Land use intensification in Indian Himlaya: meaning, measurement and implications

Joylata Laishram[1], K.S. Rao[2] and K.G. Saxena[1]
[1]*School of Environmental Sciences, Jawaharlal Nehru University, New Delhi*
[2]*Center for Inter-disciplinary Studies of Mountain and Hill Environment, Academic Research Center, University of Delhi, Delhi*

1. Introduction

Following the thesis of Boserup (1965) arguing agricultural intensification as a response to population growth and of von Thunen (1966) arguing proximity to market centres to be a decisive factor determining adoption of cash crops, land use intensification became an important theme of ecological as well economic research. The increasing demands of food can be met either by wildlife-friendly farming over larger areas or by agriculture intensification minimizing the demand for natural habitat (Green et al., 2005). However, where protection of forest is an objective, intensification can accelerate rather than contain deforestation if effective forest conservation policies are not in place. In the Ecuadorian Amazon higher yields obtained on richer soils led farmers to invest the profits in land uses that involve more extensive deforestation, namely cattle ranching. Farmers owing poor quality lands had an average of 70% of farm area under forests compared to 50% in the case of those owning highly fertile land (Pichon, 1996). In contrast, in the Indian central Himalayan region, where all uncultivated lands were notified as government forest lands and conversion of forest to agricultural land was banned way back in early twentieth century, agricultural expansion at the cost of loss of forest cover has been negligible over the last few decades (Maikhuri et al. 2000; Semwal et al., 2004). Many workers have concluded agricultural land use intensification as the major cause of losses of biodiversity and ecosystem functions, with serious threats to sustainability of local economies (Chapin et al., 2000; Tilman et al., 2002; Hoekstra et al., 2005; Urama, 2005). There are a few workers who have shown and argued for positive dimensions of intensification, e.g., Kundu et al. (2007) have shown that application of inorganic fertilizer together with organic manure may enhance carbon sequestration capacity of agroecosystems due to increase in production of root biomass and crop residues (Kundu et al., 2007). As biodiversity and ecosystem functions are likely to show non-linear responses to increasing land use intensification, management alternatives with limited ecological losses and satisfying economic gains need to be identified (DeFries et al., 2004; Steffan-Dewenter et al., 2007). As suggested by Shriar (2000), the degree to which intensification is a priority concern relative to other social and environmental objectives will vary from region to region and where intensification is seen as a priority, it likely will be a necessary but insufficient factor in achieving the broader objectives to which it relates. The article provides a review of the meanings, measurements and implications of land use intensification.

2. Meaning of land use intensification

There is a considerable variation in the expressed meaning of intensification (Box 1) and consequently substantial variation in the methods of its measurement (Table 1 & 2). The notion of increasing crop/livestock productivity cuts across all definitions of intensification. The differences in the meanings and measurements of intensification derive from the variation in the spatio-temporal scale of measuring productivity (i.e., the criteria adopted for demarcation of spatial (e.g., a crop field, a farm or a landscape) and temporal boundaries (e.g., number of harvests per year during cropping phase or number of harvests during the entire shifting cultivation cycle; short term and long term considerations)of agricultural production system), measures of productivity (human food yield or livestock feed/fodder yields or both in terms of energy or market value or both) and in selection of factors determining productivity (e.g., local inputs or external inputs or both or outputs per unit of input(s). As intensification process is driven by the humans, the magnitude of impact of man on ecosystems is a reflection of intensification (Fedroff, 2005). At field and farm scale, agricultural intensification commonly implies lack of agricultural land use expansion and increase in productivity by increasing the rates of inputs. Higher productivities can, however, be also achieved by increasing the production/technical efficiency of use of inputs for farm production (Pascual, 2005) and such intensification options become highly valuable in situations where inputs are scarce or too costly to afford. While generally intensification refers to a trend of increase in rates of use of modern agricultural inputs like chemical fertilizers, pesticides and fossil fuel driven machinery brought from outside the system, intensification also implies a trend of increase in rates of traditional inputs like organic manure, draught power and human labor (Thierfelder et al., 2005). As farming systems develop, soil fertility is first managed through reallocation and intensified use of organic material and mineral fertilizers are only used when such options are exhausted (Abdoulaye and Lowenberg-DeBoer, 2000). A mixed crop system may be more intensive in terms of productivity than a sole crop system (Nair, 1993), if species constituting the mixture have non-overlapping niche, facilitate growth of each other or a mixed crop suppress weeds detrimental to growth of some or all crops in the mixture. Increase in planned biodiversity could be an indicator of land use intensification. A tree plantation system is viewed as a land use more intensive than natural forests (Steffan Dewenter et al., 2007) or arable land use more intensive than pasture and pasture more intensive than old growth forests or tree plantations (Collard and Zammit, 2005; Fedroff et al., 2005). In regions undergoing conversions of primary forests to plantation, e.g., Indonesia, while primary forests represent the lowest, the unshaded cacao plantations the highest and shaded cacao agroforests the medium levels of land use intensity (Steffan-Dewenter et al., 2007). In these examples, intensification, apart from other things, means the magnitude of change brought in climax or near climax forest ecosystems. Differing from these examples, are the cases where intensification implies changes in rates of inputs and/or outputs within agricultural or pasture or forestry land uses (Giller, 1997; Urama, 2005; Roschewitz et al., 2005) or in relative proportions of these land uses in the landscapes (Ponge et al., 2003; Fedroff et al., 2005) (Table 3, 4).

Traditional crop-livestock mixed farming, the backbone of livelihood of local people in the Himalaya, is highly dependent on forests for livestock feed and manure. Changes in forest ecosystem structure and functions may be coupled with changes in the 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 and grazing/lopping intensity in forests may be coupled with changes in forest ecosystem structure and functions. It has been estimated that 4-5 ha of forestland would be the minimum requirement for providing fodder and manure needed for maintaining soil fertility and sustainable yields in 1 ha of traditional settled agriculture in central Himalayan region, (Hrabovzsky and Miyan, 1987; Ashish, 1993). 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 these locally valued environmental services 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). In the Himalayan mountain system and other regions, where agriculture and forests are interacting rather than independent and isolated land uses, there is a need to look at intensification in agricultural land use together with that in the forest land, i.e., a need to view intensification as a process influencing and influenced by landscape structure and processes (Ives and Messerli, 1989; Hurni, 1999; Briggs and Twomlow, 2002; Ghersa et al., 2002; Desbiez et al., 2004; Baijukya et al., 2005).

2.1. Intensification, genesis of different land use types and land use differentiation in landscapes

Generally, farmers intensify production in two situations: (i) when there is a need to intensify, e.g., land scarcity because of population pressure or other demands on land and (ii) when farmers perceive market related or other benefit from intensification (Brookfield, 1972; Boserup, 1981; Turner and Ali, 1996). Illustrating a case of Western Africa, Ridder et al (2004) show that soil fertility management practices follow a path from fallow, via intensifying recycling of nutrients combined with increased integration of livestock and arable farming to using external inputs. Instead of a complete replacement of one stage/state by another stage/state over time, different states/stages of intensification often coexist. Differentiation of land use along intensification gradient varies in time and space because of variation in factors determining nature and intensity of intensification such as environmental limits to productivity, farmers' needs, desire, resources available to farmers, market potential and government policies influencing farmers' decisons (Table 4).

Traditional land management objectives and practices have changed with changing socio-economic conditions, technological innovations and policy interventions Himalaya (Singh et al., 1997; Sherchan et al., 1999; Pilbeam et al., 2000; Plieninger and Wilbrand, 2001; Zhang et al., 2004; Baijukiya et al., 2005). This implies that the present landscape structure provides an imprint of the past courses of land use changes. The village landscapes in the Garhwal Himalaya comprise three broad land-use/cover types viz., settled agriculture, shifting agriculture and forests. Shifting agriculture is indeed confined to only a few villages now. Settled agriculture is further differentiated as (i) homegarden: a dense crown cover (> 80%), dominance of fruit trees and understorey vegetable crops irrigated by domestic waste water, (ii) rainfed agroforestry system: rainfed cultivation of food crops and scattered multipurpose trees (crown cover 10-20%), (iii) rainfed crop system: rainfed cultivation of food crops in the absence tree cover and (iv) irrigated crop system: cultivation of food crops irrigated by stream water and absence of trees. Irrigated crop systems differ based on the reasons behind their origin – at some places they derive from the government subsidy available for small run-off harvesting tanks to individual families, at some places from minor/major irrigation canal system maintained by the government and at some places from indigenous canal irrigation systems innovated and maintained by the local communities (Rao and Saxena, 1994; Chandrasekhar et al., 2007; Singh et al., 2008). While the indigenous irrigation systems may be centuries old, the introduced ones came in existence from 1970 onwards. The instances of conversion of traditional rainfed to irrigated agriculture induced by the need of intensification to meet the increasing food demands free from any external influence are rare **(CAN WE GIVE A REFERENCE HERE)** suggesting lack of any serious level of food insecurity. There are many instances where irrigation systems supported by the government collapsed after few years but not of indigenous systems possibly because of a mismatch between the introduced irrigation technologies and existing socio-cultural systems. In most village landscapes, rainfed agriculture and irrigated agriculture coexist, the latter largely in flat lands around perennial streams and the former on exposed steep slopes. The homegarden system, a minor land use in terms of spatial extent but the most intensive one in terms of output and input rates, seems as old as the agricultural land use. Farmers use multiple criteria to value a given land use, including availability of inputs, magnitudes of returns to land and labour in terms of both local food security and income and likely losses due to environmental risks and uncertainties (Table 5, 6). For example, there are three primary purposes behind maintaining homegardens viz., (i) productive recycling of household wastes, (ii) achieving nutritional security/health care and conservation of agrobiodiversity and (iii) enhancement of indigenous knowledge and it so happens, the first objective being the most important one in farmers' perceptions.

