5

Changes in agricultural biodiversity: Implications for sustainable livelihood in the Himalaya

K.G. Saxena[a], R.K. Maikhuri[b] and K.S. Rao[c]
[a]*School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India*
[b]*G.B. Pant Institute of Himalayan Environment and Development, Garhwal Unit, P.Box 92, Srinagar 246174, India*
[c]*Centre for Inter-disciplinary Studies of Mountain and Hill Environment, University of Delhi, South Campus, Benito Juarez Road, New Delhi 110 021, India*

Introduction

Himalayan mountain system covers partly/fully eight countries of south Asia viz., Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. Broadly, two distinct farming regions could be identified in the Indian Himalaya: northeastern region dominated by traditional shifting agriculture and the remaining area by settled farming on terraced slopes. Agriculture is a minor land use (covering <10% of total geographical area) but is highly significant from the point of its impacts on biodiversity, ecosystem processes and livelihoods. The changes in traditional agrobiodiversity in settled farming region, driving factors and implications of these changes are discussed in this article.

Traditional settled farming system

The landscape

Agricultural land use on terraced slopes is dispersed as patches in the matrix of forests. Cropping systems are built around two seasons, the rainy season and the winter season. Agroecosystems are characterized by: (a) cultivation of three crops in two years at lower altitudes and one crop in a year at higher altitudes; (b) a high level of crop diversity adapted to environmental heterogeneity and climatic uncertainty (Figure 1) (c) community decision on fallowing (a village is divided into two halves termed as Sar, each household owns at least one plot in each Sar, and a Sar is fallowed during one winter-crop season over a period of two years) but independent household decisions on choice of crop and management practices; (d) protection of naturally regenerating multipurpose trees and grasses on terrace margins (e) use of organic manure derived from livestock excreta mixed with forest leaf litter; (e) exchange of seeds without any monetary considerations.

Crop diversity and productivity

Even though holdings are small (average < 1 ha), number of crops cultivated by a household may vary from 17 to 30 (Sharma and Sharma, 1993; Rao and Saxena, 1994; Maikhuri et al., 2000a; Sen et al., 2002). Mixing of three species of buckwheat and six of pulses is the most diverse crop system reported from the region (Singh et al., 1997). High crop diversity is achieved through rotation of pure crops in space and time and through mixed crop systems. Except for paddy, local cultivars of a given crop are randomly mixed. Crop diversification is traditionally valued for securing survival in isolated settlements in a highly variable and uncertain biophysical environment. High levels of crop yields (e.g., 6.5 t of wheat and 14 t of potato ha^{-1}) and food sufficiency in many villages insulated from external forces due to extreme inaccessibility (Chandrasekhar, 2003; Semwal et al., 2003a) testify the potential of indigenous knowledge.

