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Changes in Agricultural Biodiversity: Implications for Sustainable Livelihood in the Himalaya

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Abstract: Himalayan mountain system is distinguished globally for a rich biodiversity and for its role in regulating the climate of the South Asia. Traditional crop-livestock mixed farming in the Himalaya is highly dependent on forests for fodder and manure prepared from forest leaf litter and livestock excreta. Apart from sustaining farm production, forests provide a variety of other tangible and intangible benefits, which are critical for sustainable livelihood of not only 115 million mountain people, but also many more people living in the adjoining plains. Extension of agricultural land-use coupled with replacement of traditional staple food crops by cash crops and of multipurpose agroforestry trees by fruit trees are widespread changes. Cultivation of *Fagopyrum esculentum*, *Fagopyrum tataricum*, *Panicum miliaceum*, *Setaria italica* and *Pisum arvense* has been almost abandoned. Increasing stress on cash crops is driven by a socio-cultural change from subsistence to market economy facilitated by improvement in accessibility and supply of staple food grains at subsidized price by the government. Farmers have gained substantial economic benefits from cash crops. However, loss of agrobiodiversity implies more risks to local livelihood in the events of downfall in market price/demand of cash crops, termination of supply of staple food grains at subsidized price, pest outbreaks in a cash crop dominated homogeneous landscape and abnormal climate years. Indigenous innovations enabling improvement in farm economy by conserving and/enhancing agrobiodiversity do exist, but are highly localized. The changes in agrobiodiversity are such that soil loss and run-off from the croplands have dramatically increased together with increase in local pressure on forests. As farm productivity is maintained with forest-based inputs, continued depletion of forest resources will result in poor economic returns from agriculture to local people, apart from loss of global benefits from Himalayan forests. Interventions including improvement in traditional manure and management of on-farm trees, participatory development of agroforestry in degraded forest lands and policies favoring economic benefits to local people from non-timber forest products could reduce the risks of decline in agricultural biodiversity and associated threats to livelihoods and Himalayan ecosystems.

Keywords: Land use/cover change; food security; cash crops; traditional agricultural practices; forest management

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Introduction

Himalayan mountain system covers partly/fully eight countries of the South Asia, that is Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. 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 regions, driving factors and implications of these changes are discussed in this article.

1 Traditional Settled Farming System

1.1 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; and (f) exchange of seeds without any monetary considerations.

1.2 Crop diversity and productivity

Even though holdings are small (average size < 1 ha), the 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). A high level of crop diversification 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 ha^{-1} of wheat and 14 t ha^{-1} of potato) 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.

1.3 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). Farmers 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) but these attributes are not clearly understood by local people.

1.4 Dependency of agriculture on forests

Because of small holdings, 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, which would meet agroecosystem requirements without any adverse impact on forest health, have not been worked out.

2 Changes in Traditional Practices, Driving Factors and Implications

2.1 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; and (c) higher profitability and labor productivity of *Phaseolus radiatus* and *Glycine max* in slash-burn environments compared to that in traditional settled agriculture. Shifting agriculture with short fallow periods of 4~5 years enables profits in the short-term but is not likely to be sustainable in the long-run (Nautiyal *et al.* 1998).