The abundance and species composition of farm tree community in the Himalaya enormously vary in time and space and this variation stem from variation in threats to the local livelihood due to shortage of forest resources, indigenous knowledge on tree-crop mixed farming and policies influencing costs and benefits of growing trees in private farm lands (Gilmour and Nurse, 1991; Nautiyal et al., 1998; Pilbeam et al., 2000). Farmers of the Indian Himalaya believe that yield depressing effects of indigenous multipurpose trees on understorey crops outweigh their yield enhancing effects, an element of traditional knowledge also supported by scientific evidences (Narain et al., 1998; Semwal et al., 2002). Although income to farmers from wood from farm trees can compensate for the loss of crop yields in tree-crop mixed farming, the policies as well as religious beliefs restrain adoption of wood trade as a means of livelihood (Sacred grove book). Farm tree density is negligible in villages where forest resources accessible to people are adequate to meet their basic needs of fodder, manure and fuelwood (Rao and Saxena, 1994 or 1996; Semwal et al., 2004). Maintenance of high quality fodder trees viz., *Grewia optiva* and *Boehmeria rugulosa*, in the rainfed agroforestry system in many Indian Himalayan villages could be viewed as an adaptive response of local farmers to cope with shortage of fodder and manure arising from the policies favouring timber-centred forest management together with reduction in forest area accessible to the local people. Farmers, however, do not maintain trees in the rainfed/irrigated crop system located far away from the homesteads because of huge labour and time required for managing trees, transporting fodder and protecting crops from birds perching on agroforestry trees (Gilmour and Nurse, 1991; Singh et al., 2008).

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.

Agricultural intensification trajectories constructed based on our studies are summarized in Figure 1. Though climate permitted harvesting of two crops, one grown during rainy season and the other during winter season, traditional rainfed agriculture involved harvesting of three crops every two, with fallowing of a field during winter season once in every two years period. The agricultural land of a village used to be divided into two almost equal halfs called Sars, with all families of the village having land parcels in both halves and each Sar was fallowed every alternate year. This traditional system has changed in response to the changes in both internal and external factors. While having two crops every year is getting more and more common, agroecosystem structure and management practices differ depending on the availability of fodder from forests and access to government support for establishing irrigation facilities and growing horticultural crops (Singh et al., 1996; Rao et al., 2003). In traditional irrigated land uses, number of crops harvested in year has remained unchanged but staple paddy and wheat crops are replaced by cash crops (particularly vegetables) and farmers often use chemicals if available at subsidized price. The examples of decline in land use intensity, though few, do exist. Agricultural land use is casual and less intensive in fields located far away from the dwellings and is often completely abandoned if a family is able to secure livelihood from non-farm occupations or extreme degradation of agricultural land as a result of past unsound land uses (Maikhuri et al., 1995; Singh et al., 2008).

2.2. Land use diversity, intensification and environmental risks and uncertainties

Agricultural land-use diversity reflects farmer’s ways of coping with the risks and uncertainties. In Garhwal Himalaya, farmers view two major risks to crop productivity in their traditional terraced agroecosystems: the risk of climate arising from uncertainty of monsoon rainfall and of cultivating distant fields arising from huge labour and time to be spent in travel/transport. Rainfed crop system was characterized by of both climate and distance related risks, rainfed agroforestry system by only climatic risks, irrigated crop system by only distance related risk and homegardens by neither of the two risks. The most risky rainfed crop system received the lowest and the least risky homegardens the highest level of agricultural inputs. Crops common to rainfed agroforestry system and rainfed crop system were paid more attention in the former system because of lesser risks. Thus, if there is a gradient of risks to crop productivity across coexisting and broadly similar agroecosystem types, less risky agroecosystems like homegardens are more intensively managed as compared to the more risky ones (Figure 2) as also concluded by 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 (Table 7). 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 (Figure 3) 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 rainfed agroforestry system and the rainfed crop system differing in manure input rates and soil nutrient levels observed by us (Table 7) 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.

Himalayan farmers view fingermillet and barnyard millet as less-delicious staple food compared to maize and rice. Yet, the former millets cover a significant area as they provide options for coping with the unpredictability and variability of monsoon climate and their yields are not much influenced by the rates of farm yard manure input. Thus, production of a less-delicious staple food is reconciled with the lesser risks of crop failure. Though farmers have been exposed to market economy since last couple of decades, they seem to have some understanding of the risks and uncertainties related to fluctuation in market prices and demands (Jodha, 2000). They tend to grow cash crops to an extent that there are minimal risks to local production based food security (Semwal et al., 2004; Singh et al., 2008). Thus, all crops/cropping systems do not equally respond to increase in inputs, the most productive crops/cropping systems may not be the most profitable ones or the most resilient ones and differentiation of land use based on intensification level in the landscape is guided by interaction of environmental and socio-economic factors.

3. Measurement of land use intensification

With population growth and market expansion being the two prime factors driving intensification, one deals with two different propositions: (i) intensification can be an incremental process, discernible through analysis of continuous variables and (ii) there are thresholds at which qualitative changes are likely and absolutely necessary if resource degradation is not to set in (Guyer and Lambin, 1993).The measures used to quantify agricultural intensity fall in three groups: (i) output as a measure of agricultural intensity measured as production intensity, i.e., productivity per unit area per unit time of some desirable product or service, (ii) cropping frequency measured as number of harvests per year from a field or relative proportion of cultivated land to fallow or forest forest land and (iii) input rates, i.e., rates of application of labour, materials, energy consumption per ha per year. Netting (1993) considers output as the ideal measure of intensity because it makes no presumptions about the effect of inputs on productivity, while Shriar (2000) considers cropping frequency and input rates as surrogate measures in situations where output data are not available.

3.1. Output based measurements

Output itself can be measured in a number of terms, e.g., human food yield, livestock fodder/feed yield, net primary productivity and income, which may not be correlated. The measures would also vary depending on the scale – spatial scale varying from a crop field to landscapes and time scale from one growing season to several seasons. A 20 year time frame of measurement enables comparison of both settled and shifting agricultural systems (Turner and Doolittle, 1978). Output of a tuber/root crop in strict sense is not equivalent to the output from a staple food crop or a fruit crop. Turner et al. (1977) note that root crops like have a different relationship with agricultural intensity than cereal crops. Introduction of cassava in urban hinterlands of Africa brought a new set of possibilities altogether – high yields on low quality land with low labour inputs and high marketability in processed forms (Guyer and Lambin, 1993). A traditional crop like *Macrotyloma uniflorum* turned as cash crop enabling labour productivity on low quality land in the Garhwal Hiamlaya (Singh et al., 2008). Outputs from an agroecosystem are different from those from forest ecosystems, but all kinds of outputs can be brought to a common measurement unit by obtaining their monetary values. Variation in the nature of outputs of different crops and variation, both spatially and temporally, in farmgate prices of different outputs warrant care in comparing intensification levels of different agroecosystems based on monetary outputs (Shriar, 2000). One could also take total net primary production or its fraction used by humans as output for comparing different agroecosystems (Table 8).

3.2. Cropping frequency based measurements

Frequency of cultivation or land use is the most common measure of agricultural intensity and is an easy measure of comparing agricultural systems where similar technologies are used (Netting, 1993). However, its use sometimes suffers from confusion and vagueness. For example, in shifting agriculture area, frequency can be measured in two ways: (i) cropped area/total crop + fallow area (ii) length of cropping phase/length of fallow phase, the latter being a more useful way of measuring intensification (Table 9). Such measures of cropping would be useful for mono-crop system where only one crop is sown and all individuals are harvested at a time but not for mixed crop system where a large number of food crops are sown together but harvested at different points of time or where perennial crops coexist with the annual crops (i.e., agroforestry systems).

3.3. Agrotechnologies based measurements

As intensification can be measured in terms of several variables which may not necessarily be correlated, the information content in different variables can be synthesized in the form of composite indices. Indexing, as in other cases, involves three steps: (i) data compression leading to selection of variables/indicators constituting the minimum data set, (ii) transformation of indicator scores to quantify all indicators on a common measurement scale and (iii) combining the indicator scores into the index. Selection of intensification indicators and their statistical/mathematical treatment to derive a composite index vary a lot. Brookfield and Hart (1971) ranked farming systems based on a sum of ranks given based on cultivation methods (or the agrotechnologies), cultivation frequency and crop segregation (Table 10). Such an approach with some modifications is also illustrated by Turner and Doolittle (1978). An element of subjective bias in assigning points for a given feature and consideration of all methods equally important are the major drawbacks of such approaches. The so called ‘low tech’ systems may not necessarily be less productive than the ‘high tech’ systems. Tractors enable cultivation of large areas with less labor input, but may not necessarily enable the high yields. Wheat yields in agricultural systems with extensive tractor uses in USA and Canada were estimated as 2128-2655 kg/ha compared to 4689-4735 kg/ha in Mexico and Central America where tractor use is much less common (FAO, 1999; Shriar, 2000). Shriar (2000) proposed that agrotechnoloies and other crop productions strategies based measures of intensification can be improved by (i) considering the proportion of the cropped area, on which the farmer applies each intensification strategy and (ii) by seeking local knowledge, and if available and valid, experimental data, on the degree to which each strategy contributes to higher higher yield per unit area per unit time. The method of ranking households based on intensification (Shriar, 2000) is summarized in table 11 and of measuring degree of intensification of different land uses in table 1. It is difficult to arrive at objective weights that accurately reflect the contribution of each strategy to overall output or to different input factors determining the outputs.

As different inputs or outputs (Table 1 and 2) may not follow the same spatio-temporal trends, a land use more intensive in terms of one input or output may appear less or equally intensive in terms of other input(s) or output(s) compared to other land uses. Roschewitz et al. (2005) found landscape complexity and farm specialization to be correlated with several parameters of land use intensity but not of pesticide use suggesting that natural enemies of insect pests may not always be more effective in structurally complex landscapes (Menalled et al., 1999; Thies and Tscharntke, 1999). To the extent possible, it will be worthwhile to identify some common denominator to obtain a clearer overall picture of the total outputs and inputs (Kates et al., 1993). All kinds of inputs and outputs can be measured in terms of their energy or monetary values as shown in Figure 2. Land use intensity may be measured as total input, total output and total output: total input ratio. Instead of taking energy or monetary output, one could also take net primary productivity and its fraction appropriated directly or indirectly by humans as an indicator of land use intensity – higher the proportion of net primary productivity utilized by human and taken out of a land use, more intensive is the land use. In the Himalayan region, net primary productivity of forests is almost equal to that of homegardens but 53-64% of forest productivity is utilized by humans compared to 84% in the case of homegardens. Net primary productivity of rainfed agriculture is about 25% lower than than that of homegardens but the two land uses resemble in terms of proportion of NPP utilized by humans (Table 8).

Working with actual indicators, which have a physical unit (e.g. kg N/ha, cm irrigation water input/ha, GJ fossil fuel energy/ha), has the merit of being more readily interpretable and transparent, whereas the overall index is likely to blur causal relationships between components of intensity and environmental variables (Herzog et al., 2006).

