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

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ABSTRACT

This study aimed to analyze the ecological, socio-economic and policy implications of land-use diversity in a traditional village landscape (900-1000 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 types of agroecosystem types viz., homegarden system (HGS), rainfed agroforestry system (RAS), rainfed crop system (RCS) and irrigated crop system (ICS), shifting agriculture system (SAS) 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. SAS, a land-use adopted to acquire 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 higher labour productivity and avaialability 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 farm yard manure input applied to the irrigated crops. Existing forest management systems are not effective in maintainance 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 farmyard manure, managing livestock and other subsidiary farm activities. Interlinkages between 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.

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 under the control of local communities surrounded by forests under the control of the government. 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 farm land 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). This study aimed to characterize the diversity of land–use/cover, in terms of variability in cropping patterns, agricultural inputs and productivity, vegetation structure, soil nutrient pools and management practices, and its environmental, socio-economic and policy implications.

2. METHODS

2.1. Study area

The study was carried out in village Bacchelikhal (29^{0}26$^{'}$ to 30^{0}28$^{'}$ N latitude and 29^{0}26$^{'}$ to 30^{0}28$^{'}$ E longitude), a typical mid-altitude (900-1000 m *amsl.*) village of Garhwal region of Indian Himalaya (Figure 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^{0}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, fewer individuals employed outside the village 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 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, where all subsistence resource uses were regulated by the Village Council (comprising 7 elected individuals) and commercial extractions by the government agencies, and (b) Reserve Forests, where all traditional resource uses were terminated, silvicultural practices favouring timber species *Shorea robusta* were applied and all income from timber was appropriated by the Government Forest Department during 1900-1976 period, (iii) suspension of cutting of green trees in forests or farmlands for timber trade since 1976, (iv) supply of chemical fertilizers, pesticides, seeds of high yielding 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) provison of government funds to meet 50% of the construction cost of tanks for harvesting of run-off 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 types 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 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 scattered multipurpose trees (crown cover 10-20%), (iii) rainfed crop system (RCS): rainfed cultivation of food crops in absence of trees and (iv) irrigated crop system (ICS): cultivation of food crops irrigated by run-off accumulated in tanks in absence of trees. HGS were nearest to the living places followed by the RAS. Settled agriculture was managed based on decisions of individual families and shifting agriculture on community decisions arrived through consensus. Lower caste families practisced only RAS and allocated larger areas to HGS as compared to higher caste families. Differences in land-use management and crop yields by caste were not evident as also observed elsewhere (Rao and Saxena, 1994; Maikhuri et al., 1996, 2000). Forests occurred on slopes varying from 30^0 to 50^0. Reserve Forests (RF) showed more luxuriant tree growth compared to the Community Forests (CF) (Table 2).

2.4. Participatory survey, crop yields and vegetation analysis

Information on land-use history, relative areas of different agroecosystem types/crops, farmers' perceptions on ecological and socio-economic attributes of different crops and land-uses 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 the 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 households were randomly selected for monitoring agricultural inputs and outputs. The heads of these households were contacted regularly to have advance information on the farming activities. Inputs viz., seed, manure, bullock power and labour and outputs viz., human food and fodder were estimated in three randomly selected plots, one in each of the three households, of each type of crop grown in the RAS (n = 15 plots), RCS (n = 15 plots), ICS (n = 6 plots) and the first and the last (fourth year) of cropping under SAS (n = 6). Mean inputs/outputs in each agroecosystem type were derived from the areas under different crops grown in the system and input/output values of respective crops. The entire HGS of a household was monitored to estimate the inputs and outputs as this agroecosystem type covered a small area and crop-wise disaggregation of inputs here was not possible because of intermixing of a large number of crops. 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. As the local people did not attach any monetary value to bullock power and fodder available from crop fields, these inputs were excluded from monetary budgeting. 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 (i.e. net monetary return and output/input ratio).

At the time of weeding, weed density was measured in 10 random quadrats (1 × 1 m size), sampled in each crop type. These obsrevations could not be made in the fields under 4th year of cropping in shifting agriculture, which were not weeded, and in the homegardens, which were so frequently weeded that we failed to track some weeding events. 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 a given ecosystem type.

2.5. Soil analysis

Soil was sampled from 0-10 cm, 10-20 cm and 20-30 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 properties of soil 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 crops, maize (*Zea mays*) and soybean (*Glycine max*) were confined to the rainfed agroforestry system (RAS) and horsegram (*Macrotyloma uniflorum*) to shifting agriculture system (SAS), while sesame (*Sesamum indicum*) was common to the irrigated crop system (ICS) and SAS and barnyard millet (*Echinocloa frumentacea*) and fingermillet (*Eleusine *coracana*) to the RAS and the rainfed crop system (RCS). Fingermillet was, however, grown as a pure crop in the RCS but mixed with soybean in the RAS. Of the two winter crops, both wheat (*Triticum aestivum*) and barley were grown in the RAS and the RCS and only wheat in the ICS. Mixed crop of wheat and barley was grown only in the RCS. In SAS, sesame was grown during the first two years and horsegram (*Macrotyloma uniflorum*) in the last two years of a 4-year long cropping phase (Table 3) alternating with a 7-year long fallow phase.

In the RAS, after the first monsoon showers in April/May, *Muatha* and *Bhagan* cultivars of barnyard millet and *Jhalarya* and *Chauras* cultivars of fingermillet were sown in a few fields. If monsoon commenced by mid-June, maize was sown in about 50% of the remaining fields. If maize growth was normal till 20-25 days after sowing, soybean was intercropped between maize rows and *Mungerikuad* cultivar of fingermillet was sown in the remaining vacant fields. If the crop growth was poor during first month after sowing, maize fields were ploughed afresh and sown with *Mungerikuad* cultivar of fingermillet. If monsoon did not commence by mid-June, all cultivars of barnyard millet and fingermillet were sown, covering almost equal areas (Figure 2).

