CHAPTER 1

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1. Introduction
Land use is an important agent of global change that impinges upon a variety of environmental and socio-economic issues including biodiversity, food security, ecosystem services and human health. Land use changes can be described at different spatial and temporal scales. The different scales are, however, mutually inclusive and when the effects at smaller scales become widespread, they have global consequences.

Shifts in area and distribution of different land uses, particularly over the last two centuries have been implied for consequences at a scale that is essentially global. A rapid increase in the extent of agricultural land use is a result of combined conversion from natural biomes, in particular, the temperate forests in the 1700's and 1800's and woodlands, grasslands and tropical forests in recent decades. Climate modification as a result of a net release of CO$_2$ from ecosystems worldwide is one such major impact of land use-land cover change. Houghton et al. (1983) have estimated that there has been a net release of $180 \times 10^{15}$ g of CO$_2$ between 1860 to 1980 from terrestrial ecosystems as a result of land use modifications. Vitousek et al. (1986) estimated that on a global scale, organic material, equivalent to 40% of the net primary production in terrestrial ecosystems is being either used directly by humans or diverted and even destroyed because of human caused change in land use. Wright (1990) interpreted the implications of these global land use-land cover changes in terms of restrictions to energy flow through natural ecosystems and related these to biodiversity loss. Related to carbon and organic matter fluxes is the productivity potential of lands. Inappropriate use of land has negative impacts on primary productivity thus limiting the capacity of land to provide benefits to humans. Daily (1995) estimated the proportion of land suffering from such a limitation to be as much as 43% of global terrestrial vegetated land.
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2. Land use extensification and intensification

Land use modifications are characterized by the rates of extensification and intensification. While extensification can be clearly defined as an increase in the area of a given land use (horizontal expansion), intensification is a much more qualitative term and incorporates spatial as well as temporal aspects. Defined as the increased use of a given area with the target of increased production per unit area per unit time, it is associated with vertical expansion, duration of use and usually accompanies increased inputs and specialization of produce. However, in traditional farming systems, particularly in the frontier regions, conventional approaches of defining and measuring land use intensity may be unsuitable because of the diversity of farming/cropping systems and production strategies which are in flux, both in area and over time (Shiriar, 2000). In such systems, intensification of land use may be associated with a more efficient management of biochemical cycling and biodiversity that determine ecosystem productivity (Allen et al., 1995; Harwood, 1996). Therefore, agroforestry, mixed cropping and intercropping could be viewed as the traditional approaches to land use intensification to meet the increased demand for biological resources (Altieri et al., 1983; Brklacich et al., 1991; Gliessman, 1992; Gliessman et al., 1981). The relative importance of these two processes (intensification and extensification) in regional land use and land cover transformations varies with each assuming importance under a more or less identifiable set of ecological and institutional factors.

Over much of the developed regions of the world (Europe, North America and USSR), rates of conversion of land to agriculture have attained negative values after 1970. Further, significant rates of abandonment of agricultural land regenerating into forests have been recorded since the middle of the 20th century (Houghton et al., 1983). Turner et al. (1987) examined changes in land use and net primary productivity in Georgia over a period of 50 years. He showed that during this period, the NPP increased from 2.5 to 6.4 tons/ha due to an increase in the harvest index of crops and external subsidy inputs. Thus, intensification rather than extensification was the main force behind this increase in agricultural production, often involving huge external/environemntal costs (Pretty et al., 2000).
In contrast over most of the developing world, needs of an increasing population have been met largely through land use extensification which has been accompanied by deforestation, land degradation and desertification (Bojo, 1991; Heliden, 1991; Kaoneka & Solberg, 1997; Myers, 1993; Thapa & Weber, 1991). When the land use expansion frontier closes in one ecosystem type, an abrupt departure into a different pattern of land use exploiting a hitherto virgin area may take place leading to large scale regional deforestation and degradation, a process which Myers (1988) has termed as 'land use discontinuity'. However, these land use-land cover changes occur in diverse circumstances with the causal factors interacting in specific ways in different places to give regionally distinct pattern of cause and resulting processes (Bilsborrow & Okoth-Okondo, 1992; Rudel & Roper, 1996).