3.4. Ordination of ecosystems along intensification gradient

Principal Component Analysis (PCA) is a data compression technique designed for data that are in the form of continuous measurements, though it has been also been applied to other kind of data such as presence/absence of an element or discrete measurements on ordinal scales. Ordination, a collective term for multivariate techniques that arrange sites along axes to show whether important environmental variables have been overlooked or the explanatory variables selected in the study adequately explain the response variables. Ordination is like a linear regression model, but with the major difference that the explanatory variables here are theoretical variables and not known environmental variables (Jongman et al., 1995). Principal components for a data set are defined as linear combinations of the variables that account for maximum variance within the set by describing vectors of closest fit to the n observations in p-dimensional feature space, subject to being orthogonal to one another. The PCA output gives as many PCs as the input variables but it is assumed that PCs receiving high eigenvalues (setting a threshold, e.g., eigenvalues > 1) or those explaining variation in the data exceeding a limit (e.g., > 5% of the variability) are 'important' and not the others (Kaiser, 1960; Wander and Bollero, 1999). Contribution of a variable to a particular PC is represented by a weight or factor loading. Only the highly weighted variables are retained from each PC and highly weighted factor loadings identified based on thresholds such as those variables with absolute values within 10% of the highest factor loading or > 0.40. When more than one factor is retained under a single PC, multivariate correlation coefficients are employed to determine if variables could be considered redundant and if the variables are correlated, that with the highest value is chosen for MDS (Andrews et al., 2001, 2002). PCA analysis based on a range of indicators land use intensification (manure input, labour input, labour input, production of food, production of fodder and income) measured at crop field level and land use type level (Figure 4a, b) showed about 80% variation in crops or land use types was explained by first two PCA axis. While the first axis seemed to reflect a gradient of manure input (lower PC1 values corresponding to lower manure inputs), we could not identify the factor explaining the variation in PC2 suggesting that either the factor explaining this variation was not included in the explanatory variables or it corresponded to outcome of more than one explanatory variables that were measured. It is also evident that radically different crops may resemble in terms of their intensification level (e.g., *Echinochloa frumentacea* grown in rainfed agroforestry system and *Trticum aestivum* in irrigated crop system – Figure 4a) or apprarently divergent land use types may resemble more in terms of intensification that the apparently similar types (e.g., rainfed agroforestry system seems closer to irrigated crop system than rainfed crop system in terms of land use intensification – Figure 4b).

3.5. Soil organic carbon concentration as an indicator of intensification

Soil organic matter serves as a primary indicator of soil quality and health for both scientists and farmers (Romig et al., 1995; Komatsuzaki and Ohta, 2007). Several researchers have observed a decline in soil organic matter with increasing agricultural land use intensity and duration (Dalal and Mayer, 1986; Golchin et al., 1995; Spaccini et al., 2001; Lemenih et al., 2005) due to changes in soil structure caused by tillage, removal of biomass and increased mineralization and decomposition of exposed soils (Oldeman et al., 1990). Mann (1986) found soil C in cultivated soil on average 20% less than uncultivated soils and the greatest rate of change during the first 20 years after land use change based on analysis of soil data from 50 different sources. The magnitude of decline in soil carbon depends on the soil depth used for carbon estimations and time scale of land use change. Davidson and Ackerman (1993) found mean carbon loss of 30% if both A and B horizons were considered compared to 40 if only A horizon was considered. However, such a decline is more prominent in labile carbon fractions, which are highly correlated with soil microbial biomass and the availability of labile nutrients such as nitrogen, phosphorus and sulfur, than in total soil organic matter (Powlson et al., 1987; Blair et al., 1995; Sangha et al., 2005; Collard and Zammit, 2006). Based on a 6-year trial of soil quality monitoring in New Zealand, Sparling et al. (2004) did not find utility of microbial biomass and soil respiration measures of soil quality because of difficulty in ephemeral nature of such biological measurements and the difficulty in justifying their target ranges. As the impacts of land management practices are marked in terms of variation in labile fraction of organic carbon or microbial quotients than in total soil organic carbon (Breland and Eltun, 1999), an index derived from both labile and non-labile carbon fractions is likely to be a more sensitive indicator of land use intensification or land management practices compared with a single measure of soil carbon content.

Blair et al. (1995) proposed carbon management index (CMI), a multiplicative function of carbon pool index (CPI) and lability index (LI) as an indicator of the rate of change of soil organic matter in response to land management changes, relative to a more stable reference soil:

Carbon pool index (CPI) = Total C of a given land use/Total C of the reference land use

Lability index (LI) = [Labile carbon content of a given land use/Non-labile carbon content of a given land use] X [Labile carbon content of the reference land use/Non-labile carbon content of the reference land use]

Carbon management index (CMI) = CPI X LI X 100

Collard and Zammit (2006) extended this concept initially applied at ecosystem/land use type scale to landscape scale. They calculated ‘landscape CMI’ as sum of the products of multiplication of the CMI values of different land uses differentiated in a landscape by the relative areas (%) of different land uses.

Unlike many other regions where there are negligible resource flows among ecosystem/land use types differentiated in the landscape, traditional resource management practices in the Himalaya are such that some outputs of forests (e.g., litter and livestock feed) are inputs to agroecosystems (farm yard manure prepared by mixing forest leaf litter and livestock excreta) and crop-livestock-forests interactions are such that diverse land uses like rainfed agriculture, pine forests and oak forests resemble in terms of mean soil organic carbon and nutrient concentrations of soil columns. The effect of land use on soil chemical properties are visible more in surface soil than in the deeper soils or the entire soil column. Homegardens which receive larger quantitities of manure have soil organic carbon and nutrient stocks larger than rainfed agriculture and forests (Figure 5). Magdoff (1998) reported potential crop yield increases of 12% for every 1% of soil organic matter based on his studies in USA. There has been no consensus on what the critical level of soil organic matter should be in an agricultural soil and how this level will vary between soils of different textural classes under different environmental conditions (Nortcliff, 2002).

4. Conclusions

There are several measures and indicators of land use intensification, which may not be necessarily correlated. Thus, a land use concluded to be more intensive based on some indicator(s) or measure(s) may be less intensive based on other indicator(s) or measures. Land use intensity should be evaluated at agroecosystem types/farm type and village landscape level rather than at individual crop level. A list of variables related to intensification identified for the Himalayan region is given in Table 12.

Achieving higher yields and profits is an important but not the sole objective of Indian farmers. The evaluation of past and present land uses bring out opportunities of achieving higher profits by three pathways: (i) increasing the rates of locally available inputs, e.g., farm yard manure, providing deficient /life saving irrigation and intermixing of crops/cultivars (ii) increasing the efficiency of use of inputs for farm production, e.g., improving the quality of farm yard manure and chosing crops/cultivars based on their ecological adaptations, e.g., growing *Macrotyloma uniflorum* in sandy/stony soil without any irrigation and *Eleusine coracana* on residual soil fertility.

In Himalayan region, one observes coexistence of a variety of land use types differing in terms of input rates, yields (outputs), outputs in relation to inputs, resilience to environmental and economic variability and uncertainty rather than any trend of replacement of less intensive by more intensive land uses with increasing population pressure and market forces. Homegardens, which constitute a minor land use (rarely >2% of total village area or 5% of total farm land area), represent the most intensive land use system in terms agricultural input rates, output rates, output to input ratios and the most rich one in terms soil organic carbon and nutrient stocks.

Conclusions about land use intensification-biodiversity-ecosystem function relationships would depend on what criteria and spatio-temporal scales have been chosen for measuring explanatory and response variables.

References

Abdoulaye, T. and Lowenberg-DeBoer, J. 2000. Intensification of Sahelian farming systems: Evidence from Niger. Agriculture Systems, 64: 67-81.

Ashish, M. 1993. Decentralized management of natural resource in the U.P. Hills. Economic and Political Weekly, XXVII: 1793-1796.

Baijukya, F.P., Ridder, N. de., Masuki, K.F., and Giller, K.E.: 2005, ‘Dynamics of banana-based farming systems in Bukoba district, Tanzania: changes in land-use, cropping and cattle keeping,’ *Agric. Ecosys. Env.* **106**, 395-406.

Bardsley, D. 2003. Risk allevation via in situ agrobiodiversity conservation : drawing from experience in Switzerland, Turkey and Nepal. Agirculture, Ecosystems and Environment, 99: 149-157.

Blair, G.J., Lefroy, R.D.B. and Lisle, L. 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Australian Journal of Agricultural Resaech, 46: 1459-1466.

Bohle, H., and Adhikari, J.: 1998, ‘Rural livelihoods at risk. How Nepalese farmers cope with food insecurity,’ *Mountain Res. Dev.* **18**, 321-332.

Boserup, E. 1965. The Conditions of Agricultural Growth. Chicago: Aldine.
Boserup, E. 1981. Population and Technology. Oxford: Blackwell.
Briggs, L., and Twomlow, S.J.: 2002, 'Organic material flows within a smallholder highland farming system of South West Uganda,' *Agric. Ecosys. Env.* **89**, 191-212.
Brookfield, H.C. 1972. Intensification and disintensification in Pacific agriculture: A theoretical approach. Pacific Viewpoint, 25: 15-44.
Brookfield, H.C. and Hart, D. 1971. Melanesia: A geographical Interpretation of an Island World. London: Methuen.
Cairns, M., and Garrity, D.P.: 1999, 'Improving shifting cultivation in Southeast Asia by building on indigenous fallow management strategies,' *Agrof. Sys*. **47**, 37-48.
Carter, S.E., and Murwira, H.K.: 1995, 'Spatial variability in soil fertility management and crop response in Mutoko communal area, Zimbabwe,' *Ambio* **24**, 77-84.
Chandrasekhar, K., Rao, K.S., Maikhuri, R.K., and Saxena, K.G.: 2007, 'Ecological implications of traditional livestock husbandry and associated land-use practices: A case study from the trans-Himalaya, India,' *J. Arid Env.* **69**, 299-314.
Collard, S.J. and Zammit, C. 2006. Effects of land-use intensification on soil carbon and ecosystem services in Brigalow (Acacia harpophylla) landscapes of southeast Queensland, Australia. Agriculture, Ecosystems and Environment, 117: 185-194.
Dalal, R.C. and Mayer, D.G. 1986. Long-term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. I. Overall changes in soil properties and trends in winter cereal yields. Australian Journal of Soil Research, 24: 265-279.
Desbiez, A., Matthews, R., Tripathi, B., and Ellis-Jones, J.: 2004, 'Perceptions and assessment of soil fertility by farmers in the mid-hills of Nepal,' *Agric. Ecosys. Env.* **103**, 191-206.
Fedoroff, E., Ponge, J. –F., Dubs, F., Fernandez-Gonzalez, F. and Lavelle, P. 2005. Small-scale response of plant species to land-use intensification. Agriculture, Ecosystems and Environment, 105: 283-290.
Ghersa, C.M., Ferraro, D.O., Omacini, M., Martinez-Ghersa, M.A., Perelman, S., Satorre, E.H., and Soriano, A.: 2002, 'Farm and landscape level variables as indicators of sustainable land-use in the Argentine Inland-Pampa,' *Agric. Ecosys. Env.* **93**, 279-293.
Giller, K.E., Beare, M.H., Lavelle, P., Izac, A.-M.N. and Swift, M.J. 1997. Agricultural intensification, soil biodiversity and agroecosystem function. Applied Soil Ecology, 6: 3-16.
Gilmour, D.A. and Nurse, M.C. 1991. Farmer initiatives in increasing tree cover in central Nepal. Mountain Research and Development, 11: 329-337.
Golchin, A., Clarke, P., Oades, J.M. and Skjemstad, J.O. 1995. The effects of cultivation on the composition of organic matter and structural stability of soils. Australian Journal of Soil Research, 33: 975-993.
Guyer, J.I. and Lambin, E.F. 1993. Land use in an Urban Hinterland: ethnography and remote sensing in the study of African intensification. American Anthropologist, 95: 839-859.
Hrabovzsky, J. and Miyan, K. 1987. Population growth and land use in Himalaya. Mountain Research and Development, 7: 264-270.
Hurni, H.: 1999, 'Sustainable management of natural resources in African and Asian mountains,' *Ambio* **28**, 382-389.