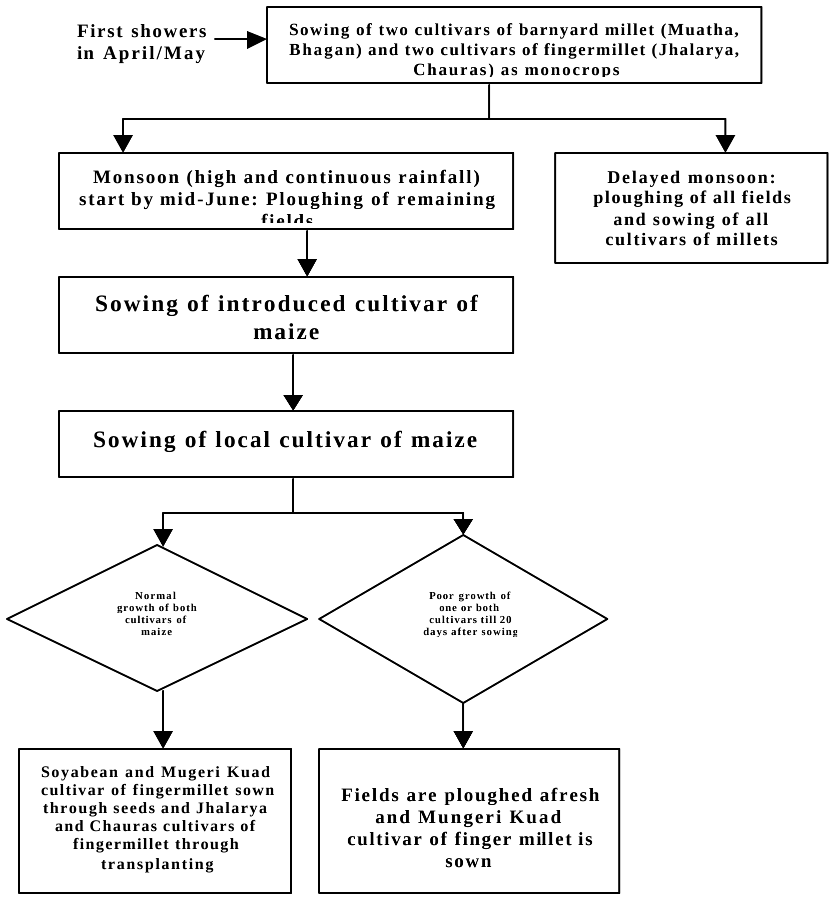

Figure 1. Cropping pattern as determined by climatic conditions in a mid altitude village (based on Singh, 2002)

Traditional perceptions related to agroforestry trees

Farmers view yield decreasing effects of trees on understory annual crops (shade stress and competition for belowground resources) to outweigh the yield increasing effects (nutrient enrichment). They consider proper terracing, drainage, manuring and protection of forest cover around farmland to be more crucial than the potential of farm trees in achieving agroecosystem sustainability (Maikhuri et al., 1997; Nautiyal et al., 1998). They value farm trees for availability of fodder, fuelwood and other products near homesteads when harsh weather or labor scarcity delimits access to forests. Tree density is reported in the range of 182 to 419 trees ha^{-1} and species richness in the range of 8 to 90 species (Toky et al., 1989; Sundriyal et al., 1994; Thapa et al., 1995; Nautiyal et al., 1998). People value *Boehmeria rugulosa*, *Ficus glomerata* and *Ficus roxburghii* as the best fodder species, *Albizzia lebbek* and *Dalbergia sissoo* as the best timber species, and *Alnus nepalensis* as a medium quality fuelwood and timber species. Tree species also differ in terms of litter quality and nutrient enrichment capacities (Semwal et al., 2003b) which are not clearly understood by local people.

Dependency of agriculture on forests

Because of smallholdings, farm trees meet only a small fraction of local biomass needs. Forests provide a significant amount of fodder needed to sustain livestock and leaf litter to produce farmyard manure. To sustain productivity of each ha of cropland, 2-15 ha of forest area might be required (Singh et al., 1984; Hrabvozsky and Miyan, 1987). Litter removal and lopping reduce inputs to forest floor but may favor regeneration of some species. Amount, timing and frequency of litter removal and lopping that would meet agroecosystem requirements without any adverse impact on forest health have not been worked out.

Changes in traditional practices, driving factors and implications

New agroecosystems - shifting agriculture by traditional settled farmers

This land use by a traditionally settled agriculture oriented society in isolated pockets has come up in recent times as a result of: (a) neglect of people's needs in forest management favored by the government (b) ineffective enforcement of policy of restriction on agriculture in forestland (c) higher profitability and labor productivity of *Phaseolus radiatus* and *Glycine max* in slash-burn environments compared to that in traditional settled agriculture (Nautiyal et al., 1998). This system enables profits in the short-term but is not likely to be sustainable in the long-run.