In 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 grown in rainy season in the RAS and the 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 common to the RAS and the RCS, showed similar levels of productivity and manure/labour inputs in the two systems. In wheat, a winter crop common to the ICS, RAS and RCS, productivity increased with increase in labour and manure inputs. In 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 1st 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 of cropping but the two crops did not differ significantly ($P > 0.05$) in terms of land productivity. Land productivity of sesame, a rainy season crop common to the SAS and ICS, was two-times higher in the former compared to the latter system, while the 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 agroecosystems differed in terms of crop composition and number of crops harvested from a plot in a year and degree of crop-wise segregation of inputs was not feasible in the HGS, it seemed useful to compare inputs and outputs in different agroecosystems on an annual time scale (Table 4, 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 all settled agroecosystems (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 the RCS.

The HGS was the most productive system followed by the RAS and the RCS in terms of land and labour productivity of human food, the RAS and RCS were more productive than the HGS in terms of fodder productivity. The ICS, a land use facilitated by the government, required 33 times higher manure input and two 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 (Table 4).

Land and labour productivities of the ICS were 3.1 times and 1.4 times, respectively, higher compared to the RCS. Further, the ICS was less efficient than the HGS and the 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. SAS was as efficient as the RAS and more efficient than the RCS and ICS in terms of labour productivity, but less efficient than all settled agroecosystem types except the RCS in terms of land productivity.

Only the HGS and SAS showed positive values of net annual 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 8750 adult person days per year of labour compared to the available labour of 27010 adult person days per year. Subsidiary farm activities (including preparation stall-feeding/herding of livestock, preparation of farm yard manure and transport of farm inputs/outputs between homesteads and crop fields) combined with other domestic tasks (e.g., collection of fuelwood, wild edibles and medicinal plants and maintenance of natural springs providing drinking water) involved labour input (24500 person days in a year) 3.8 times higher than that to the 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 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*, rainfed agroforestry system by high quality fodder trees *Boehmeria rugulosa* and *Grewia optiva*, Community Forests (CF) by moderate quality fodder/fuelwood species *Adina cardifolia* and *Gmelina arborea* and Reserve Forests (RF) by high quality timber species *Shorea 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 the alien invasive species *Lanatana camara* 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 SAS. *Ageraturm conyzoides* was the most abundant species in 4th year cropping/1-year old fallow field of the SAS and RAS, *Commelina erecta* in the RCS and 1st 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 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 change in soil properties over 7 years of fallow development. All soil pools except exchangeable Ca were significantly larger in the CF compared to the RF (Figures 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 the following deductions:

- Farmers distinguished crops/cultivars in terms of their adaptations to various stresses determining risks to productivity under varied climatic and management conditions together with their economic values (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 under 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.
- 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 trents. 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 type 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 or low intensity irrigation from existing tank based irrigation 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 RAS but reconciled this loss with the availability of tree fodder available in limited quantities from the forests. Similarly, they reconciled the loss in yields due to less intense weeding in SAS with the contribution made by weeds in terms of soil conservation and rapid growth of fallow vegetation.
- 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 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 and practices have changed over time with changing socio-economic conditions, technological innovations and policy interventions, resulting in differentiation within traditional rainfed agriculture as well as adoption of altogether new land-uses 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., 1998; 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 forestland 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 four times larger than the area under agriculture (Rao and Saxena, 1996; Semwal et al., 2004) suggest that farmers adopt tree-crop mixed farming when 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 influencing costs/benefits of growing trees on farm land (Gilmour and Nurse, 1991; Nautiyal et al., 1998; Pilbeam et al., 2000; Semwal et al., 2004). In Bacchelikhal village landscape, crop productivity in settled agriculture seems to be constrained by shortage of fodder and manure, as evident from the forest area accessible to the people being only 1/4th of that required for maintaining soil fertility and sustainable yields (i.e., only one ha of community forest land available against the requirement of 4 ha) through traditional means.. Maintenance of high quality fodder trees *Grewia optiva* and *Boehmeria rugulosa* in the rainfed agroforestry system (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 homesteads because of huge labour and time required for managing trees, transporting fodder (Gilmour and Nurse, 1991) and protecting crops from birds perching on agroforestry 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 (Bohle and Adhikari, 1998) including the present village landscape. Establishment of shifting agriculture system (SAS) in previously uncultivated lands requires lesser energy and time compared to the traditional settled farming. Further, the former land-use does not require manure and draught power inputs used in the latter land-use. 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 of central Himalaya to practise shifting agriculture for two reasons : (i) establishment of shifting agriculture in previously uncultivated lands was a more 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 inputs (i.e., fodder and manure) for maintenance of soil fertility (Rawat, 1995; 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 farm yard manure), 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 any further expansion of settled agriculture. Third, labour shortage arising from migration of rural people to urban areas favours maintenance of SAS 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.

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 and of coping with the climatic risks and other constraints to agricultural productivity. In Garhwal Himalaya, farmers view two major risks to crop productivity: (a) the risk of climate arising from uncertainty of monsoon rainfall and (b) the risk of cultivating distant fields arising from huge labour and time to be 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 by only climatic risks and the ICS by only distance related risk and the highest inputs 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 on 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 a means of coping with 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 and 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 the RCS differing in manure input rates and soil nutrient levels observed in this study and a 17 fold variation in maize yield compared to 2 fold variation in millet yield over a range of manure/fertilizer input rates and 2.1 fold variation in maize yield compared to 1.6 fold variation in millet yield over a period of 8 years of experiment reported in Sherchan et al. (1999). Further research is needed to validate farmers' perceptions about crop/cultivar-environment relationships.

Local people view fingermillet and barnyard millet as less-delicious staple food compared to maize 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 quantitities of farm yard 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 farm yard manure input rates. Conversion of rainfed to irrigated farming seems to have confined to a limited area for three reasons. First, as discussed above, farmers face a shortage of manure due to scarcity of forest resources required to produce it. Use of chemical fertilizers can reduce dependence on manure but is not feasible partly because run-off accumulated in the tanks is too low to realize potential benefits of chemical fertilizers and partly because farmers have to block a significant portion of their income to stock this input due to uncertainty of its availability. Second, 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 irrigation tanks. Third, labour productivity/net economic returns from the tank based irrigated crop system is lower than the other traditional land uses line HGS. Government support to canal based community 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-use types 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 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 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 fires by local people to improve quality and productivity of herbaceous fodder coupled with unregulated grazing may be attributed to lower soil organic C and nutrients in the Reserve Forests (RF) compared to the Community Forests (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 farm yard manure is a form of environmental service to local inhabitants from natural forests. Coupled with this locally valued environmental service are the globally valued environmental services from forests viz., recharge of springs, soil conservation and carbon sequestration. Excessive removal of litter from the forest floor is 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 forest disturbances which do not pose any threat to both global and local benefits from forest ecosystemss.

