–293

Rawat AS (1994) Deforestation and forest policy in the lesser-Himalayan Kumaun: impacts on peasant women and tribal populations. Mountain Res Dev 15:311–322

Rawat JS, Rawat MS (1994) Accelerated erosion and denudation in the Nana Kosi watershed, Central Himalaya, India. Part I. Sediment load. Mountain Res Dev 14:25–38

Salcedo IH, Tiessen H, Sampaio EVSB (1997) Nutrient availability in soil samples from shifting cultivation sites in the semi-arid Caatinga of NE Brazil. Agric Ecosyst Environ 65:177–186

Saxena KG, Rao KS, Purohit AN (1993) Sustainable forestry—prospects in India. J Sust For 1:69–95

Schmidt MG, Screier H, Shah PB (1993) Factors affecting the nutrient status of forest sites in a mountain watershed in Nepal. J Soil Sci 44:417–425

Schreier H, Shah PB, Lavkulich LM, Brown SP (1994) Maintaining soil fertility under increasing land-use pressure in the middle mountains of Nepal. Soil Use Manage 10:137–142

Semwal RL, Maikhuri RK, Rao KS, Singh K, Saxena KG (2002) Crop productivity under differently lopped canopies of multipurpose trees in Central Himalaya, India. Agroforest Syst 56:57–63

Semwal RL, Nautiyal S, Sen KK, Rana U, Maikhuri RK, Rao KS, Saxena KG (2004) Patterns and ecological implications of agricultural land-use changes: a case study from central Himalaya, India. Agric Ecosyst Environ 102:81–92

Sharma S, Sharma E (1993) Energy budget and efficiency of some cropping systems in Sikkim Himalaya. J Sust Agric 3:85–94

Sherchan DP, Pilbeam CJ, Gregory PJ (1999) Response of wheat-rice and maize/millet systems to fertilizer and manure applications in the mid-hills of Nepal. Exp Agric 35:1–13

Singh A, Reddy VS, Singh JS (1995) Analysis of woody vegetation of Corbett National Park, India. Vegetatio 120:69–79

Singh GS, Rao KS, Saxena KG (1997) Energy and economic efficiency of the mountain farming system: a case study in the north-western Himalaya. J Sust Agric 9:25–49

Singh JS, Singh SP (1992) Forests of Himalaya: structure, functioning and impact of man. Gyanodaya Prakashan, Nainital, India

Singh SP, Mer GS, Ralhan PK (1988) Carbon balance for a central Himalayan crop field soil. Pedobiologia 32:187–191

Sirios ML, Margolis HA, Camire C (1998) Influence of remnant trees on nutrients and fodder biomass in slash and burn agroecosystems in Guinea. Agroforest Syst 40:227–246

Smeding FW, Joenjeb W (1999) Farm-nature plan: landscape ecology based farm planning. Land Urban Plan 46:109–115

Snedecor GW, Cochran WG (1967) Statistical methods. Oxford & IBH Publishing Company, New Delhi, India

Thadani R, Ashton PMS (1995) Regeneration of banj oak (*Quercus leucotrichophora* A. Camus) in the central Himalaya. For Ecol Manage 78:217–224

Tittonell P, Vanlauwe B, Leffelaar PA, Shepherd KD, Giller KE (2005) Exploring diversity in soil fertility management of smallholder farms in western Kenya. II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. Agric Ecosyst Environ 110:166–184

Uhl C (1987) Factors controlling succession in a slash and burn agriculture. J Ecol 75:377–407

Wiersum KF (2004) Forest gardens as an 'intermediate' land-use system in the nature-culture continuum: characteristics and future potential. Agroforest Syst 61:123–134

Zhang Q-J, Fu B-J, Chen L-D, Zhao W-W, Yang Q-K, Liu G-B, Gulinck H (2004) Dynamics and driving factors of agricultural landscape in the semiarid hilly area of the Loess Plateau, China. Agric Ecosyst Environ 103:535–543