Replacement/abandonment of traditional crops

Spatial extent and cropping intensity in settled farms have not changed as drastically as crop diversity. Crops like *Echinochloa frumentacea, Glycine max, Setaria italica, Panicum miliaceoum,* *Hordeum himalyens, Fagopyrum tataricum* and *Fagopyrum botrydis* have been abandoned or their area drastically reduced due to increasing emphasis on cash crops like *Solanum tuberosum* and *Phaseolus* spp. (Table 1). Unlike some other areas where policies promoted cash crops (Ives and He, 1996; Preston, 1998; Renaud et al., 1998), expansion of cash crops in Himalaya seems to be an indigenous initiative driven by a socio-cultural change from subsistence to market economy, comparative ecological advantages for these crops in hills, changing food habits and supply of food grains at subsidized price by government (Semwal et al., 2003a).

Farmers substantially benefited economically by expanding cash crops but at the cost of increased vulnerability to climatic and market uncertainties. Middlemen in the marketing channel exploit marginal farmers. Abandonment of traditional crops/cultivars means a loss of agrobiodiversity that remains 'lesser known' or 'unknown' to wider communities. Differing from this widely encountered trend, there are a few isolated pockets where a change from subsistence to market economy progressed without any significant loss of crop diversity (Singh et al., 1997). Expansion of potato, whose by-products do not have any fodder value, implies lesser production of fodder from private farmland. Soil loss from potato is 6-8 times higher than that from the traditional crops it has replaced (Table 2) despite of a much higher manure input (Sen et al., 1997; 2002). Reduction in fodder yield from farmland and application of larger quantities of manure in the changed scenario (Table 3) implies more threats to forests arising from intensive litter removal and lopping. Plant breeders have developed high yielding varieties of selected crops viz., paddy, wheat and maize, but their adoption has been limited because they are poorly adapted to environmental variability, they require external inputs not accessible to majority of farmers and they yield lower quantities of fodder (Singh et al., 1997).

Domestication of new crops

In a few high altitude (> 1300 m) villages, farmers' innovations led to cultivation of several medicinal species (Table 1) which used to be harvested from the wild (Maikhuri et al., 2000a; Nautiyal et al., 2001). As these species are threatened, their cultivation contributes to conservation of wild biodiversity. Because of strong aroma, they are not as much depredated by wildlife as are food crops (Rao et al.,

Table 1. Area (% of total cropped area), change in area during 1970-75 and 95 period and monetary value of yield (mean ± SE) of different crops in villages near and away from the core zone of the Nanda Devi Biosphere Reserve, India. Values for any variable with different superscript letters are significantly different ($P<0.05$) within rows.

Crops	Near core zone and low altitude			Away from core zone and high altitude		
	% of total cropped area in 1995 (n = 117) (%)	Increased (+) decreased (-) /no change (o) of total cropped area between 1970 - 75 and 1995 (n = 46) (%)	Monetary Value (n=10) (US$/ha)	% of total cropped area in 1995 (n = 117) (%)	Increased (+) decreased (-) /no change (o) of total cropped area between 1970 - 75 and 1995 (n = 17) (%)	Monetary Value (n=10) (US$/ha)
Food crops						
Monocropping						
Amaranthus paniculatus	4.4	+36	289±31	-	0	-
Brassica campestris	0.6[a]	0	519±37[a]	3.1[b]	-	494±34[a]
Echinochloa frumentocea	0	-100	-	0	0	-
Eleusine coracana	0.6	-10	311±28	-	0	-
Fagopyrum esculentum	7.7[a]	0	337±21[a]	16.3[b]	-30	503±27[b]
Fagopyrum tataricum	8.2[a]	-19[a]	343±30[a]	2.3[b]	-76[b]	474±28[b]
Glycine max	0	-100	-	0	0	-