4.3. Vegetation

Extensive shifting agriculture in hills with cultivation cycles shorter than 10 years may result in a severe loss of forest regeneration potential (Uhl, 1987; 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 observed 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 alien invasive 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 crop 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 homegarden systems (HGS) compared to CF suggest that policies allowing cultivation of cash fetching annual/perennial crops on a limited scale in CF and RF 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 realised, knowledge on ways and means of meeting this need is limited. This study shows that (i) traditional homegarden systems (HGS) are economically the most efficient production system and have 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 adopted shifting agriculture systems (SAS) as a means of acquiring inheritable rights over larger land holdings provided in the policies during the 1890s and subsequently continued it as a means of income together with availability of high quality fuelwood, (iv) cultural norms favour integration of different socio-economic classes by discouraging hiring of labour from outside the village, (v) dominance of fodder tree species in rainfed agroforestry system (RAS) derives from the policy interventions causing reduction in fodder available from forests, (vi) existing forest management systems are not effective in maintaining a large basal area together with a high level of species richness and soil fertility and ability to resist invasion by alien species, (vii) irrigation facilities supported by the government increase pressure on forests due to increase in the rate of farm yard manure input and (viii) farmers have to spend huge amount of labour and time in producing manure, managing livestock and other subsidiary activities. Interlinkages between 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 farm lands, economic benefits to local people from sustainable utilization of forest resources and more productive utilization of human labor. Further studies are needed to improve the scientific knowledge required for developing sustainable development policies and programmes in the Himalayan region.

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LEGEND TO FIGURES

Figure 1. Location and land-use/cover types differentiated in village Bacchelikhal, Garhwal, India.

Figure 2. Farmers’ decision making on cropping pattern during rainy season in rainfed agroforestry system.

Figure 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, respectively, of cropping after slash-burn in shifting agriculture; 1YF and 7YF, first and seven year old fallow field 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.

Figure 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, respectively, of cropping after slash-burn in shifting agriculture; 1YF and 7YF, first and seven year old fallow field 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 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*	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

*Permanent outmigration is altogether lacking

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	5-8^0 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	5-8^0 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	5-8^0 outward sloping terraces; absence of trees	Land owned and managed by individual families
Irrigated crop system	0.6	2.5-3.0	5-8^0 outward sloping terraces; absence of trees	Land owned and managed by individual families; irrigated by stream water stored in small tanks, with irrigation intensity markedly lower than that in homegarden
Shifting agriculture	21.4	2.5-4.0	10-15^0 outward sloping terraces; absence of trees	Privately owned but collectively managed
Forests				
Community forests	35.7	3.0-4.5	natural 30-40^0 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 20-30^0 slopes; tall trees (> 15 m) of *Shorea robusta* and crown cover of 45-60%	Land and resources both owned and managed by the government; unregulated uses of non-timber forest products and frequent disturbance of ground fire.

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 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^{d}	0.07^{d}	0.21^{d}	34^{b}	5219^{de}	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	8^{de}	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}	5076^{de}	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}	18^{de}	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}	13^{de}	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

* crops grown in rainy season, ** crops grown in winter season, values with different letters within a column are significantly ($P < 0.05$) different

Table 4

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

	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						
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^{b}
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

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*

	Input						
Land-use system	Labour (Rs ha^{-1} yr^{-1})	Manure (Rs ha^{-1} yr^{-1})	Seed (Rs ha^{-1} yr^{-1})	Total (Rs ha^{-1} yr^{-1})	Output (Rs ha^{-1} yr^{-1})	Net return (Rs ha^{-1} yr^{-1})	Output/input ratio
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}

*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 land-use/cover types in Bacchelikhal village landscape, Garhwal, India

	Homegarden			Rainfed agroforestry 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.

Table 7

Density (individuals ha^{-1}) of shrub species in different land-use/cover types* 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

*Settled agricultural land-uses had negligible shrub component and hence not shown here

Table 8

Density (individuals m^{-2}) of herbaceous species in different land-use/cover types in Bacchelikhal village landscape, Garhwal, India

	Rainfed agroforestry system	Rainfed crop system	Irrigated crop system	1st year crop: shifting agriculture	4th year crop: shifting agriculture	1-year fallow: shifting agriculture	7-year fallow: shifting agriculture	Community forest	Reserve forest
Ageratum conyzoides L.	43	_	19	5	103	20	_	_	_
Artemisia scoparia Waldstein & Kitaibel	_	_	_	_	_	3	7	1	1
Brachiaria ramosa (L) Stapf.	1	8	7	7	7	_	_	_	_
Bulbostylis densa (Wallich. ex Roxb.) Hand-Mazz	_	12	1	1	_	_	_	_	_
Commelina benghalensis L.	12	2	2	2	14	_	_	_	_
Commelina erecta L.	1	20	1	_	_	_	_	_	
Cymbopogon martinii (Roxb.) W. Watson	_	_	_	_	_	_	_	1	1
Cyperus rotundus L.	12	13	22	3	_	_	_	_	_
Euphorbia hirta L.	_	_	_	_	_	1	5	1	_
Hedyotis corymbosa (L.) Lam.	1	_	1	6	1	_	_	_	_
Oxalis corniculata L.	_	_	_	_	_	_	20	1	_
Rumex hastatus D. Don	_	_	_	_	_	_	_	1	1
Stellaria media (L.) Villars	_	18	66	_	_	_	_	_	_
Tridax procumbens L.	_	_	1	_	12	1	2	2	1
Others	32	16	19	_	_	13	42	_	_
Total	102	89	139	24	137	38	76	7	4

Table 9. Farmers' criteria of distinguishing crops grown in Bacchelikhal village landscape, Garhwal Himalaya, India

Crops	Adaptation to stress due to					Economic value
	Moisture*	Nutrients*	Agroforestry trees*	Absence of tillage*	Weeds*	
*Echinocloa frumentacea***	High	High	Low	Low	Low	Low
*Eleusine coracana***	High	High	Low	Low	Low	Low
Zea mays	Low	Low	Low	Low	Low	High
Glycine max (Soybean)	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

* 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

**In rainfed conditions, *Muatha* and *Bhagan* cultivars of barnyard millet and *Jhalarya* and *Chauras* cultivars of fingermillet require longer growing perio as compared to *Mungerikuad* cultivar of fingermillet.