Ives, J.D., and Messerli, B. : 1989, *The Himalayan Dilemma: Reconciling Development and Conservation*, Routledge, London.

Jodha, N.S.: 2000, 'Globalisation and fragile mountain environments: Policy challenges and choices,' *Mountian Res. Dev.* **20**, 296-299.

Kates, R.W., Hyden, G. and Turner, B.L.II. 1993. Theory, evidence, study design. In: Turner, B.L.II, Hyden, G. and Kates, R.W. (Eds.). Population Growth and Agricultural Change in Africa. PP. 1-40. University Press of Florida, Gainesville FL., USA.

Kundu, S., Bhattacharyya, R., Prakash, V., Ghosh, B.N. & Gupta, H.S. 2007. Carbon sequestration and relationship between carbon addition and storage under rainfed soybean-wheat rotation in a sandy loam soil of the Indian Himalayas. Soil & Tillage Research, 92: 87-95

Lemenih, M., Karltun, E and Olsson, M. 2005. Assessing soil chemical and physical property responses to deforestation and subsequent cultivation in smallholders farming system in Ethiopia. Agriculture, Ecosystems and Environment, 105: 373-386.

Maikhuri, R.K., Rao, K.S., and Saxena, K.G.: 1996, 'Traditional crop diversity for sustainable development of Central Himalayan agroecosystems,' *Int. J. Sust. Dev. World Eco.* **3**, 8-31.

Maikhuri, R.K., Semwal, R.L., Rao, K.S., Singh, K. & Saxena, K.G. 2000. Growth and ecological impacts of traditional agroforestry tree species in central Himalaya, India. Agroforestry Systems, 48: 257-272.

Mann, L.K. 1986. Changes in soil carbon storage after cultivation. Soil Science, 142: 279-288.

Menalled, F.D., Marino, P.C., Gage, S.H. and Landis, D.A. 1999. Does agricultural landscape structure affect parasitism and parasitoid diversity? Ecological Applications, 9: 634-641.

Nair, P.K.R. 1993. Introduction to Agroforestry. Kluwer Academic Publishing, Dordrecht, The Netherlands, 499pp.

Narain, P., Singh, R.K., Sindhwal, N.S. and Joshie, P. 1997. Agroforestry for soil and water conservation in the western Himalayan valley region of India. I. Runoff, soil and nutrient losses. Agroforestry System, 39: 175-189.

Nautiyal, S., Maikhuri, R.K., Semwal, R.L., Rao, K.S. and Saxena, K.G. 1988. Agroforestry systems in the rural landscape – a case study in Garhwal Himalaya, India. Agroforestry System, 41: 151-165.

Negi, A.K., Bhatt, B.P., Todaria, N.P. and Saklani, A. 1997. The effect of colonialism on forests and the local people in the Garhwal Himalaya, India. Mountain Research and Development, 17: 159-168.

Netting, R.McC. 1993. Smallholdrs, Householders: Farm Familes and the Ecology of Intensive, Sustainable Agriculture. Stanford, California: Stanford University Press.

Oldeman, L., van Engelen, V. and Pulles, J. (Eds.). 1990. The Extens of Human-Induced Soil Degradation. International Soil Reference and Information Center, Wageningen.

Pascual, U. 2005. Land use intensification potential in slash-and-burn farming through improvements in technical efficiency. Ecological Economics, 52: 497-511.

Pichon, F.J. 1996. The forest conversion process: a discussion of the sustainability of predominant land uses associated with frontier expansion in the amazon. Agriculture and Human Values, 13: 32-51.

Pilbeam, C.J., Tripathi, B.P., Sherchan, D.P., Gregory, P.J., and Gaunt, J.: 2000, 'Nitrogen balances for households in the mid-hills of Nepal,' *Agric. Ecosys. Env.* **79**, 61-72.

Plieninger, T., and Wilbrand, C.: 2001, 'Land-use, biodiversity conservation, and rural development in the dehesas of Cuatro Lugares, Spain,' *Agrof. Sys.* **51**, 23-34.

Powlson, D.S., Brookes, P.C. and Christensen, B.T. 1987. Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. Soil Biology and Biochemistry, 19: 159-164.

Ponge, J.F., Gillet, S., Dubs, F., Fedoroff, E., Haese, L., Sousa, J.P. and Lavelle, P. 2003. Collembolan communities as bioindicators of land use intensification. Soil Biology & Biochemistry, 35: 813-826.

Ramakrishnan, P.S.: 1992, *Shifting Agriculture and Sustainable Development – An Inter-disciplinary Approach from North-Eastern Himalayas*, UNESCO and Parthenon Publishing Group, UK.

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., and Saxena, K.G.: 1996, 'Minor forest product's management - problems and prospects in remote high altitude villages of Central Himalaya,' *Int. J. Sust. Dev. World Eco.***3**, 60-70.

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,' *Trop. Ecol.* **44**, 93-111.

Rawat, A.S. 1994. Deforestation and forest policy in the lesser-Himalayan Kumaon: impacts on peasant women and tribal populations. Mountain Research and Development, 15: 311-322.

Rawat, J.S., and Rawat, M.S.: 1994, 'Accelerated erosion and denudation in the Nana Kosi watershed, Central Himalaya, India. Part I. Sediment load,' *Mountain Res. Dev. 14,* 25-38.

Roschewitz, I., Thies, C. and Tscharntke, T. 2005. Are landscape complexity and farm specialization related to land-use intensity of annual crop fields? Agriculture, Ecosystems and Environment, 105: 87-99.

Saxena, K.G., Rao, K.S. and Purohit, A.N. 1993. Sustainable forestry – prospects in India. Journal of Sustainable Forestry, 1: 69-95.

Semwal, R.L., Maikhuri, R.K., Rao, K.S., Singh, K., and Saxena, K.G.: 2002, 'Crop productivity under differently lopped canopies of multipurpose trees in Central Himalaya, India,' *Agrof. Sys.* **56**, 57-63.

Semwal, R.L., Nautiyal, S, Sen, K.K., Rana, U., Maikhuri, R.K., Rao, K.S. & Saxena, K.G. 2004. Patterns and ecological implications of agricultural land-use changes: a case study from central Himalaya, India. Agriculture, Ecosystems & Environment, 102 (1): 81-92.

Sherchan, D.P., Pilbeam, C.J., and Gregory, P.J.: 1999, 'Response of wheat-rice and maize/millet systems to fertilizer and manure applications in the mid-hills of Nepal,' *Exp. Agric*. **35**, 1-13.

Shriar, A.J. 2000. Agricultural intensity and its measurement in frontier regions. Agroforestry Systems, 49: 301-318.

Shriar, A.J. 2001. The dynamics of agricultural intensification and resource conservation in the buffer zone of the Maya biosphere reserve, Peten, Guatemala. Human Ecology, 29: 27-48.

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,' *J. Sust. Agric.* **9**, 25-49.

Singh, K., Maikhuri, R.K., Rao, K.S. and Saxena, K.G. 2008. Characterizing land-use diversity in village landscapes for sustainable mountain development: a case study from Indian Himalaya. Environmentalis, (in press).

Spaccini, R., Zena, A., Igwe, C.A., Mbagwu, J.S.C. and Piccolo, A. 2001. Carbohydrates in water-stable aggregates and particle size fractions of forested and cultivated soils in two contrasting tropical ecosystems. Biogeochemistry, 53: 1-22.

Sparling, G.P. Schipper, L.A., Bettjeman, W. and Hill, R. 2004. Soil quality monitoring in New Zealand: Practical lessons from a 6-year trial. Agriculture, Ecosystems and Environment, 104: 523-534.

Steffan-Dewenter, I., Kessler, M., Barkmann, J., Bos, M.M., Buchori, D., Erasmi, S., Faust, H., Gerold, G., Glenk, K., Gradstein, S.R., Guhardja, E., Harteveld, M., Hertel, D., Hohn, P., Kappas, M., Kohler, S., Leuschner, C., Maertens, M., Marggraf, R., Migge-Kleian, S., Mogea, J., Pitopang, R., Schaefer, M., Schwarze, S., Sporn, S.G., Steingrebe, A., Tjitrosoedirdjo, S.S., Tjistrosoemito, S., Twele, A., Weber, R., Woltmann, L., Zeller, M. and Tscharntke, T. 2007. Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. PNAS, 104: 4973-4978.

Thierfelder, C., Amezquita, C.E. and Stahr, K. 2005. Effects of intensifying organic manuring and tillage practices on penetration resistance and infiltration rate. Soil & Tillage Research, 82: 211-226.

Thies, C. and Tscharntke, T. 1999. Landscape structure and biological control in agroecosystems. Science, 285: 893-895.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R., Polasky, S. 2002. Agricultural sustainability and intensive production practices. Nature, 418: 671-677.

Turner, B.L. II, and Doolittle, W.E. 1978. The concept and measure of agricultural intensity. The Professional Geographer, 30: 297-301.

Turner, B.L. II, Hanham, R.O. and Anthony, V.P. 1977. Population pressure and agricultureal intensity. Annals of the Association of American Geographers, 67: 384-396.