Hordeum himalayens	5.6^{a}	-41^{a}	235 ± 27^{a}	8.1^{a}	-60^{b}	239 ± 15^{a}
Hordeum vulgare	4.0	-28^{a}	247 ± 24	0	-100^{b}	-
Pennisetum typhoides	0	-100	-	0	0	-
Panicum miliaceum	0.6^{a}	-82^{a}	268 ± 27^{a}	2.5^{b}	-79^{a}	310 ± 27^{a}
Phaseolus lunetus	14.6^{a}	$+43^{a}$	549 ± 62^{a}	8.6^{b}	$+68^{a}$	626 ± 63^{a}
Phaseolus vulgaris	6.0^{a}	$+40^{a}$	906 ± 27^{a}	8.9^{a}	$+143^{b}$	969 ± 82^{a}
Pisum sativum (Var.1)	0.3	+25	485 ± 49	0	0	-
Pisum sativum (Var.2)	0.3^{a}	-28^{a}	547 ± 55^{a}	2.3^{b}	-50b	647 ± 44^{a}
Solanum tuberosum	6.6^{a}	$+97^{a}$	805 ± 81^{a}	31.3^{b}	$+650^{b}$	1048 ± 28^{b}
Setaria italica	0	-100	-	0	0	-
Triticum aestivum	21.3	+13	265 ± 29	0	-	-
Mixed cropping						
A.paniculatius +P.vulgaris	3.4	-	842 ± 92	-	-	-
H.himalayens+Pisum sativum (Var.2)	-	-	-	4.8	-	511 ± 27
S.tuberosum + P.vulgaris	10.1^{a}	-	1133 ± 115^{a}	7.1^{b}	-	1505 ± 68^{b}
S.tuberasum + P.vulgaris+ A.paniculatus	4.0	-	1151 ± 75	-	-	-
Medicinal plants						
Allium humile	0.9^{a}	-7^{a}	846 ± 79^{a}	2.3^{b}	-7^{a}	945 ± 87^{a}
Allium stracheyi	0.9^{a}	-6^{a}	502 ± 48^{a}	1.2^{a}	-13^{a}	560 ± 87^{a}
Angelica glavacai	-	-	-	0.3	+100	544 ± 57

Carum carvi	-	-	-	0.3	+100	971$\pm$85
Dactylorhiza hatagirea	-	-	-	0.2	+100	786$\pm$80
Megacarpaea polyandra	-	-	-	0.2	+100	272$\pm$19
Pleurosperum angelicoides	-	-	-	0.2	+100	627$\pm$60
Saussurea costus	-	-	-	0.3	+100	690$\pm$68

*Var.1 and Var.2 are the two local varieties of *Pisum sativum*, locally called Mitha Matar and Kong Matar, respectively (after Maikhuri et al., 2000b).

2002). Medicinal species require lesser quantities of manure (Nautiyal et al., 2001) which implies lower intensity of litter removal from forests. At lower altitudes (500-1500 m), a few farmers have started cultivating Cleome viscosa (Maikhuri et al., 2000b). However, these changes falling in line with the goals of environmental conservation are highly localized partly because of low productivity from indigenous cultivation techniques, small holdings and marketing problems.

Table 2. Soil loss from different crops grown on varied terrace slopes in the Pranmati watershed, Indian central Himalya (partly based on Sen et al., 1997).

Crops	Soil loss from terrace slope (t ha^{-1} yr^{-1})					
	Low(<2^0)		Medium (2^0-6^0)		High (6^0-10^0)	
	1993	1994	1993	1994	1993	1994
Eleusine coracana	0.658	0.089	1.199	0.386	6.037	0.525
Amaranthus paniculatus	0.517	0.372	1.462	0.437	3.435	1.475
Echinocloa frumentacea	0.536	0.093	1.213	0.310	7.578	0.652
Oryza sativa	0.300	0.334	2.950	0.429	8.122	1.050
Solanum tuberosum	0.606	0.327	7.653	1.812	4.400	3.758

Table 3. Farmyard manure (FYM) input (t/ha/year), fodder yield (t ha^{-1} $year^{-1}$) and monetary return (Thousand Rs ha^{-1}: Rs. 34 = US$ 1 in 1994-95) across elevation zones in Pranmati watershed, India. (based on Sen et al., 2002).