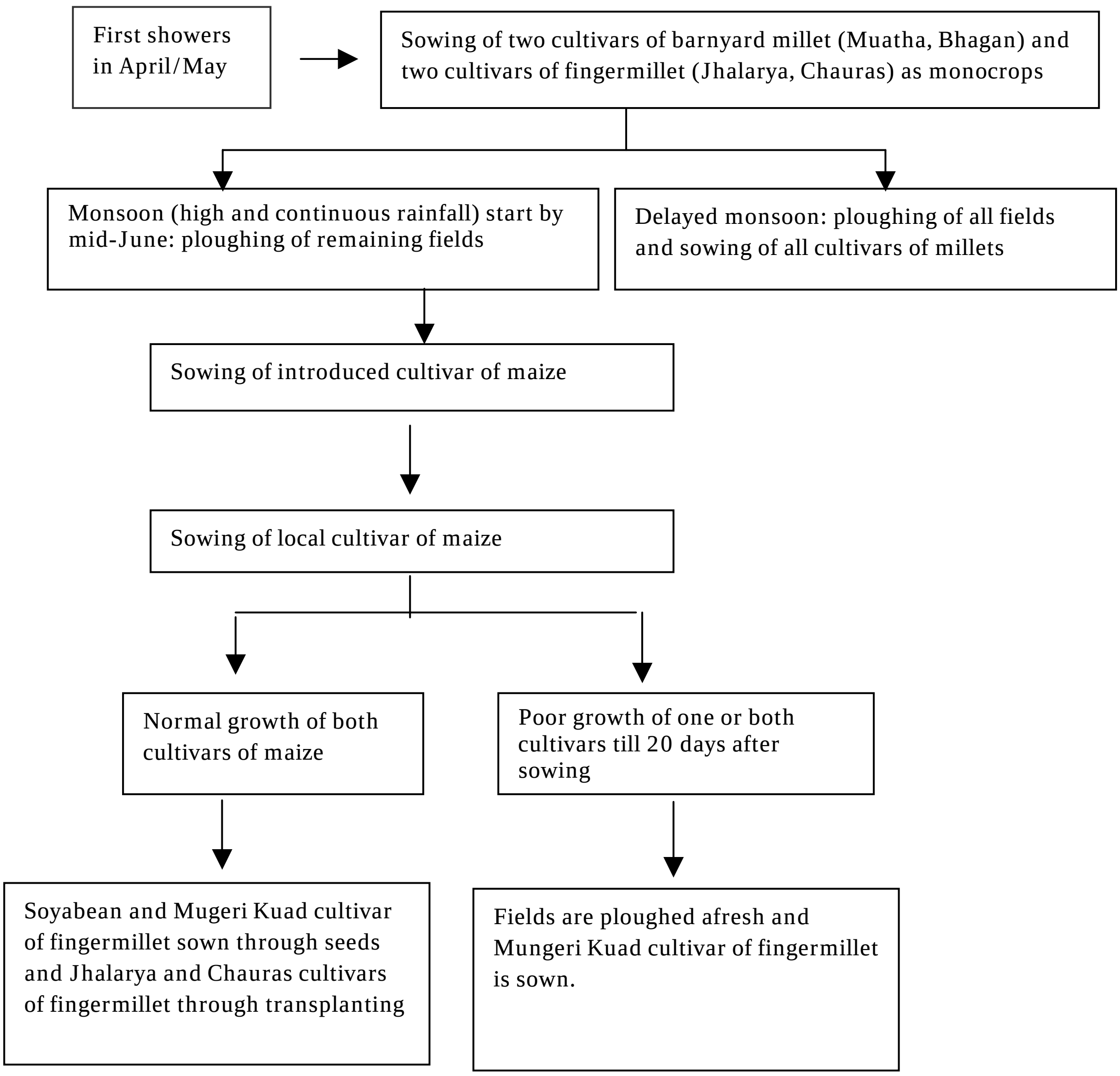

Figure 1 Cropping pattern as determined by climatic conditions in a mid-altitude village (based on Singh 2002)

2.2 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 miliaceum, 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 the 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 uplands, changing food habits and supply of food grains at subsidized price by the government (Semwal *et al.* 2003a).

Farmers are 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 the potato field is 6~8 times higher than that from the traditional crops that has been replaced (Table 2) despite of a much higher manure input in the former (Sen *et al.* 1997, 2002). A 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).

2.3 Domestication of new crops

In a few high altitude (>1300 m) villages, farmers' innovations led to cultivation of several medicinal plants (Table 1), which used to be harvested from the wild (Maikhuri *et al.* 2000a, Nautiyal *et al.* 2001). As these plant species are threatened, their cultivation contributes to the conservation of wild biodiversity. Because of strong aroma, they are not as much depredated by wildlife as by food crops (Rao *et al.* 2002). Medicinal plants 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 problems faced by farmers in marketing.