In much of Latin America, the highly fragile tropical soil is unable to sustain agriculture over a long period of time and much of the conversion of moist tropical forest into a mosaic of pastures and regrowth forests is the result of deliberate government strategy to encourage settlement, colonization, migration, cattle ranching and indirectly, road building (Barbier et al., 1991; Nepstad et al., 1991). The indigenous communities have an uncertain land tenure, government ownership is fast disappearing and private land ownership is highly skewed, thus forcing small land owners to work for larger landowners and then move on to new areas leaving land for larger tenants who are more oriented towards animal husbandry (Syers et al., 1996): In areas where soil fertility constraints are absent, such as the Argentinian pampas, extensification of cropland, intensification of agriculture and a general increase in area allocated to soil fertility depleting crops like oilseeds has been observed (Vigillizo et al., 1997).

In most of Asia, particularly South/Southeast Asia, an early phase of rapid population increase coincided with high rates of deforestation and conversion of forest into agriculture. However, a continued rural to urban migration and fertility decline combined with strict settlement laws resulted in considerable land abandonment. But the slowed rate of agricultural extensification was compensated by heavy commercial logging encouraged by government policy and gave rise to a highly fragmented landscape with secondary forests (Hussain & Doanne, 1995; Myers, 1993).
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While fertility rates in Asia and Latin American populations declined during the 1980’s, they remained high in almost every African country. Unlike Asia and Latin America, communal ownership is still a major land tenure in Africa which discourages farmers to invest in land management. Agricultural extensification in response to population pressure has given rise to conflicts between settled farmers and traditional cattle herders whose rights are restricted only to access to forage resources. This has led to widespread land degradation and desertification, particularly in the Sahel of Africa (Heliden, 1991; Livingstone, 1991; Olsson & Rapp, 1991).

In recent years, emphasis has been given on local studies which are particularly useful in elucidating the complex interactions between biophysical factors and social behaviour under a uniform regional policy environment. Such efforts are better suited to capture finer changes in land use and land cover which are overlooked at regional or global scales. Thus, change in crop cover, intensification of land use and their relationship to socioeconomic factors can be evaluated appropriately only at lower spatial scales. Also, a more accurate estimate of the ecological status of various land use/cover classes, characteristic of a heterogeneous landscape, can be derived only through an inquiry at a local level.

3. Determinants and patterns of land use – land cover change

The expansion of agriculture in marginal land is one of the prominent causes of land degradation. However, the conventional concept of marginality may not correspond to the unsuitability of land in the context of the farmer’s land use decisions (Reenberg et al., 1998). Characteristic pattern of land use extensification followed by intensification occurs as a result of expansion driven by social and economic factors that are delimited by physical and ecological constraints. Specific technological, institutional and natural resource policy of the government determine to a large extent the changing land use pattern. Kammerbauer & Ardon (1999) could identify two distinct phases in the land use development in the La Lima watershed in Central Honduras. The first phase of agricultural extensification driven by population pressure, migration movement and lack of forest regulation was followed by a phase of agricultural intensification when ecological constraints were encountered and forest regulation coupled with improved access to local...
markets and subsidized agricultural input prices promoted agricultural intensification. A study in northern Thailand reported similar trends opening of frontier area followed by intensification over a period of time resulted in a highly fragmented landscape (Fox et al., 1995).

The stages of changes in production system reflect either specialization and simplification or diversification of production. Abandonment of traditional land use and food storage practices in favour of specialized production for commercial purposes is reported widely from many formerly subsistence areas (Chipika & Kowero, 2000; Khogali, 1991; Maikhuri et al., 1997; Tsegaye, 1997).

Highly uncertain and risky production environments may foster maintenance and co-existence of extensive, subsistence oriented traditional production systems along with new, intensive production systems (Sierra, 1999). The commercial production of para-rubber by small holders of Indonesia who also cultivate food crops for subsistence is one revealing example of such a pattern of land use (Dove, 1993). Home gardens/intensive mixed arable systems with diversified patterns of planting including intercropping and efficient nutrient recycling, may also develop at this stage, existing as patches in the matrix of agricultural land/forests characterized by relatively low input/outputs (Bekunda & Woomer, 1996; Huijun & Padoth, 1995; Rerkasem & Rerkasem, 1995).