Turner, B.L.II., and Ali, A.M.S. 1996. Induced intensification: Agricultural change in Bangladesh with implications for Malthus and Boserup. Proceedings of the National Academy of Sciences USA, 93: 14984-14991.

Urama, K.C. 2005. Land-use intensification and environmental degradation: empirical evidence from irrigated and rain-fed farms in south eastern Nigeria. Journal of Environmental Management, 75: 199-217.

von Thunen, J. 1966. Isolated State: As English Version of Der Isolierte Statt. Oxford and New York: Pergamon Press.

Zhang, Qiu-Ju., Fu, Bo-Jie., Chen, Li-Ding., Zhao, Wen-Wu, Yang, Qin-Ke., Liu, Guo-Bin., and Gulinck, H.: 2004, 'Dynamics and driving factors of agricultural landscape in the semiarid hilly area of the Loess Plateau, China,' *Agric. Ecosys. Env.* **103**, 535-543.

Missing references

Nortcliff, 2002
Magdoff, 1998
Breland and Eltun, 1999
Sandha et al., 2005
Romig et al., 1995
Komatsuzaki & Ohta, 2007
Andrews et al., 2001, 2002
Kaiser, 1960
Wander and Bollero, 1999
Jongman et al., 1995
Herzog et al., 2006
Giller, 1997
DeFries et al., 2004
Hoekstra et al., 2004
Chapin et al., 2000
Green et al., 2005
Leaf, 1987
FAO 1984
Billeter et al., 2008

Table 1. Measures and indices of agricultural intensification

Author(s)	Measures or indicator of intensification
Leaf (1987)	Area under irrigation Number of harvests per year Input and output per ha and per person Capitalization per ha and per person Population density per ha Energy consumption per ha Total tonnage and calories produced per ha and per person
FAO (1984)	Land use factor = years of cultivation plus years of fallow/years of cultivation
Ruthenberg (1976)	R value = (Farm unit area under cultivation/total area available for arable farming) x 100; R < 33 is classified as shifting cultivation, R = 33-66 as semi-permanent fallowing systems and R > 66 as permanent systems with mostly annual or perennial crops
Pryor (1985)	Cropping index = Land area used annually/total land area used primarily for agriculture; a value >1 implies the land is multicropped.
Boserup (1965, 1981)	Frequency of cropping: (a) length of cropping phase compared to that of fallow phase in shifting agriculture (intensification gradient : forest fallow cultivation → bush fallow cultivation →short fallow cultivation → annual cropping →multicropping (b) average cultivated area/cultivated area+fallow area x 100
Billeter et al. (2008)	Average number of crops cultivated on a farm Average nitrogen input Share of intensively fertilized arable area (>150 kg N/ha/year) Livestock density (livestock units per ha or per farm) Average number of pesticide application per field
Pascual (2005)	Productivie (Technical) efficiency – production per unit of input,higher the value more intensive the system is
Giller et al. (1997	Low value of land use intensity as defined by Ruthenberg (1980) x nutrient use (0 for completely internal cycling and 1 for completely external manure/fertilizer inputs) x pest management (0 for no intervention and 1 for full mechanical/chemical control x energy input rate (labour or fossil fuel) x water management (0 for rainfed and 1 for irrigated conditions)
Roschewitz et al. (2005)	Farm specialization: proportion of arable land per farm Landscape complexity: proportion of arable land per landscape

Table 2. Scale ranges and weights associated with the agricultural intensity index (Shriar, 2000)

Intensification activity	Scale range	Weight	Max. points
Scale of established Mucuna plots (use of Mucuna for maize production)	0-3	3.5	10.5
Scale of high value crop production	0-3	2.5	7.5
Scale of plowing	0-3	2.5	7.5
Scale of ranching intensity (number of cows per ha of pasture land)	0-3	2.5	7.5
Scale of intercropping	0-3	2	6
Scale of fertilizer use per ha	0-2	3	6
Scale of pesticide use per ha	0-3	2	6
Scale of permanent crop cultivation	0-3	1.5	4.5
Homegarden quality scale	0-3	1.5	4.5
Vegetable plot in season 1	0-1	2	2
Vegetable plot in season 2	0-1	2	2
Mucuna planted as some time	0-1	1	1
Use of other organic pest control	0-1	1	1
Use of other organic fertilization	0-1	1	1
Total			67

Table 3. Land use stages/types in intensification gradients studied in a cross section of studies (land use in the topmost row refers to the least and lowest row the most intensive land use in the given study)

Steffan-Dewenter et al. (2007)	Collard and Zammit (2006)	Fedroff et al. (2005)	Urama (2005)	Pascual (2005)	Giller et al. (1997)	Thierfelder et al. (2005)	Roschewitz et al (2005)
Near-primary forest	Brigalow (Acacia harpophylla)	Old growth forests	Rainfed farms	Shifting agriculture with low technical efficiency, i.e., ability to transform inputs into outputs	Low value of land use intensity as defined by Ruthenberg (1980) x nutrient use (0 for completely internal cycling and 1 for completely external manure/fertilizer inputs) x pest management (0 for no intervention and 1 for full mechanical/chemical control x energy input rate (labour or fossil fuel) x water management (0 for rainfed and 1 for irrigated conditions)	Crops receiving 4 t/ha/year of chicken manure	Areas with higher landscape complexity, higher farm specialization, higher fertilization input rates and higher yields
Cacao agroforest - 80% shade	Grasslands following clearing of original vegetation	Managed forests	Irrigated farms	Land uses with high technical efficiency		Crops receiving 8 t/ha/year of chicken manure	Areas with lower landscape complexity, lower farm specialization, lower fertilization rates and higher yields
Cacao agroforest -	Grasslands that have been	Mixed landscape dominated by					

40% shade	previously cultivated but left fallow for 3-15 years	woodland					
Cacao agroforest - unshaded	Recently (< 2 years) cultivated land	Mixed landscape not dominated by a single land use					
		Mixed landscape dominated by pasture					
		Mixed landscape dominated by arable crops					

Table 4. Factors influencing agricultural strategy and intensification in Northern Peten (Shriar, 2001)

Farm/household scale factors	Community and regional scale factors
Property size	Land quality and microclimate
Amount of remaining forest or property	Market conditions
Amount of land in fallow	Physiologic density
Amount of degraded land on property	Land distribution
Tenure	Availability of off-farm employment
Plot locations	Settler origins and number of years since the area was colonized
Soil quality	
Wealth	
Labour supply	
Extent of off-farm employment	
Farmer experience and knowledge	

Table 5. Objectives and risks identified by farmers for different land uses (Farmers were asked to list a maximum of three purposes and of three risks associated with different land use-land cover types in selected villages of Garhwal Himalaya)

Land use	Purposes/objectives associated with land use (in the order of priority given by numbers 1-3; the objectives given equal priorities are referred by digits followed by alphabets)	Risk(s) to production
Homegarden (nearest to the dwellings)	1a. Productive recycling of household wastes 1b. Nutritional security and local health care 2. Conservation of agrobiodiversity and enhancement of indigenous knowledge on uses of wild/domesticated plant species	1. Shortage of labour (e.g., due to outmigration for off-farm employment in urban/sub-urban centres) constraining realization of the potential of this highly productive system
Rainfed settled agroforestry (nearer to dwellings)	1. Food security based on a diverse food base, particularly the millets 2. Availability of fodder, particularly during winters, close to dwellings 3. Availability of other tree products close to dwellings	1. Variability and uncertainty of precipitation 2. Crop depredation due to wildlife attracted by trees (the birds perching on trees food eating crops and earthworms
Rainfed crop system (farthest from the dwellings)	1. Assertion of land ownership	1. Wastage of huge time and labour in travel and tranport 2. A low level of management results in abundance of weeds increasing risks of their speread to other land uses
Irrigated crop system (away from dwellings)	1. Benefting from subsidy provided by government for construction of irrigation structures and management 2. Improving food security by raising staple food crops, viz., rice and wheat, yields 3. Growing cash crops	1. Wastage of huge time and labour in travel and transport 2. Damages caused by overflow of water
Shifting agriculture	1a. Assertion of land ownership 1b. Achieving higher labour productivity 1c. Growing cash crops *(Macrotyloma uniflorum)*	1. Occurrence of extreme low monsoon
Forests	1a. Protection of agricultural land and dwellings from peak run-off flows during rainy season 1b. Recharge of springs, the sources of potable water 1c. Availability of manure and livestock feed required for sustaining crop cultivation 2. Availability of fuelwood, timber, medicinal plants and wild edibles for livelihood 3. Conservation of culture of not cutting green trees for income	Forest fire

Table 6. 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 7. 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 8. Indicators of land use intensification in major land uses in the Himalaya.

	Oak forest	Pine forest	Rainfed Agriculture	Home garden
Dominant tree species	*Quercus leucotrichophora*	*Pinus roxburghii*	*Grewia optiva*	*Grewia optiva*
Relative area (%)	14	74	11	1
Tree density (individuals/ha)	578	503	107	501
Irrigation	Nil	Nil	Nil	Domestic waste water
Tillage intensity	Nil	Nil	3 times in 2 years	3-4 times in a year
Farmyard manure input (t/ha/year)	Nil	Nil	18	38
Fire	Nil	Ground fire once in 2 years	Nil	Nil
Grazing	28.6 LUs/day/ha on 35 days in a year	5.4 LUs/day/ha on 95 days in a year	36.4 LUs/day/ha on 35 days once in two years	Nil
	1001 LU-days per ha per year	513 LU-days per ha per year	637 LU-days per ha per year	Nil
Lopping	40-80% of canopy opened during winter	10-20% of canopy opened during summer	80-90% of canopy opened during winter	Low intensity lopping all through the year
Litter removal	50-70% of leaf litter	80-90% of litter	Nil	Nil
	80-90% of woody litter	80-90% of woody litter	Nil	Nil
Net primary productivity (t/ha/year)	12.8	10.9	8.1	10.2
Annual biomass removal as % of NPP	53.1	64.2	85.7	84.1

Table 9. Some examples of calculation of cropping frequency (from Shriar, 2000)