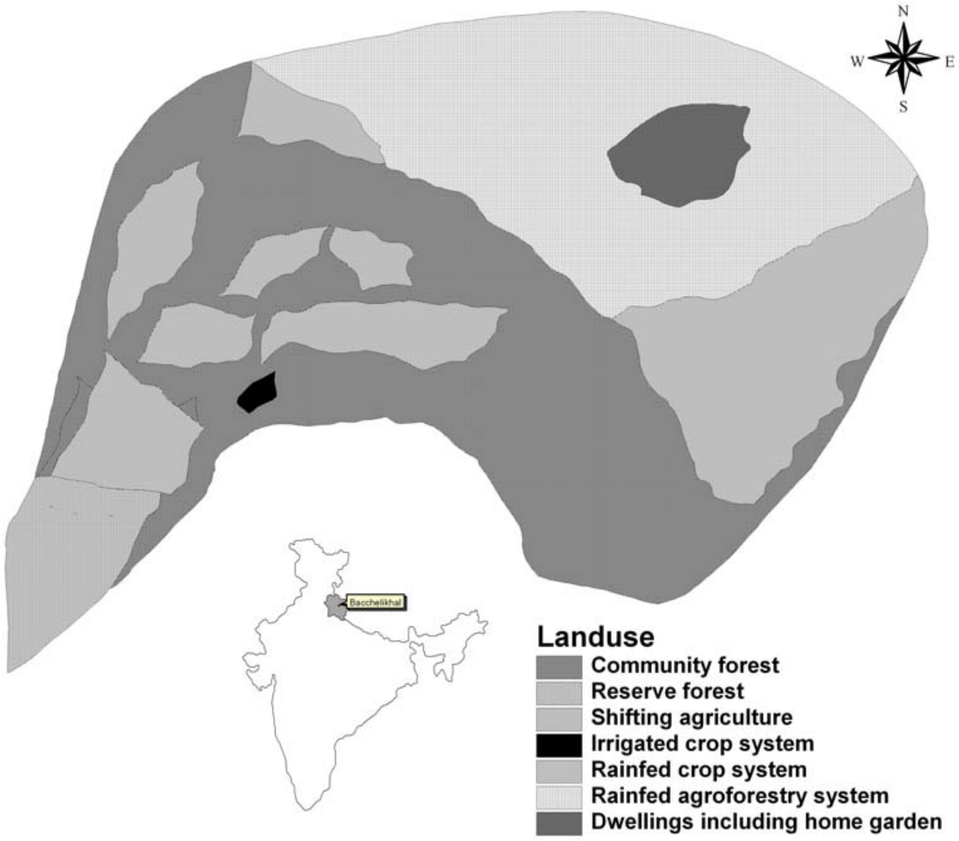

N
W
E
S
Bacchelikhal
Landuse
Community forest
Reserve forest
Shifting agriculture
Irrigated crop system
Rainfed crop system
Rainfed agroforestry system
Dwellings including home garden

Fig 1.

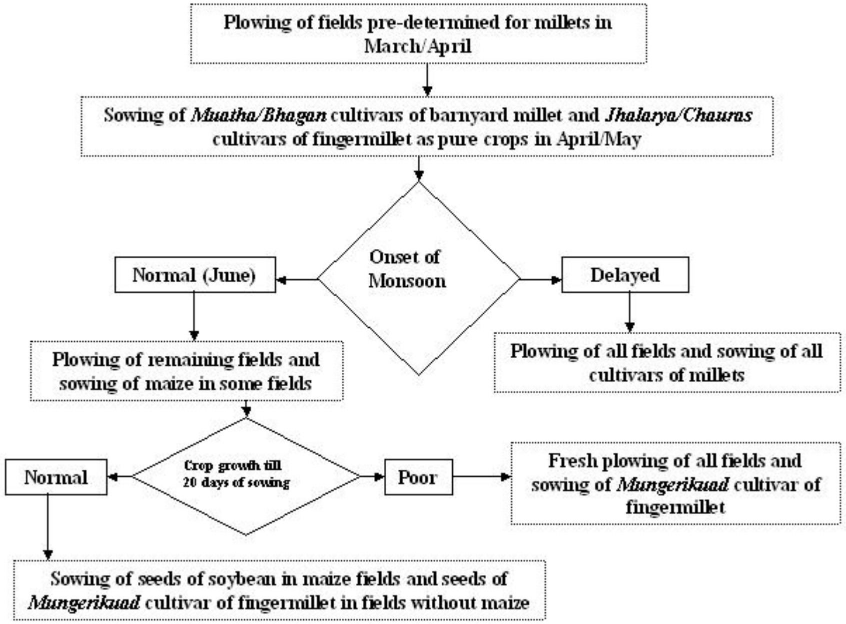

Plowing of fields pre-determined for millets in March/April
Sowing of *Muatha/Bhagan* cultivars of barnyard millet and *Jhalarya/Chauras* cultivars of fingermillet as pure crops in April/May
Onset of Monsoon
Normal (June)
Delayed
Plowing of remaining fields and sowing of maize in some fields
Plowing of all fields and sowing of all cultivars of millets
Crop growth till 20 days of sowing
Normal
Poor
Fresh plowing of all fields and sowing of *Mungerikuad* cultivar of fingermillet
Sowing of seeds of soybean in maize fields and seeds of *Mungerikuad* cultivar of fingermillet in fields without maize

Fig 2.