Availability of off-farm employment opportunities may lead to large scale rural to urban migrations or may lead to what Harwood (1996) has defined as the ‘structural transformation turning point’, when the number of workers per unit area begin to decline and the withdrawal of labour generally coincides with a decrease in both system structure and diversity. A study carried out by Gbadegesin (1996) in the Olokomeji forest reserve in south-western Nigeria dealt with the critical links between local land use dynamics and regional economic policies through the intervening variables of migration and gender specific land use practices. Three phases of economic development were identified; an oil boom period during which the male members started to migrate to urban centers, a second phase of trade liberalization policies which drove many male members back to village to grow export oriented crops like cotton and palm which were environmentally damaging, and a third phase of large scale rural to urban migration which left women more conscious about the need for environmental conservation. The female headed
households reverted back to less nutrient demanding traditional crops like cassava and yam, use of organic manure, and adopted terracing and taungya system instead of shifting cultivation. Opportunities for diversification of livelihood activities may allow inhabitants to participate in market economy without resorting to intensified use of land and labour and allows for the adoption of ecologically more sustainable land use like agroforestry (Hiraoka, 1995).

Tenurial changes in land ownership are also a significant institutional change, which affects land use practices. Generally, tenurial security has been found to be an important driving force behind some of the finer changes in land use strategies like adoption of soil conservation measures and tree planting on private agricultural land (Omiti et al., 1999). Tenurial reforms may also result in more drastic changes in land management such as a switch from food crop agriculture to commercially oriented agroforestry economy (Huijun & Padoch, 2000).

4. Effect of land use transformation and land use practices on ecosystem structure and function

4.1. Ecosystem function
Land use transformations usually involve a drastic shift from natural state evident in terms of changes in soil fertility, biotic structure and ecosystem processes. The capacity of the ecosystem to recover varies depending on inherent ecological features and the nature and degree of transformation that it has been subjected to. Conversion of forest ecosystems to lower biomass system like pastures, agriculture or secondary forests results in loss of soil fertility (Fujisaka et al., 1998; Lugo et al., 1986). These changes are related to reduced rate of organic matter input as well as the loss of soil organic matter, changes in soil physical properties and adverse impact on soil biota and its functions (Gupta & Lekha, 1989; Matson et al., 1997; Paul et al., 1997). De Jong et al. (1999) examined the effects of change from native closed forest to pastures and cultivated land on ecosystem carbon fluxes and recorded a significant decrease in the C densities of the modified land uses due to reduction in aboveground and root biomass carbon pool. Cultivation of soil previously supporting natural vegetation leads to considerable losses of soil
organic matter, microbial biomass and mineralization rates (Motavalli et al., 2000; Post & Mann, 1990; Shepherd et al., 2001; Srivastava & Singh, 1989).

4.1.1. Soil organic matter fractions
Soil organic matter dynamics in relation to land use-cover changes could be better understood by examining the dynamics of different fractions differentiated by particle size and level of soil aggregation (micro and macro aggregate soil structural components) (Duxbury et al., 1989; Elliot, 1986; Elliot et al., 1991; Parton et al., 1987; Tisdall & Oades, 1982). Soil organic matter depletion and transformation during land use conversions is associated with a change in the composition of organo-mineral particle size fractions (Koutika et al., 1999). This redistribution of soil organic matter between particle size fractions is characterized by depletion of more labile/more active fractions and a shift towards less labile/recalcitrant fine silt and coarse clay associated fractions. It has been postulated by Tisdall & Oades (1982) that organic matter corresponding to transient (microbial and plant derived polysaccharides, rapidly decomposing) and temporary (root and fungal hyphae) binding agents which hold the soil microaggregates together to form macroaggregates are rapidly lost under the influence of cultivation of native soil. The particulate organic matter (POM) fraction that closely matches the soil organic pool described variously as slow, decomposable and stabilized is another indicator of the soil’s capacity to retain and release nutrients and might be related functionally to the transient binding agents (Van Faassen & Lebbink, 1994; Woomer et al., 1994). Significant losses of POM-carbon coupled with enrichment of mineral associated carbon have been reported for cultivated soils derived from native grassland soils (Cambardella & Elliot, 1992). Two phases in SOM changes following cultivation have been observed: (1) phase I characterized by redistribution of organic matter (decomposition of floatable organic matter/low density particles and accumulation in the silt and clay fractions) such that there is no perceptible change in total soil carbon stock (2) phase II characterized by a net loss of organic matter, primarily the floatable and fine clay fraction (Tiessen & Stewart, 1983).
4.1.2. Microbial biomass and mineralization rates