FYM/fodder	1100-1800 m		1800-2400 m		2400-2600 m	
	1963	1993	1963	1993	1963	1993
Manure input	15.0	16.5	18.3	27.4	16.8	32.4
Fodder yield	5.0	4.3	3.3	2.1	1.5	0.2
Monetary return	21.3	34.2	27.9	52.5	36.8	77.3

Abandonment/expansion of agricultural land use

In some villages, there has been a large-scale outmigration leading to abandonment of agricultural land use. Slow natural regeneration in abandoned land is expected to cause severe site degradation. On a regional scale, however, rate of agricultural expansion exceeds the rate of abandonment (Rao and Pant, 2001).

Livestock population

Increase in livestock population and changes in composition of livestock popualation are a common trend (Sharma and Shaw, 1993; Mishra, 1997). A change from preference of joint to nuclear families but, persistence of traditions of maintaining self-sufficiency at household level in respect of cattle and of considering sheep/goat/ mule husbandry as occupation of lower castes seem to have contributed to higher rate of increase in cattle population (Sen et al., 2002). Increase in livestock population but reduction in fodder production from farmland with changing cropping patterns implies more intensive grazing in forests. New livestock husbandry practices has been promoted by the government by giving subsidy for poultry, rabbits yielding high quality wool, buffaloes and cross-breeds of sheep/goats) but have not been adopted widely because they are not adapted to mountain terrain and locally available feed, and are inappropriate for production of traditional farmyard manure.

Loss/replacement of traditional multipurpose trees

The diversity of traditional multipurpose tree community has been decimated because of promotion of apple plantation in the western Himalaya (Singh et al., 1997) and plantation of *Alnus nepalensis* and *Albizia stipulata* in the eastern Himalaya during last 50 years (Rai, 1995). While there are huge direct economic benefits from apple trees, *Alnus* and *Albizia* provide a better microenvironment to cardamom. Fodder available from pruning of these trees does not compensate reduction in production of palatable crop by-products caused by tree canopy. Manure is applied in larger quantities to apple based systems as compared to the traditional multipurpose tree based ones. Such changes have increased dependency of farming on forests and hence more threats to forest biodiversity and ecosystem functions. In order to promote apple based economy, government granted price concessions on extraction of forest wood to be used for packing farm products for marketing, further compounding pressure on forests (Singh et al., 1997).

Improvement in traditional agriculture and rehabilitation of degraded lands

Upland agriculture was seemingly sustainable till population pressure was low and ultimate goal of agriculture was to achieve local production based food security. With integration of mountain societies with the mainstream market, the management goal has been shifting more and more towards profit maximization. The overall outcome of this change is visible in terms of land degradation and decimation of both domesticated and wild biodiversity. Selected interventions enabling improvement in agricultural productivity together with recuperation of biodiversity and ecosystem function are summarized in this section.

Mulching and manuring

Quality of manure derived from oak forests is of better than that from pine forests (Rao et al., 2003). It has been observed that crops treated with oak manure give higher yields compared to those treated with pine manure (Table 4). Rejuvenation of oak forests in degraded lands will thus not only improve forest biodiversity and ecosystem function but also agricultural productivity.

Table 4. Biomass production (mean _ SD, g m^{-2}) of wheat crop on a sandy soil treated with oak based and pine based manure (@ 10 t ha^{-1}). Two treatments are significantly ($P<0.05$) different for all parameters (based on Rao et al., 2003).

Component	Manure type	
	Oak based	Pine based
Grain	58.5 ± 3.8	46.7 ±2.7
Straw	108.8 ± 12.1	81.7 ± 5.6
Roots	8.5 ± 0.6	7.3 ± 0.1
Total	175.8 ± 11.6	135.7 ±9.8

Lopping

Farmers usually lop all branches of farm trees during winter season because green fodder and fuel wood are scarce in forests at this time of the year. An insignificant difference in yields between 75% and full lopping (100%) treatments observed by us (Semwal et al., 2002) suggest that there will be no loss of crop yields if 25% of branches are retained (Figure 2). Such a practice might also improve biodiversity, tree vigor and soil fertility in traditional agroecosystems.