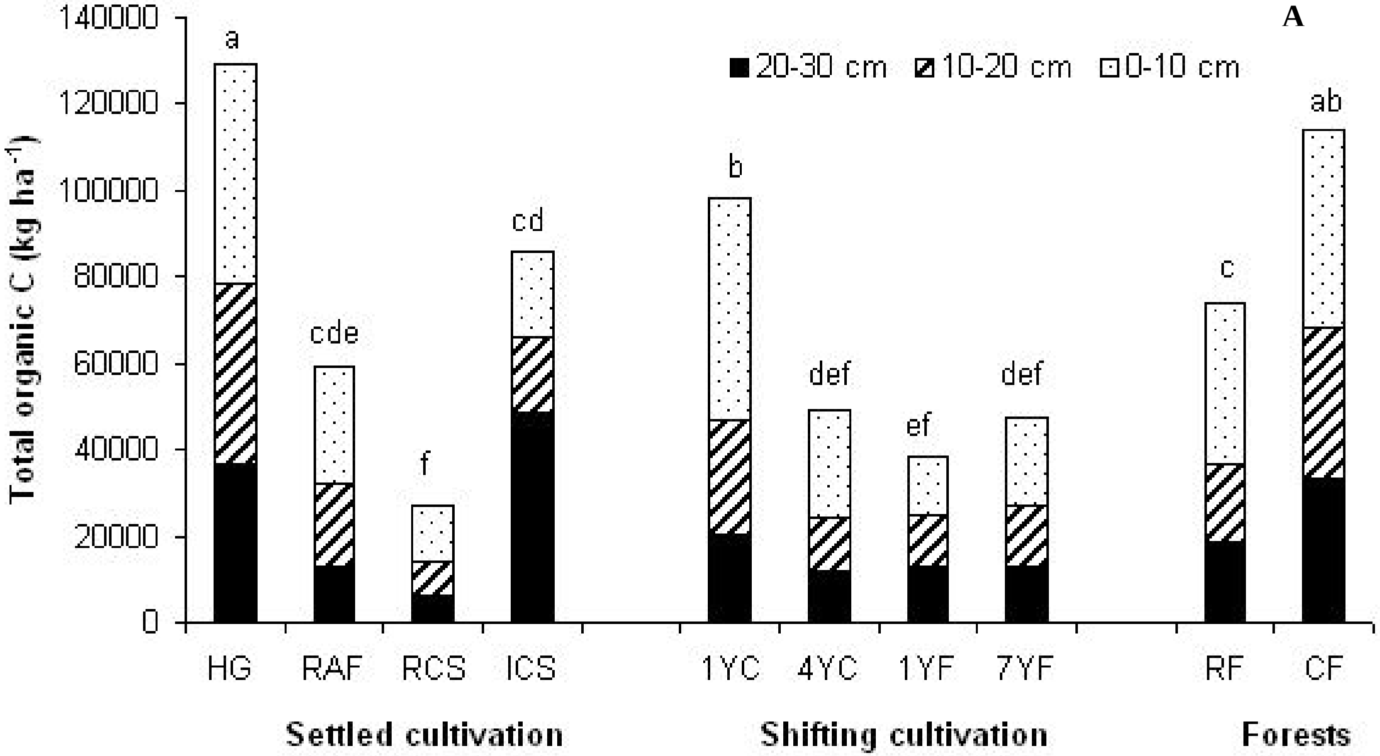
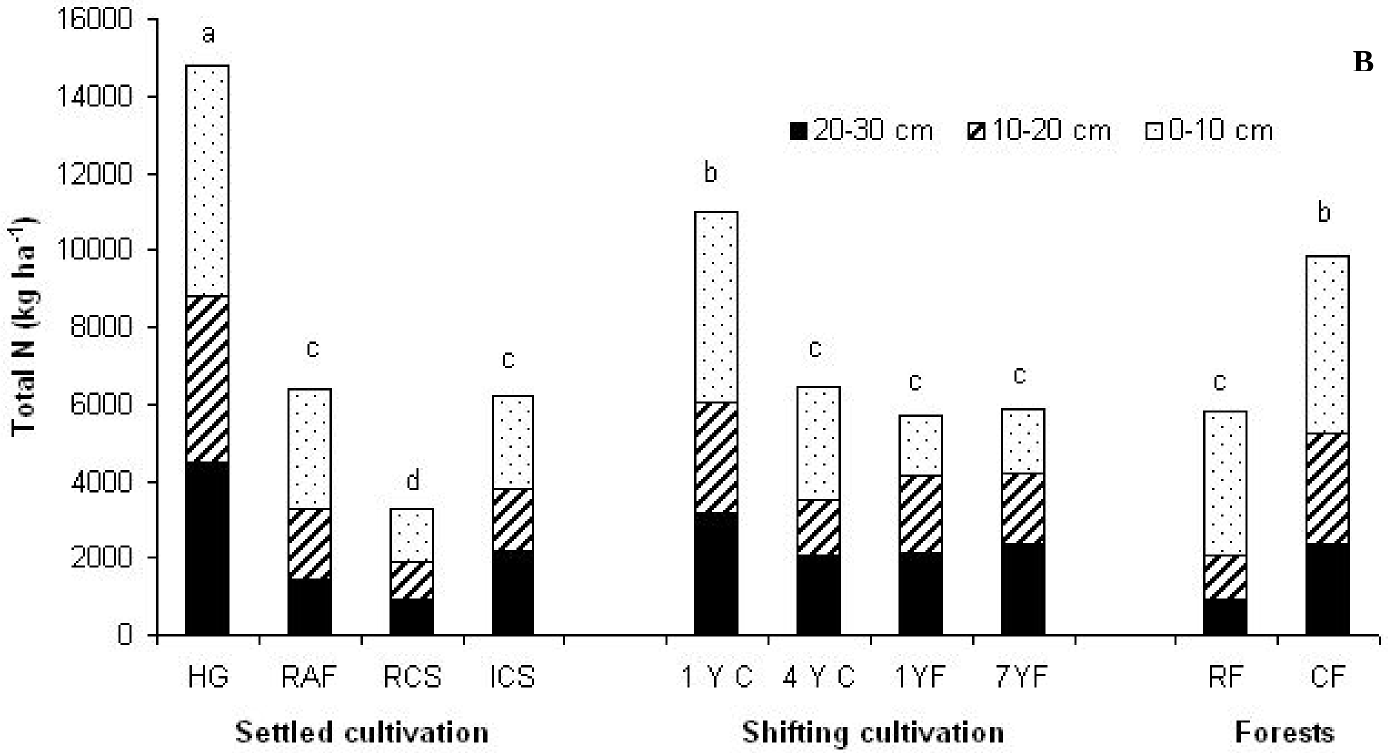