Soil microbial biomass responds much more rapidly to altered land use than total organic matter and therefore is a sensitive indicator of soil fertility status (Gupta & Kaur, 1998; Pietikainen & Fritze, 1995; Powlson et al., 1987). Being an indispensable intermediary in organic matter transformations and a ready source of labile S, N and P, fluxes in microbial biomass pool have been linked to mineralization and availability of essential nutrients (Jingguo & Bakken, 1997; Lodge, 1993; Smith & Paul, 1990). A number of studies have demonstrated the effects of disturbance and altered land use on microbial biomass, C & N mineralization rates and nutrient losses, and their interrelationship (Ellis, 1974; Maithani et al., 1998; Srivastava & Singh, 1991; Vitousek & Mellilo, 1979).

4.1.3. Agricultural land use and its management

In agricultural ecosystems, management practices modify climate-vegetation-soil interactions operating in the native ecosystem (Hu et al., 1997; Katterer & Andren, 1999). In some situations, micro-environmental variability in the landscape could be so huge and complex that it might be difficult to segregate management effects on soil fertility processes from the effects of due to inherent attributes of the landscape (Phiri et al., 1999). Incorporation of organic inputs and maintenance of tree cover can mitigate to a large extent the losses of organic matter and enhance associated physical attributes like bulk density, aggregate size & stability, infiltration rate and tilth index (Alegre & Cassel, 1996; Srivastava & Singh, 1989).

Estimation and monitoring of nutrient cycling patterns have been identified by researchers as one of the possible ways of evaluating the impact of land use on soil fertility (De Jager et al., 1998; Van den Bosch et al., 1998). In agroecosystems, where food production is the main objective, nutrient transfers are influenced not only by the conditions and processes within the system but also controlling forces outside the system. Nutrient balances have been estimated at various spatial and temporal scales by researchers. For instance, Wortmann & Kaizzi (1998) estimated nutrient balances for small scale farming systems at crop, land use type and farm level. They reported that due to significant nutrient transfer in the form of manure and crop residue from one land use type to another, and cumulative effect of several low input management practices, the farm level
nutrient balances were near zero, although there were wide variations, ranging from net negative to net positive balance for the various component crops and land use types. Elias et al. (1998) included the role of socio-economic variability in their estimations of N & P balances at farm and field level and concluded that aggregated land use level and farm scale balances varied considerably across socioeconomic groups. Interestingly, non-uniform patterns of land use management and resource allocation, and therefore nutrient balances were observed for the same socioeconomic strata in different agroecological zones. Elias et al. (1999) showed that N depletion was severe for rich farmers in highlands as poor farmers in highlands carried out intensive soil enriching and soil conservation practices whereas in the lowland, N depletion was severe for the poor farmer as they had limited access to soil fertility amendments. This study showed that although field level balances were either positive or in equilibrium in most land uses, the negative balance of one single land use distorted farm level balance to negative. Harris (1998) reported a high degree of spatio-temporal variability in nutrient balances.

Traditional agroecosystems where crops, livestock and forest are integrated in time/space, soil fertility and nutrient flows are more appropriately addressed and examined at a landscape or village territory level (Mohamad Saleem, 1998; Scoones & Toulmin, 1998). At this level, the spatial relationship between landuses may be influenced by nutrient flows and erosion dynamics resulting in redistribution of nutrients within the landscape which is often central to the functioning of the agroecosystem. Powell et al. (1996) carried out such a landscape level study, integrating and analyzing the structural and functional linkages between croplands and rangelands and found that although rangeland nutrient balances were in equilibrium, croplands lacked the internal capacity to replenish nutrients lost as grain and crop residue offtakes. Pilbeam et al. (2000) demonstrated the critical role forested areas have in maintenance of equilibrium through net transfer of nutrients from non-agricultural to agricultural areas in Nepal thus endorsing the utility of landscape level studies.