Cropping/agricultural system	Simplification	Calculation of cropping frequency
1/2 : 8 crop fallow cycle, i.e., cropping phase of two years and one crop harvested in each year and fallow phase of 8 years	1 crop harvested in a year followed by 4 years of fallow; crop+fallow period = 5 years	Cropping frequency = 1/5 = 0.2
1/3 : 15 crop fallow cycle, i.e., cropping phase of 3 years and one crop harvested in each year and fallow phase of 15 years	1 crop harvested in a year followed by 5 years of fallow phase; crop + fallow period = 6 years	Cropping frequency = 1/6 = 0.16
2/1 : 0 crop fallow cycle, i.e., two crops harvested in a year and no fallow phase	Crop + fallow phase = 1 year and two crops harvested in a year	Cropping frequency = 2/1 = 2
2/2 : 7 crop fallow cycle, i.e., cropping phase of two years and two crops harvested in each year	4 crops harvested in two years; cropping + fallow period = 2+7 = 9 years	Cropping frequency = 4/9 = 0.44
30% of cultivated area with cropping frequency of 0.2 and 70% with cropping frequency of 0.5		Overall weighted cropping frequency = 0.2 x 0.3 + 0.5 x 0.7 = 0.6 + 0.35 = 0.41

Table 10. Method of comparing agricultural intensity in different farming systems given by Brookfield and Hart (1971)

Step 1	Step 2	Step 3
Prepare a check list of cultivation methods in the study area, e.g., clearing without fire, Mounding, Use of compost, irrigation etc	Assign a value of 0 if the method is not adopted, 1 if present with marginal significance and 2 if present with high significance	Find out a total sum of score for all methods for a given farming system
Find out patterns of cropping and fallow periods, i.e., the cultivation frequency	Assign 3 points for continuous cultivation, 2 for fallow periods shorter than cropping periods and 1 for repeated cultivation after single clearing from a fallow	
Find out differentiation of crops, i.e., crop segregation	Assign 0 points if none or insignificant (e.g., complete mixture of all crops in single undifferentiated swidden field), 1 for if some but minor, 2 if partial, or for the minor crops only, 3 for distinct open fields and 4 for complete crop segregation (i.e., complete separation of crops into plots that are managed in quite different ways	

Table 11. Steps in evaluating intensification level of households illustrated by (Shriar, 2000)

Preparation of a check list of farmers' activities and strategies for achieving high productivity
Estimation of area under each activity/strategy and its scaling, e.g., each household ranked based as low, medium or high scale intercropper, with a scale of 0 (i.e., no intercropping) to 3 (1, 2 and 3 representing low, medium and high scale intercropping as given in Table 2)
Assign a weight to each intensification activity based on the degree to which its use contributes to higher production per unit land per unit area, e.g., of plowing and manuring, which one is more effective
For each household multiply the weight value by a number linked to scale at which the activity is used by the household (e.g., a household plowing at medium level, value of 2 in the scale, multiplied by a weight of 2.5 given to this activity as given in table 2)
Sum up the points associated with each activity to get an overall intensity score for a household

Table 12. Scale ranges and weights associated with the agricultural intensity index – application of Shriar's conept to the Himalayan region (Shriar, 2000)

Intensification activity	Scale range	Weight
Plot scale		
Scale of plowing	1-2	9.5
Scale of fallowing	1-2	4.5
Scale of livestock grazing	1-2	4.5
Scale of agroforestry tree density	1-3	6
Scale of irrigation	1-3	8
Scale of weeding	1-2	7
Scale of manure input	1-3	9.5
Scale of fertilizer input	1-2	3
Scale of pesticide input	1-2	1.5
Scale of high yielding varieties	1-2	1.5
Landscape scale		
Forest/farm land area ratio	1-3	6
Forest fire	1-2	1
Tree lopping regime in forests	1-2	3
Grazing regime	1-2	3
Litter removal regime	1-2	3
Access to market	1-2	5
Degree of off-farm employment	1-3	7

Box 1: Selected definitions of intensification

Intensification is a process of increasing the utilization of productivity of land currently under production, and it contrasts with expansion, that is, the expansion of land under cultivation (Netting, 1993)

Intensification means, in relation to constant land, the substitution of labour, capital or technology for land, in any combination, so as to obtain higher long-term production from the same area (Brookfield, 1993)

Agricultural intensification is a set of patterns of land-use change with the common feature of increased use of the same resources for agricultural production, usually as a result of a switch from intermittent to continuous cultivation of the same area of land (Giller et al., 1997).

Intensification can be defined as higher production per unit area, per unit time, of desired outputs (e.g., proteins, calories, animal feed, building materials and cash) (Shriar, 2001).

Intensification is the process that allows the reduction in use of inputs (including land acreage) without negatively affecting output levels. Land use intensification in slash and burn farming can occur in two ways: (a) farmers' adoption of new technologies to reduce the need for further burning by reducing fallow-cultivation cycle towards more continuous cropping and (b) improvement in productive (technical) efficiency under the actual (or traditional) practices (Pascual, 2005).

Land use intensification can be defined subjectively by the increasing impact of man on the landscape (Fedoroff et al., 2005).

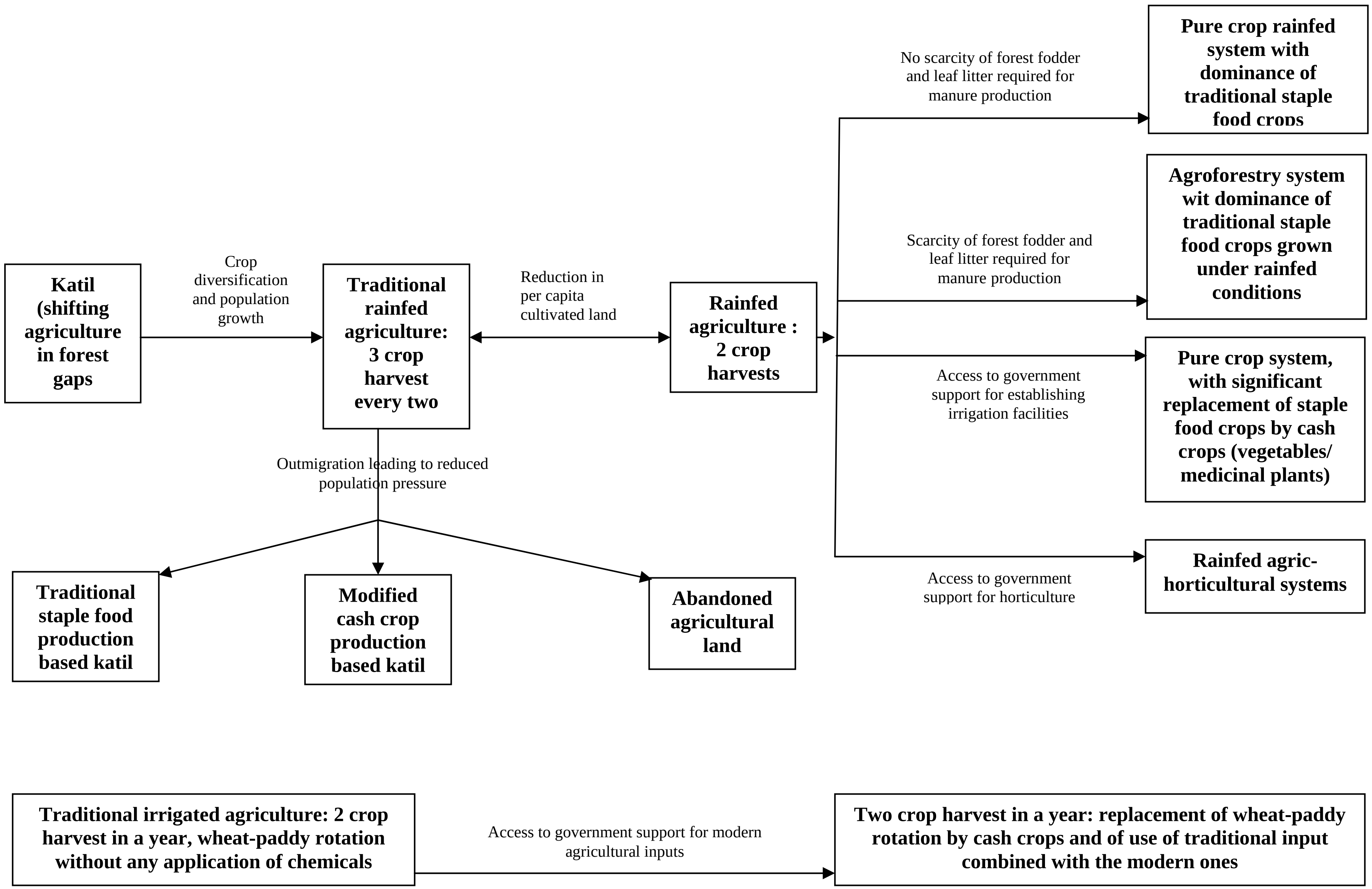


Figure 1. Stages in land use intensification in traditional agriculture in Garhwal Himalaya