A
Total organic C (kg ha^{-1})
140000
120000
100000
80000
60000
40000
20000
0
■ 20-30 cm
▨ 10-20 cm
⊡ 0-10 cm
a
cde
f
cd
b
def
ef
def
c
ab
HG
RAF
RCS
ICS
1YC
4YC
1YF
7YF
RF
CF
Settled cultivation
Shifting cultivation
Forests

Figure 3A



B
Total N (kg ha-1)
0
2000
4000
6000
8000
10000
12000
14000
16000
■ 20-30 cm
▨ 10-20 cm
□ 0-10 cm
a
c
d
c
b
c
c
c
c
b
HG
RAF
RCS
ICS
1 Y C
4 Y C
1YF
7YF
RF
CF
Settled cultivation
Shifting cultivation
Forests

Figure 3 B.

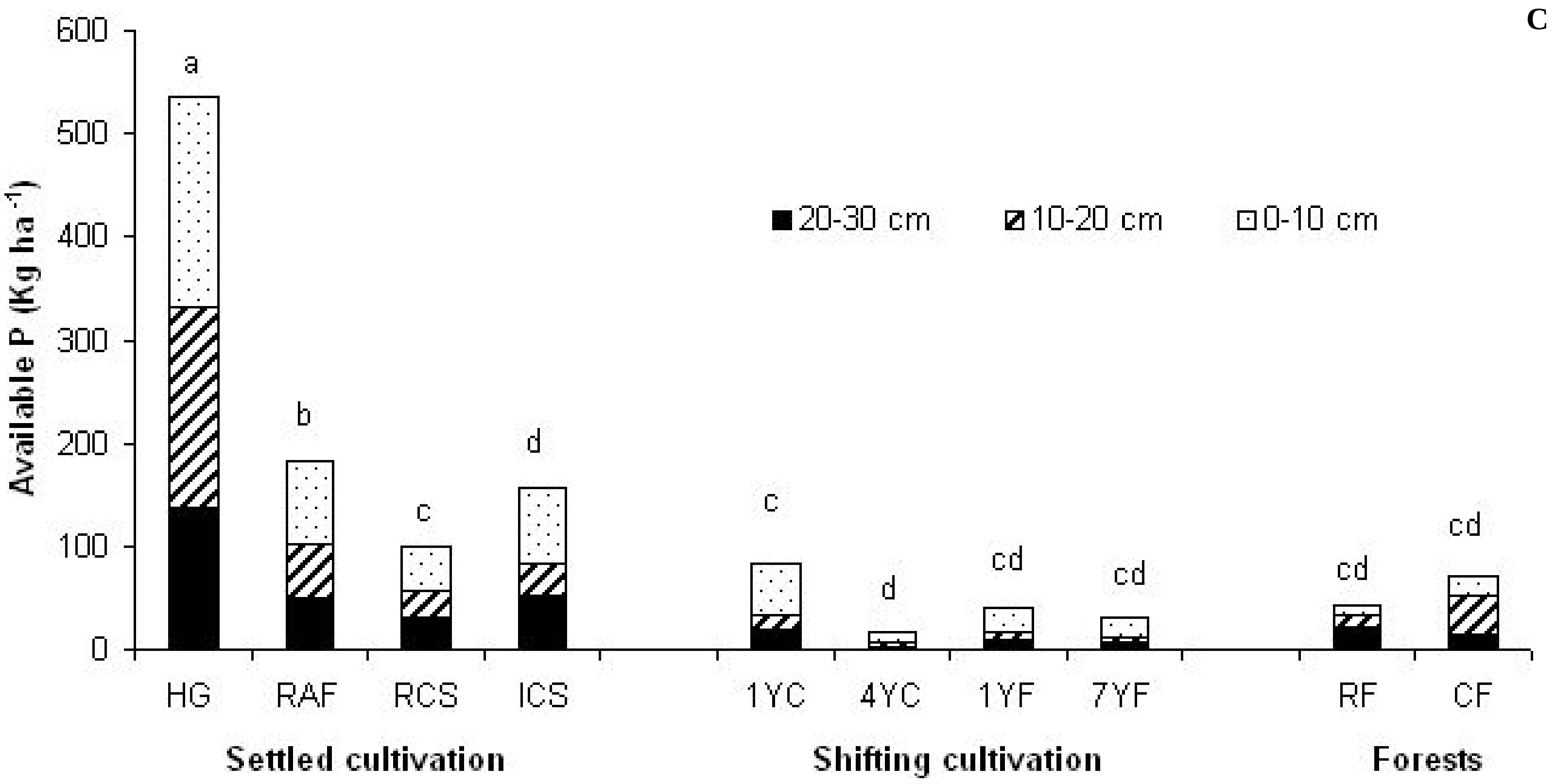

C
Available P (Kg ha^{-1})
600
500
400
300
200
100
0
■ 20-30 cm
▨ 10-20 cm
□ 0-10 cm
a
b
c
d
c
d
cd
cd
cd
cd
HG
RAF
RCS
ICS
1YC
4YC
1YF
7YF
RF
CF
Settled cultivation
Shifting cultivation
Forests

Figure 3 C.