A basic challenge to agricultural research and development is to identify the processes that are associated with nutrient losses and farming practices that produce and accentuate such processes. Intensive use of fertilizers, manure and
heavy machinery in conventional, arable farming systems can cause serious losses of nutrients and deterioration of soil structure. Agriculture may not be sustainable in the long run if high nutrient efficiencies occur at the expense of decreasing level of soil organic matter (Van Faassen & Lebbink, 1994). Large quantities of nutrients may be lost by leaching, volatilization and erosion when nutrient release pattern does not synchronize with crop uptake pattern. Adepteu & Corey (1978) showed that despite of a large amount of N release through decomposition (1000 kg/ha of N), maize yield was limited by N in a 15 year old fallow site brought under cultivation in Nigeria, indicating severe loss of nutrients and release at a time when there was no crop demand. Significant losses take place during the process of nutrient transfer from the livestock component (as manure) and to crop fields. For instance, in animals that are grazed, 50% of the faeces and urine were estimated to be deposited in the grazing areas where 10% of nitrogen was lost (Wortman & Kaizzi, 1998). In the same study, 80% N, 20% P and 20% K were lost from farmyard manure in uncovered pen and 20% of N/P/K in covered pen. Powell (1992) estimated that collection of manure from stall results in loss of 40%-60% of N and suggested corraling of animals to be a more nutrient conserving option. A strategic shift in livestock diet to a high tannin and proanthocyanadins causes more N to be secreted in faeces from where its loss from volatalization may be lower than that from urine (Powell, 1996).

Interventions aimed at arresting and reversing distorted nutrient budgets imply the development of an integrated nutrient management system, which has been theoretically conceptualized as the judicious management of input and output processes (Batiano et al., 1998; Nandwa & Bekunda, 1998). Strategies aiming to arrest soil fertility decline in agroecosystems are differentiated into: (a) management practices that conserve nutrients already present and cycle nutrient efficiently such as erosion control, restitution of crop residues, agroforestry and cover crops, extended fallowing, recycling of manure and household waste and (b) those that add nutrients to the system through application of inorganic nutrient amendments. In recent years, integrated farming systems have been proposed which involve lower fertilizer inputs, reduced soil tillage, and reduced use of chemicals for soil protection and no soil fumigation. It has been hypothesized that a change from conventional to integrated farm management can be compensated
for by a higher mineralization of nutrients from organic matter by soil biota (Bloem et al., 1994; Lopez-Real, 1986). Soil biota influences C and N cycling in the soil as they play an important role in breakdown and mineralization of organic matter and maintenance of soil structure (Juma, 1994). Almost 80% of the soil macropores could be affected by soil biota in integrated farming systems as compared to only 10% in conventional farming systems where mechanical intervention takes over a larger role in soil structure formation (Kooistra et al., 1989). Intensity of tillage also affects soil organic matter pools and hence the microbial pool and its associated activity (Kandeler & Bohm, 1996). Substitution of inorganic fertilizers by organic matter amendments is an integral part of integrated farming systems which aims at increasing the soil organic matter pool, particularly at stabilizing the ‘young’ humus pool (particulate organic matter) which may act as a slow biorelease fertilizer (Persson & Kirchmann, 1994). This ‘young humus’ pool may increase the overall efficiency of nutrient use once it reaches a steady state (Persson & Kirchmann, 1994; Van Faassen & Lebbink, 1994).

In recent years, manipulation of organic matter inputs in terms of time and position of placement, quantity and quality in order to synchronize nutrient release with crop uptake has emerged as a priority research area. The fallow frequency and the crop rotation pattern can influence the labile organic matter pool through its effect on the quality, quantity and timing of organic input addition (Biederebeck et al., 1994). Marked variations in decomposition rates and nutrient release patterns have been observed in organic matter inputs which have been ascribed to characters like nitrogen content, non-structural carbohydrates and recalcitrant compounds such as lignin and polyphenol (Fox et al., 1990; Saini et al., 1984). The relative proportion of energy rich components and nitrogen content largely dictates whether nutrient release through mineralization takes place or the nutrient gets immobilized as microbial biomass (Jingguo & Bakken, 1997; Mengel, 1996). External additions of nitrogen may not always ensure enhanced nitrogen availability because increased biomass/organic matter production/decomposition as a result of nutrient enrichment may encourage microbial growth leading to immobilization (Bremer & Kuikman, 1997; Mary et al., 1996). Complex
interactions between soil properties and organic matter input may influence the release and uptake of nutrients (Janzen & Kucey, 1988).