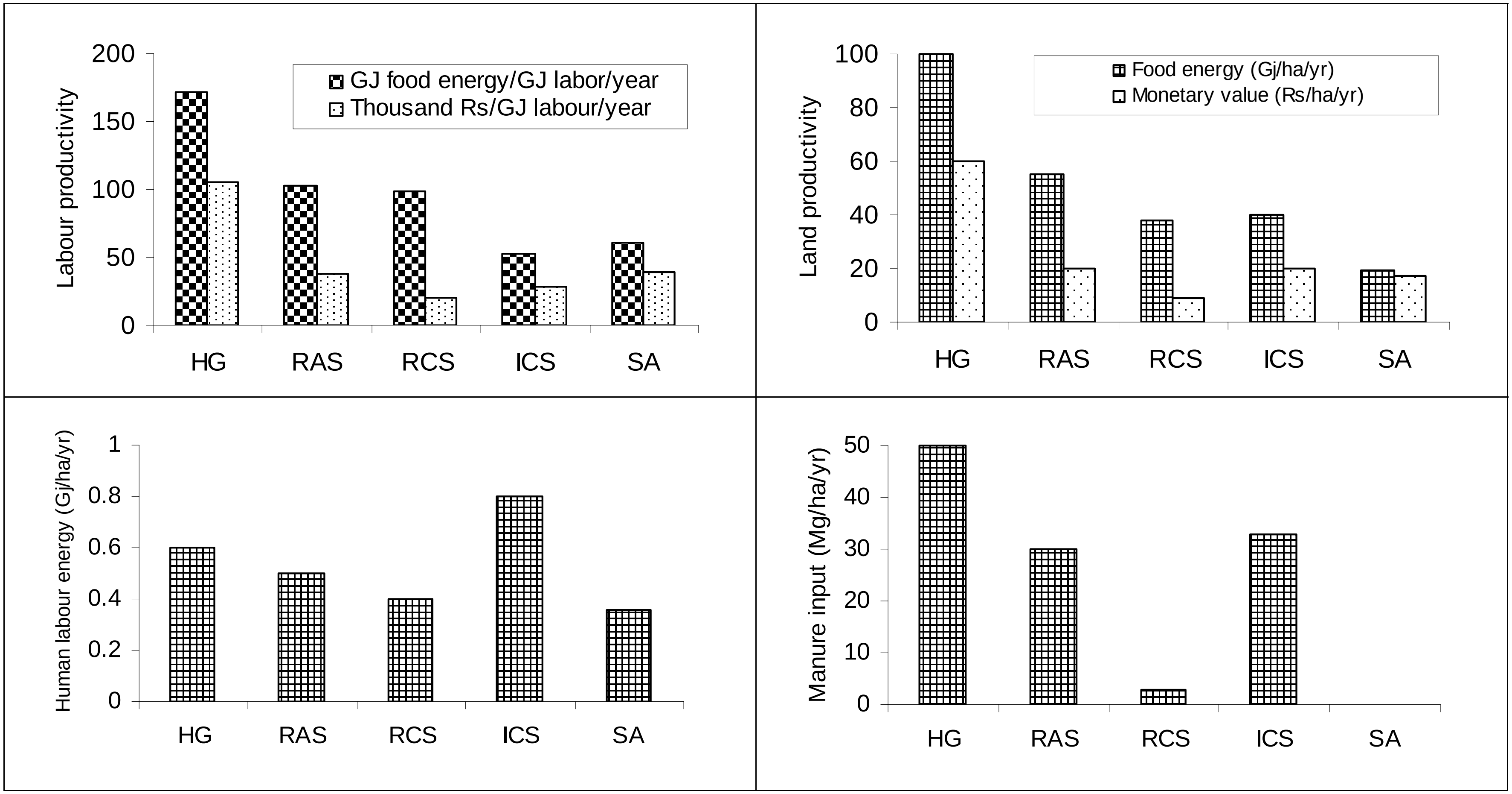


Figure 2. Variation in inputs and cost of production in various land uses in village Bacchelikhal, Garhwal, India

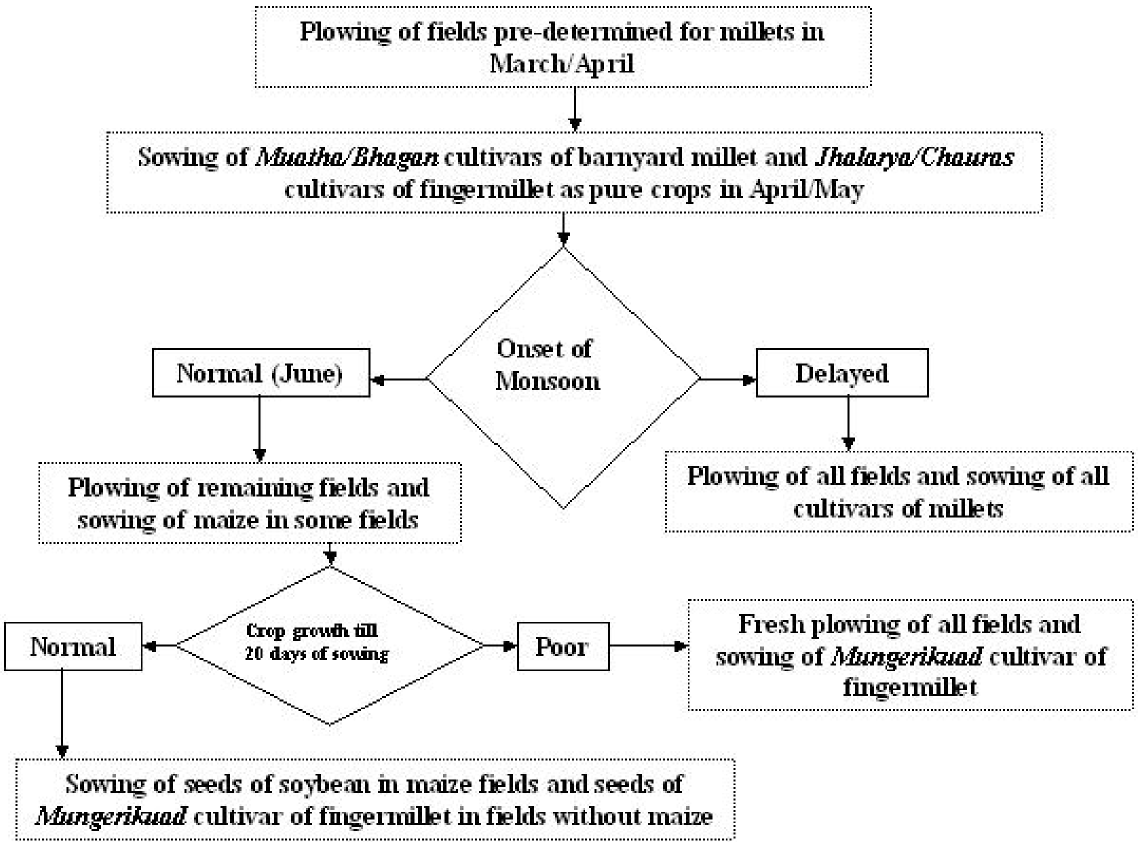


Figure 3. Farmers' decision making on cropping pattern during rainy season in rainfed agroforestry system in village Bacchelikhal, Garhwal, India