Agroforestry on degraded lands

Out of the 59 million ha total geographical area of the Indian

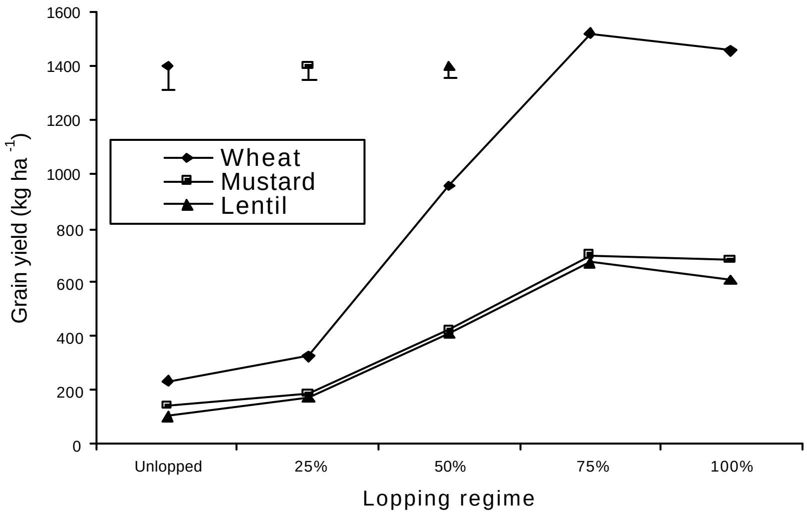

Figure 2. Yield of winter season crops grown under unlopped, 25, 50, 75 and 100% lopping of agroforestry trees in village Banswara, India. LSD (*P*=0.05) between means of a crop grown under different lopping regimes are given as vertical lines (Based on Semwal et al., 2002)

Himalayas, 21 million ha are degraded lands. As traditional farm holdings are small, agroforestry in such lands could be a viable option for land rehabilitation. External support is required for successful rehabilitation because of limited scope of indigenous capacity to identify and implement appropriate technologies and also because rehabilitation is a costly and risky proposition. Sustainable rehabilitation would mean addressing people's needs and ecological restoration of degraded ecosystems such that threats to the left-over intact forests are also reduced. People are more concerned for immediate tangible benefits from rehabilitation than about intangible benefits (soil conservation, hydrological balance, carbon sequestration and biodiversity conservation), the prime national and global concern. Hence, people show callous or negative attitudes to programs that aim for merely increasing the forest cover. Local economic development concern can be integrated with global environmental conservation concern by making people aware of weaknesses of indigenous practices and the scope of overcoming them with scientific and institutional inputs. An appreciation of positive dimensions of indigenous knowledge and practices can drastically reduce rehabilitation cost.

Huge variation in environmental and socio-economic features in the mountains demands location specific rehabilitation packages, e.g., tree-bamboo-medicinal plant based agroforestry will be more appropriate for higher altitudes and annual food crop-tree based system including a water management component at lower altitudes (Maikhuri et al., 1997; Rao et al., 1999). Such approaches, apart from delivering direct economic benefits to local people, enhance biodiversity and ecosystem function such as carbon sequestration (Table 5) within as well as outside treated ecosystems. The investment is recovered over a period of 7 years. The availability of fodder, medicinal plants and bamboo from the rehabilitated site close to the dwellings on one hand saves time and energy spent in collecting these products from distant forests and reduces threats to forest conservation on the other (Rao et al. 1999).

Table 5. Carbon sequestration rate (t ha^{-1} yr^{-1}) in soil and vegetation after rehabilitation in a low altitude village (Banswara, Chamoli) and a high altitude village (Khaljhuni, Almora) villages in Indian Central Himalaya (based on Maikhuri et al., 2000c and Rao et al., 1999).