Crop residues, animal manure, litter and weeds when recycled into the system constitute a primary source of replenishment of organic matter and nutrients, and often the only fertility management option available to a majority of farmers in the developing countries. Singh and Shekhar (1989), in a study on decomposition of maize and wheat roots found that the peak nutrient release would overlap with seedling growth period of the successive crops. In addition these decomposing roots might have visible carry over effects on the later crops. Nutrients derived from crop residue assume much significance in situations where their recovery from inorganic fertilizers is low. In a sequential multiple cropping system in Indonesia, cowpea residues were found to supply nutrients to crops upto the sixth successive crop (Sisworo et al., 1990). Net nutrient removal from cropping systems is largely due to harvest of grains, more so in crops with a high harvest index like cereals and oilseeds (French, 1995; Powell, 1996). Legume species like groundnut and pigeonpea combine moderate grain yield with high root and leaf biomass, and thus lower N harvest, offer a useful compromise of meeting farmer's food security and improving soil fertility (Snapp et al., 1998). Tree prunings and green manures hold promise as potential soil fertility enhancing inputs for resource poor farmers. Desirable rates of nutrient release may be attained by mixing prunings of different quality (Handayanto et al., 1997).

However, experiences with introduction of green manure in small scale farming systems suggest that the risk involved with a unsatisfactory residual effects due to rapid leaching, variable biomass production and labour investment may elicit reluctant and ambivalent response from farmers when it comes to the diversion of productive land to green manure crops (David, 1995; Drechsel et al., 1996; Drechsel and Reck, 1998). Much of the knowledge about organic resource based soil management is derived from theoretical concepts and limited experimental trials. Their transfer to real field conditions will need careful consideration of both the biophysical and socioeconomic characters of the production environment.
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4.2. Ecosystem structure

Human mediated land use change involves changes in species composition and diversity, and the structural complexity of the ecosystem (Fujisaka et al., 1998, Fujisaka et al., 2000). These changes are usually unidirectional with a trend towards simplification when a natural ecosystem is converted to an agroecosystem. Salami et al. (1998) investigated the extent of vegetation modification in two rural landscapes in South West Nigeria and concluded that a complex set of factors affect the ecological structure of man impacted landscapes. Moreover high structural or vertical complexity does not necessarily lead to high horizontal complexity (floristic diversity) and is dependent on the creation of suitable habitats through appropriate management practices.

A major shift in land use, usually a conversion of natural to human managed system as through clearing and/or slash and burn may be followed by a series of incremental changes. Harwood (1998) traced the development of human managed land uses after the initial lands use transformation through slash and burn using biodiversity as a classificatory determinant. Level of biological interaction has also been used to analyze and conceptualize the dynamics of forest–people and agriculture–people interrelationship (Rice & Greenberg, 2000; Swift et al., 1996; Wiersum, 1999).

Biodiversity in domesticated landscapes can be defined at various scales, with the specific structure/organisation of planned and associated biodiversity and its functions, influencing and being influenced by the resource management regimes and production environment (Duelli, 1997; Kotliar & Wiens, 1990; Turner, 1990; Vandermeer et al., 1998). Whereas production functions of the planned (deliberately introduced) biodiversity are primarily directed at providing direct benefits to humans, associated biodiversity component (e.g., below and aboveground flora and fauna) performs major ecological functions. This associated biodiversity comprises species that filter out from the regional pool into the agricultural landscape with their composition being determined by specific niches available in the area. Areas with a long cultivation history, mosaic landscape with traditional agriculture and forestry mixed with patches of natural and semi-natural areas offer a high number of ecological niches and may therefore support a rich biodiversity (Elsen, 2000; Fujisaka et al., 2000; Pimentel et al., 1992). Although
biodiversity in such patchy environments has been traditionally explained on the basis of the equilibrium theory given by Mc Arthur and Wilson, Duelli (1997) proposed an alternative ‘mosaic concept’ to predict and evaluate biodiversity in agricultural landscapes. According to this concept: (a) habitat variability (number of biotopes per unit area) (b) habitat heterogeneity (number of habitat patches and ecotone length per unit area) (c) surface proportion of natural and intensively cultivated areas can act as useful indicators to assess biodiversity. One important deviation from the island biogeography theory was that whereas island biogeography places importance on the area of the individual patches as the factor determining biodiversity, the mosaic concept incorporates elements from metacommunity dynamics where the absolute number of patches even of the same biotic type, irrespective of their size, determine species diversity as each patch is exposed to different extinction and colonization rates (Husband & Barrett, 1996).