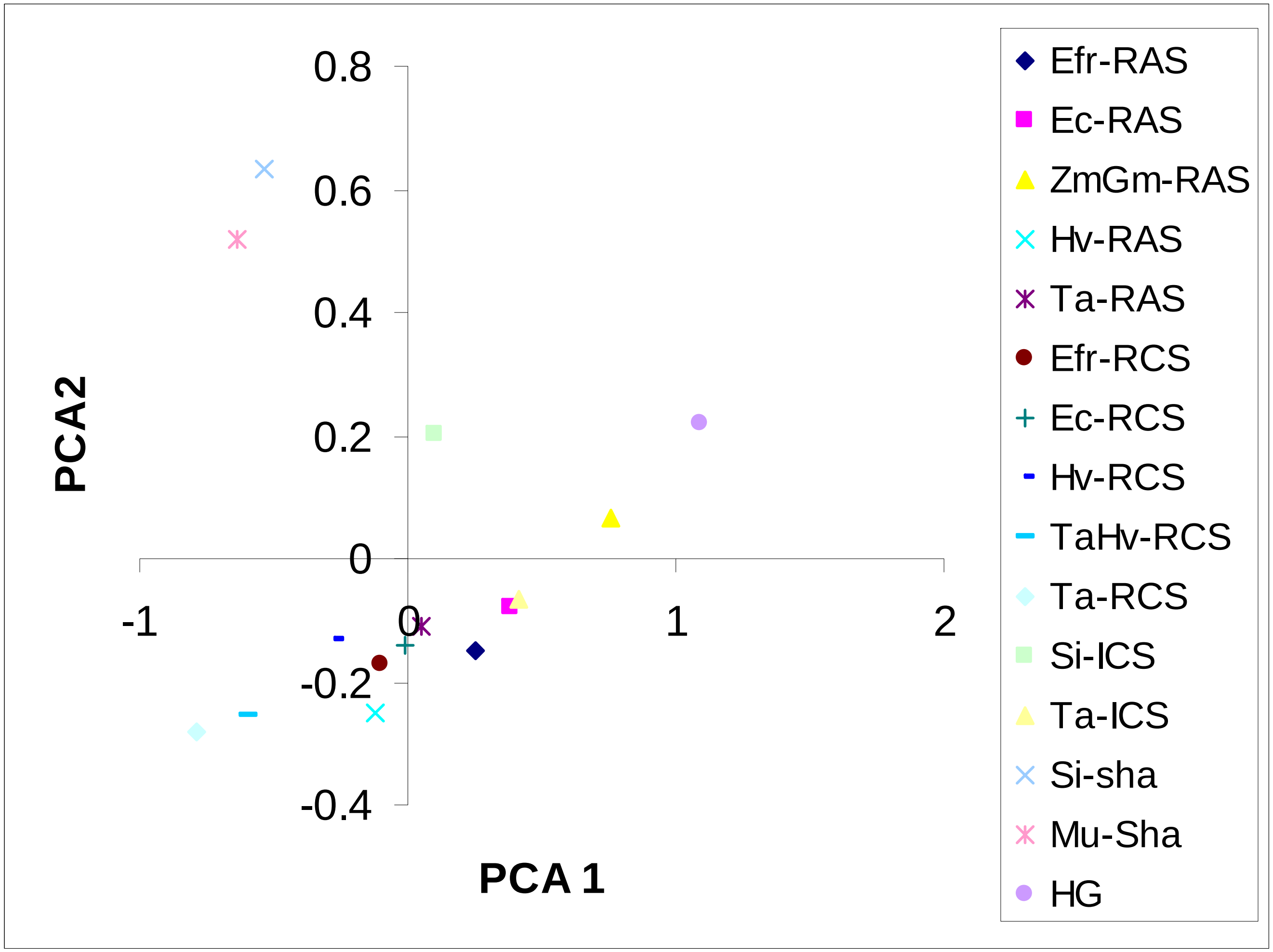


Figure 4a. Scatter plot of different crops based on crop-wise input/output rates

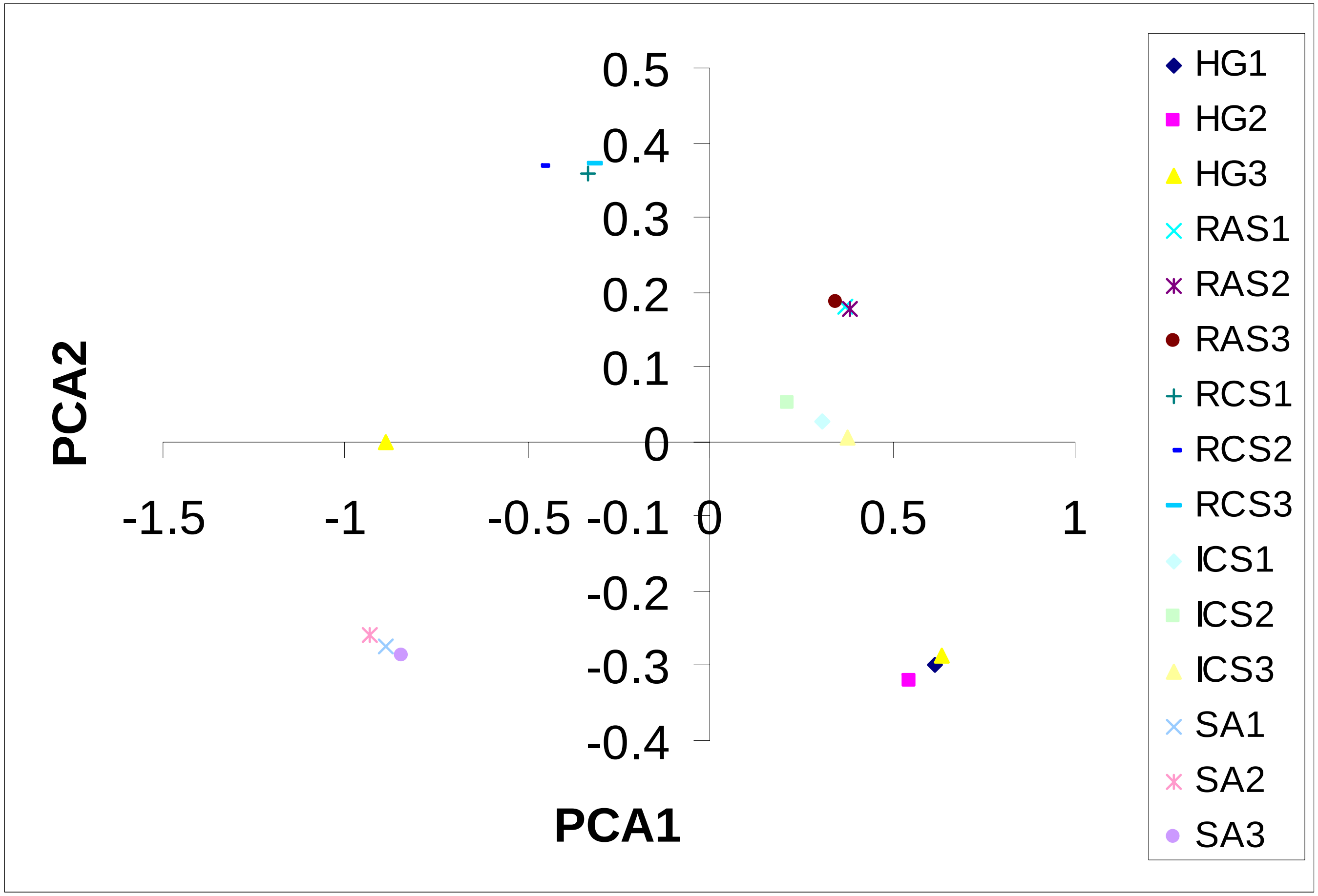


Figure 4b. Scatter plot of different crops based on agroecosystem-wise input/output rates

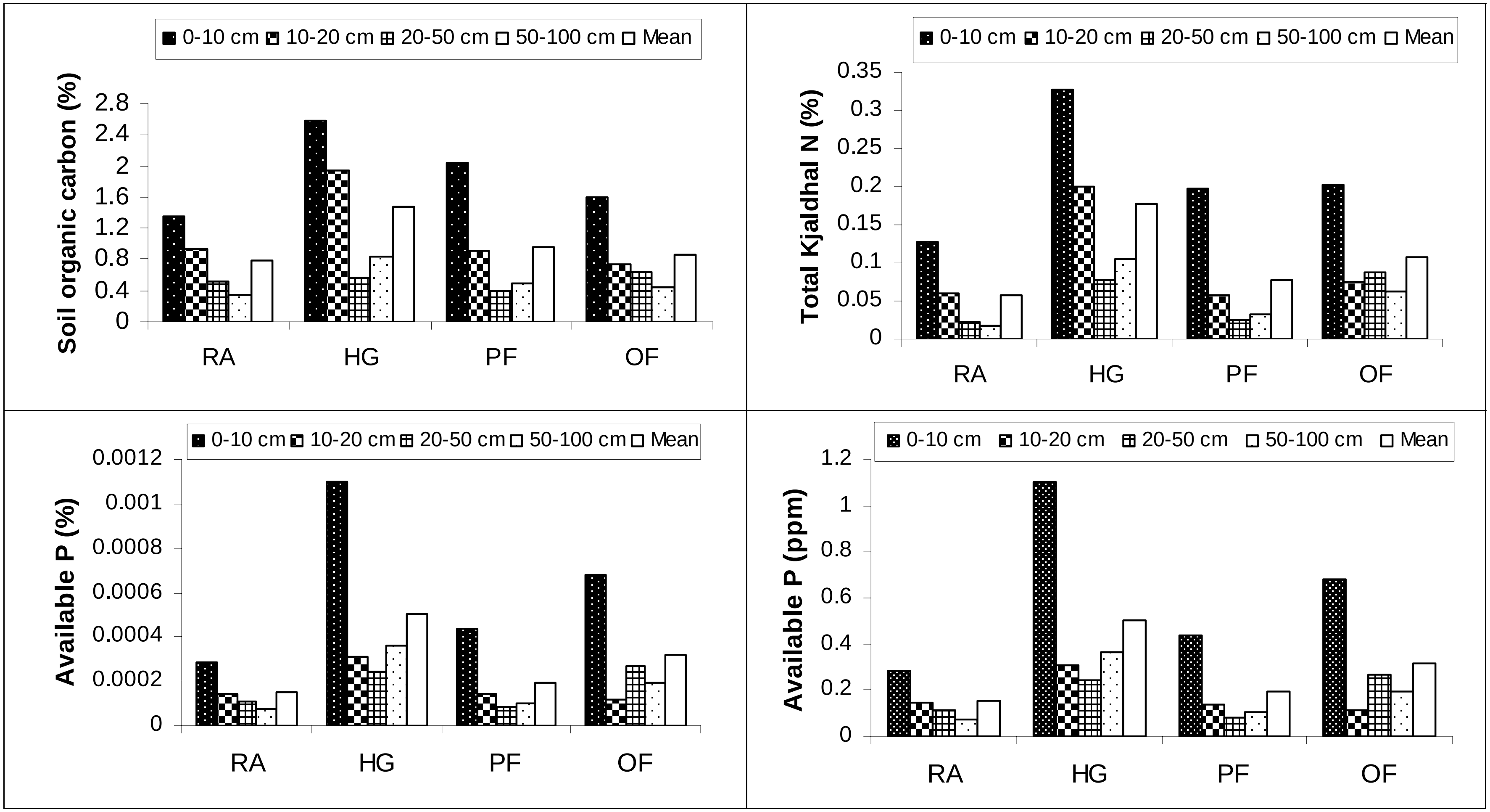
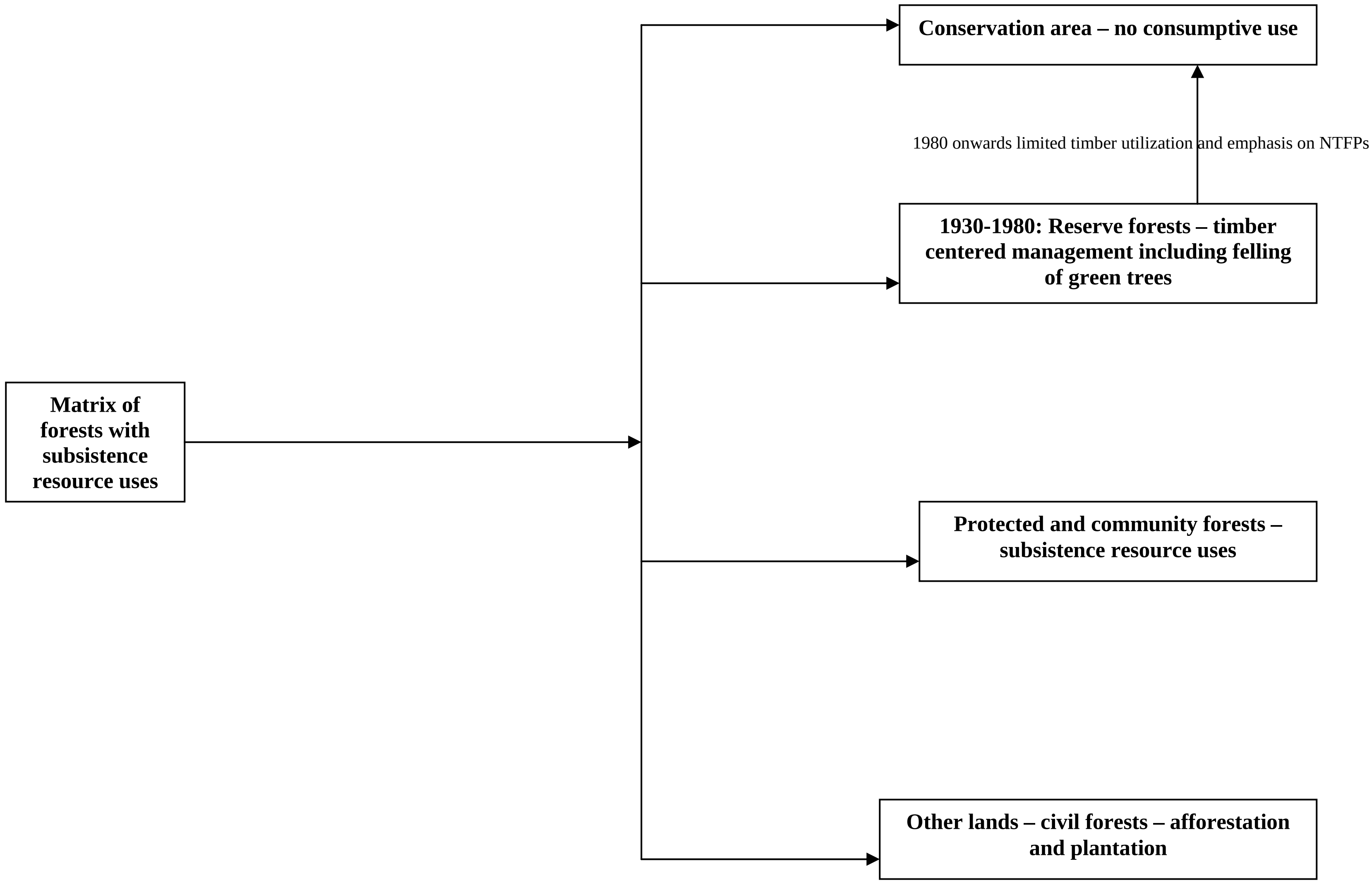


Figure 5. Organic C, Total N and Available P pools in soil under different land use/cover types in village Bacchelikhal, Garhwal, India


Conservation area – no consumptive use
1980 onwards limited timber utilization and emphasis on NTFPs
1930-1980: Reserve forests – timber centered management including felling of green trees
Matrix of forests with subsistence resource uses
Protected and community forests – subsistence resource uses
Other lands – civil forests – afforestation and plantation