Characteristic	Carbon sequestration	
	Banswara	Khaljhuni
Soil (0-15 cm)	2.2	3.4
Tree bole/bamboo culm	0.9	4.3
Total	3.1	7.7

Conclusions

With increasing emphasis on market economy and 'maximization of profit' motive, agrobiodiversity and agroecosystem management have changed such that there has been a significant decline in both domesticated and wild biodiversity. Such changes have benefited local people in economic terms but at the same time increased their vulnerability to environmental and economic risks. Indigenous innovations such as cultivation of medicinal plants and traditional practices to cope up with the variability and uncertainty in biophysical environment point towards a scope of building on indigenous practices to cope with the emerging global challenges.

Acknowledgements

We are grateful to the Director, G. B. Pant Institute of Himalaya Environment and Development for the facilities and to the Director, TSBF Institute of CIAT for partial financial support. Views expressed here are of the authors and not of the organisations they are affiliated to or funding agencies.

References

Chandrasekhar, K. 2003. Ecological Analysis of Settled Agropastoral Farming in Cold Desert (Spiti Catchment, Himachal Pradesh). Ph.D. Thesis, Jawaharlal Nehru University, New Delhi, India.

Hrabovzsky, J. and Miyan, K. 1987. Population growth and land use in Himalaya. Mountain Research and Development 7: 264-270.

Ives, J. D. and He, Y., 1996: Environmental and cultural change in the Yulong Xue Shan, Lijiang District, N W Yunnan, China. In, Rerkassem, B. (Ed.), Montane Mainland South East Asia in Transition. Chiang Mai University, Chiang Mai, Thailand, pp. 1-16.

Maikhuri, R.K., Nautiyal, S., Rao, K.S., Chandrasekhar, K., Gavali, R. and Saxena, K.G. 2000a. Analysis and resolution of protected area - people conflicts in Nanda Devi Biosphere Reserve, India. Environmental Conservation 27: 43-53.

Maikhuri, R.K., Semwal, R.L., Rao, K.S. and Saxena, K.G. 1997. Rehabilitation of degraded community lands for sustainable development in Himalaya: a case study in Garhwal Himalaya, India. International Journal of Sustainable Development and World Ecology 4: 192-203.

Maikhuri, R.K., Semwal, R.L., Rao, K.S., Nautiyal, S. and Saxena, K.G. 2000b. Cleome Viscosa Capparidaceae: a weed or a cash crop? Economic Botany 54: 150-154.

Maikhuri, R.K., Semwal, R.L., Rao, K.S., Singh, K. and Saxena, K.G. 2000c. Growth and ecological impacts of traditional agroforestry tree species in central Himalaya, India.

Agroforestry Systems 48: 257-272.

Mishra, C., 1997: Livestock depredation by large carnivores in the Indian trans-Himalaya: conflict perceptions and conservation prospects. Environmental Conservation 24: 338-343.

Nautiyal, S. Maikhuri, R.K., Semwal, R.L., Rao, K.S. and Saxena, K.G. 1998. Agroforestry systems in the rural landscape - a case study in Garhwal Himalaya, India. Agroforestry Systems 41: 151-165.

Nautiyal, S., Maikhuri, R.K., Rao, K.S. and Saxena, K.G. 2001. Medicinal plant resources in Nanda Devi Biosphere Reserve in the central Himalaya. Journal of Herbs, Spices and Medicinal Plants 8: 47-64.

Preston, D. 1998. Post-peasant capitalist graziers: the 21st century in southern Bolivia. Mountain Research and Development 18: 151-158.

Rai, S.C. 1995. Land use options in Sikkim Himalaya: an analysis from the Mamlay Watershed in South District. Journal of Sustainable Agriculture 6: 63-79.

Rao, K.S. and Pant, Rekha. 2001. Land use dynamics and landscape change pattern in a typical micro watershed in the mid elevation zone of central Himalaya, India. Agriculture, Ecosystems and Environment 86: 113-124.

Rao, K.S., Maikhuri, R.K, Nautiyal, S. and Saxena, K.G. 2002. Crop damage and livestock depredation by wildlife: a case study from Nanda Devi Biosphere Reserve, India. Journal of Environmental Management 66: 317-327.