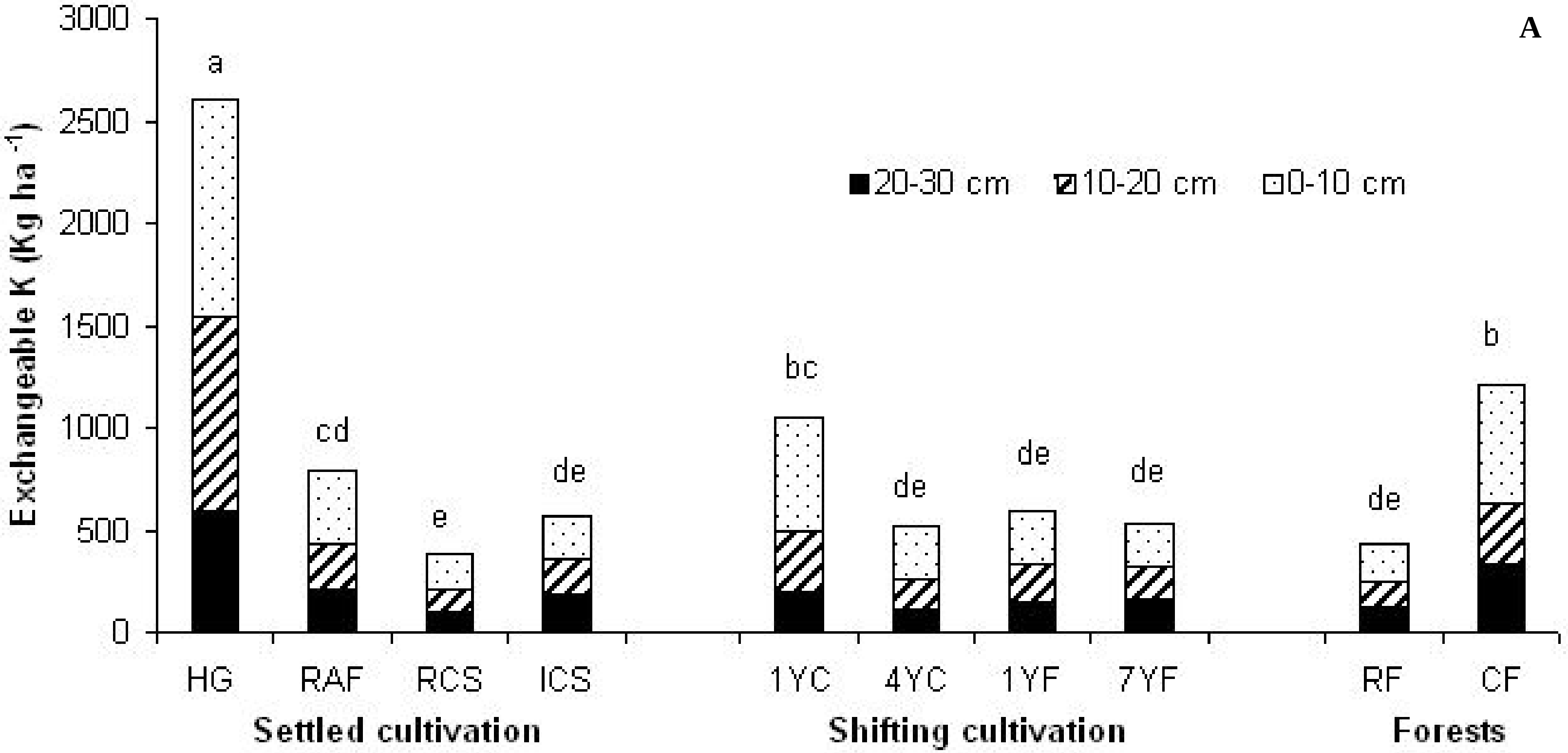

A
3000
2500
2000
1500
1000
500
0
Exchangeable K (Kg ha -1)
■20-30 cm
▨10-20 cm
□0-10 cm
a
cd
e
de
bc
de
de
de
de
b
HG
RAF
RCS
ICS
1YC
4YC
1YF
7YF
RF
CF
Settled cultivation
Shifting cultivation
Forests

Figure 4 A.