2.4 Abandonment/expansion of agricultural land use

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

2.5 Livestock population

A trend of increase in livestock population and changes in composition of livestock population are common (Sharma and Shaw 1993, Mishra 1997). A change from preference of joint to nuclear families but persistence of the traditions of maintaining self-sufficiency in respect of cattle at household level and of considering sheep/goat/mule husbandry as an occupation of lower castes, seems to have contributed to higher rate of increase in cattle population compared to other livestock types (Sen *et al.* 2002). An increase in livestock population but reduction in fodder production from farmland

Table 1 Area (% of total cropped area), change in area during 1970~75 and 1995 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)	Increase (+)/ decrease (-)/no change (0) of cropped are between 1970~75 and 1995 (n = 46) (%)	Monetary Value (n=10) (US$/ha)	% of total cropped area in 1995 (n=42)	Increase (+) /decrease (-) /no change (0) of cropped area between 1970~75 and 1995 (n = 17)(%)	Monetary value (n=10) (US$/h)
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 frumentacea	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}	-50^{b}	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+P. 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 glauca	-	-	-	0.3	+100	544±57
Carum carvi	-	-	-	0.3	+100	971±85
Dactylorrhiza hatagirea	-	-	-	0.2	+100	786±80
Megacarpaea polyandra	-	-	-	0.2	+100	272±19
Pleurosperum angelicoides	-	-	-	0.2	+100	627±60
Saussurea costus	-	-	-	0.3	+100	690±68

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

Table 2 Soil loss from different crops grown on varied terrace slopes in the Pranmati watershed, Indian central Himalaya (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^{-1} yr^{-1}), fodder yield (t ha^{-1} yr^{-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

with changing cropping patterns implies more intensive grazing in forests. The government efforts to encourage husbandry of birds (poultry and duckery), rabbits yielding high quality wool, buffaloes and cross-breeds of sheep/goats have met limited success because of poor adaptation of these introduced animals to mountain terrain and locally available feed, and their unsuitability for the production of traditional farmyard manure.

2.6 Loss/replacement of traditional multipurpose trees

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

3 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.

3.1 Mulching and manuring

The quality of manure derived from oak forests is 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 (at 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

3.2 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) suggests 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.

3.3 Agroforestry on degraded lands

Of the 59 million ha total geographical area of the Indian Himalayas, 21 million ha are degraded lands. As traditional farm holdings are small, development of agroforestry in such lands could be a viable option for land rehabilitation. External support is required for successful land rehabilitation because of limited scope of indigenous capacity to identify and implement appropriate technologies. Sustainable rehabilitation would mean to address people's needs and ecological restoration of degraded ecosystems, otherwise the threats to the left-over intact forests are also reduced. The local people are concerned more for immediate tangible/economic benefits than for intangible/environmental benefits (soil conservation, hydrological balance, carbon sequestration and biodiversity conservation) from land rehabilitation programmers. The local economic development concern can be integrated with the 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 (Maikhuri *et al.* 1997, Rao *et al.* 1999).

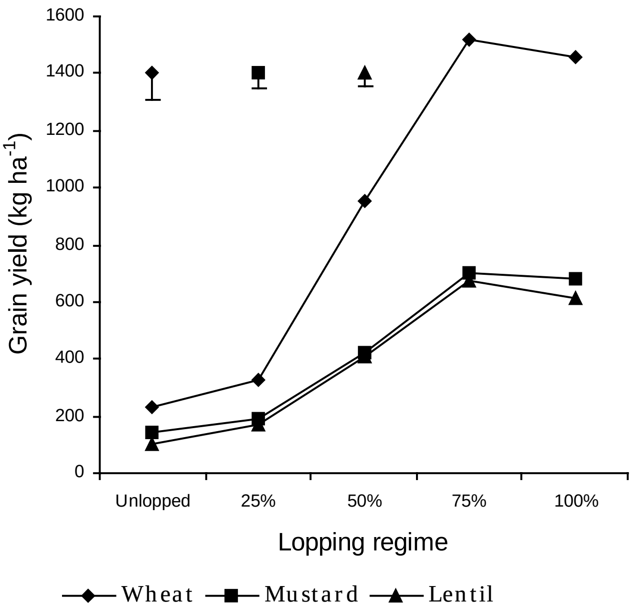

Figure 2 Yield of winter season crops grown under unlopped, 25, 50, 75 and 100% lopping of agroforestry trees in village Banswara, India. LSD (P=0.05) between means of a crop grown under different lopping regimes are given as vertical lines (Based on Semwal *et al.* 2002)

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. 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 the treated ecosystems. 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. The investment is recovered over a period of 7 years (Maikhuri *et al.* 1997, 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) in Indian Central Himalaya (based on Maikhuri *et al.* 2000c and Rao *et al.* 1999)

Component	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

4 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.

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