Rao, K.S., Maikhuri, R.K. and Saxena, K.G. 1999. Participatory approach to rehabilitation of degraded forest lands: a case study in high altitude village of Indian Himalaya. International Tree Crops Journal 10: 1-17.

Rao, K.S. and Saxena, K.G. 1994. Sustainable Development and Rehabilitation of Degraded Village Lands in Himalaya. Bishen Singh Mahendra Pal Singh, Dehradun, India.

Rao, K.S., Semwal, R.L., Maikhuri, R.K., Nautiyal, S., Sen, K.K., Singh, K., Chandrasekhar, K. and Saxena, K.G. 2003. Indigenous ecological knowledge, biodiversity and sustainable development in the central Himalayas. Tropical Ecology 44, 93-111.

Renaud, F., Bechstedt, H.D. and Udomachai, N., 1998: Farming system and soil conservation practices in a study area of northern Thailand. Mountain Research and Development 18: 345-356.

Semwal, R.L., Maikhuri, R.K., Rao, K.S., Singh, K. and Saxena, K.G. 2002. Crop productivity under differentially lopped canopies of multipurpose trees in central Himalaya, India. Agroforestry Systems 56: 57-63.

Semwal, R.L., Maikhuri, R.K., Rao, K.S., Sen, K.K. and Saxena, K.G. 2003. Leaf litter decomposition and nutrient release patterns of six multipurpose tree species of central Himalaya, India. Biomass and Bioenergy 24, 3-11.

Semwal, R.L., Nautiyal, S, Sen, K.K., Rana, U., Maikhuri, R.K., Rao, K.S. and Saxena, K.G. 2004. Patterns and ecological implications of agricultural land-use changes: a case study from central Himalaya, India. Agriculture, Ecosystems & Environment 102: 81-92.

Sen, K.K., Rao, K.S. and Saxena, K.G. 1997. Soil erosion due to settled upland farming in Himalaya: a case study in Pranmati. International Journal of Sustainable Development and World Ecology 4: 65-74.

Sen, K.K., Semwal, R.L., Rana, U., Nautiyal, S., Maikhuri, R.K., Rao, K.S. and Saxena, K.G. 2002. Patterns and implications of land-use/cover change: a case study in Pranmati watershed (Garhwal Himalaya, India). Mountain Research and Development 22: 56-62.

Sharma, S. and Sharma, E. 1993. Energy budget and efficiency of some cropping systems in Sikkim Himalaya. Journal of Sustainable Agriculture 3: 85-94.

Sharma, U.R. and Shaw, W.W., 1993: Role of NepalÆs Royal Chitwan National Park in meeting the grazing and fodder needs of local people. Environmental Conservation 20: 139-142.

Singh, G.S., Rao, K.S. and Saxena, K.G. 1997. Energy and economic efficiency of the mountain farming system: a case study in the north-western Himalaya. Journal of Sustainable Agriculture 9: 25-49.

Singh, J. S., Pandey, U. and Tiwari, A. K. 1984. Man and forests: a central Himalayan case study. Ambio 13: 80-87.

Singh, K. 2002. Ecological Diversity in Relation to Agricultural Land Use Intensity in a Mid-Altitude Village in Central Himalaya. Ph.D. Thesis, Jawaharlal Nehru University, New Delhi, India.

Sundriyal, R.C., Rai, S.C., Sharma, E. and Rai, Y.K. 1994. Hill agroforestry systems in south Sikkim. Agroforestry Systems 26: 215-235.

Thapa, G.B., Sinclair, F.L. and Walker, D.H. 1995. Incorporation of indigenous knowledge and perspectives in agroforestry development. Part 2. Case study on the impact of explicit representation of farmersÆ knowledge. Agroforestry Systems 30: 249-261.

Toky, O.P., Kumar, P. and Khosla, P.K. 1989. Structure and function of traditional agroforestry systems in the western Himalaya. I. Biomass and productivity. Agroforestry Systems 9: 47-70.