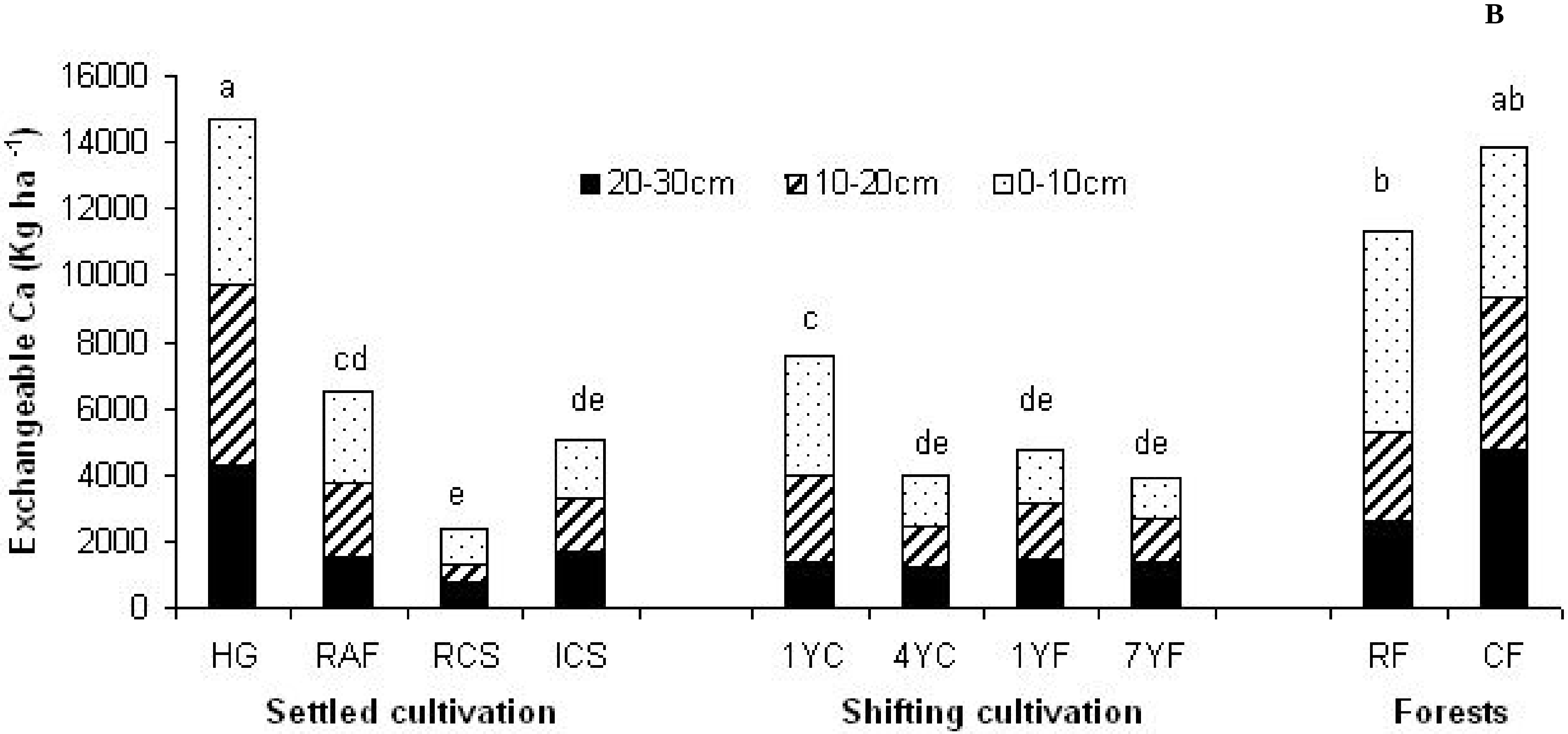

B
Exchangeable Ca (Kg ha -1)
0
2000
4000
6000
8000
10000
12000
14000
16000
■ 20-30cm
▨ 10-20cm
□ 0-10cm
a
cd
e
de
c
de
de
de
b
ab
HG
RAF
RCS
ICS
1YC
4YC
1YF
7YF
RF
CF
Settled cultivation
Shifting cultivation
Forests

Figure 4 B.

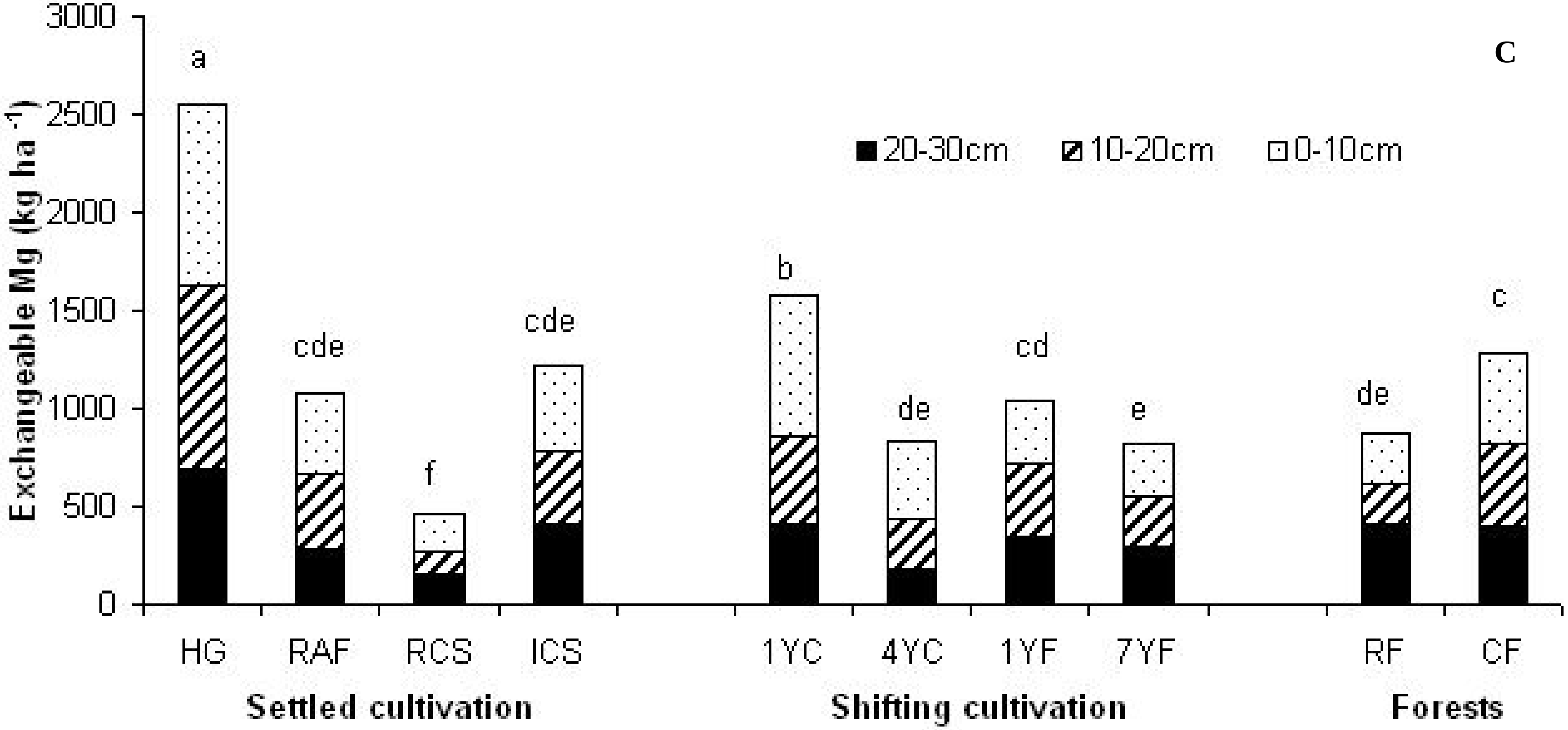

C
Exchangeable Mg (kg ha -1)
3000
2500
2000
1500
1000
500
0
20-30cm
10-20cm
0-10cm
a
cde
f
cde
b
de
cd
e
de
c
HG
RAF
RCS
ICS
1YC
4YC
1YF
7YF
RF
CF
Settled cultivation
Shifting cultivation
Forests

Figure 4 C.