Attempts to illustrate the patterns of non-crop species occurrence in agricultural landscape have centered on species response to disturbance intensity, resource enrichment and competition. Kleyer (1999) examined the non-cultivated herbaceous vegetation in an agricultural landscape comprising of meadows, fields and roadside under a range of soil fertility and disturbance intensities within the theoretical framework of adaptive plant functional traits and their relation to environmental gradients. Correlated functional traits like life history strategies, age at first reproduction and vegetative regeneration usually demonstrated clear response to disturbance and resource supply patterns. A shift from stress tolerant to competitive functional traits (lateral expansion) was observed with decreasing disturbance intensity under all resource supply regimes sampled.

Landscape differentiation due to variability in management regime (intensity of use/fertility transfer between land uses like cropland and pastures) influences and interacts with landscape level processes of species dispersal and establishment. Such differentiation may persist over long periods of time and lead to specific patterns of species enrichment, seed bank characteristic and species composition in terms of agronomic, life form and seed bank characters (Foster, 1992; Koerner et al., 1997; Lopez- Marino et al., 2000).

In domesticated landscapes, non-cultivated areas like forests and pastures subsidize the agroecosystem as they may be source of fodder, fuelwood and other
harvestable products. Therefore, utilization patterns of these resources and the
effect of increasing intensity of harvest on the sustainability of resource use is an
issue that needs to be addressed while designing sustainable land use systems.
Samant et al. (2000) assessed the fuelwood utilization patterns along an altitudinal
gradient in Kumaon Himalaya. Their study indicated that availability of species
was the most crucial factor determining user’s choice, and species richness of the
forest community widened the resource base thus reducing pressure on any one
species. Frequency and timing of harvest are important factors to be considered so
that sufficient recovery is allowed during the favourable growing season (Chen et
al., 1998; Larbi et al., 2000).

4.2.1. Associated biodiversity
Associated biodiversity includes organisms (e.g., weeds, soil flora and fauna) that
are not deliberately incorporated into the agroecosystem but which nevertheless
influence the agroecosystem structure and function (Altieri, 1991; Vandermeer et
al., 1998). Conventional agroecosystem management aimed at completely
eliminating every non domesticated species using environmentally and
economically costly chemical and mechanical means. Associated biodiversity
responds to management decisions of the farmer that include selection of crop
species, presence or absence of tree cover, frequency and magnitude of mechanical
intervention/disturbance, inputs added and biomass removals, and may also
contribute significantly towards landscape level biodiversity.

4.2.1.1. Weed Flora
Weeds, when competing with crops, demand considerable investment from the
farmer for their control. In recent years, ecological characteristics of weeds have
been linked to the valuable functional role they might be performing in the
agroecosystem. Weeds might prevent nutrient losses from the system as they
immobilize substantial quantities of nutrients in biomass (Lambert & Arnason,
1986). Weedy species may increase overall species diversity in the landscape
(Fujisaka et al., 2000) and may modify microclimatic conditions in favour of
planted crop species (Chacon & Gleissman, 1982). In traditional farming systems,
weeds may have some fodder value (Semwal & Maikhuri, 1996).
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Weed community on arable lands is determined by biotic factors (competition from trees and crops; vegetation of neighboring and/interspersed non-cultivated areas which act as a source of new recruits; seed bank character of the weed community), abiotic factors (climate; soil type; terrain) and management factors (which regulate and influence all the above factors apart from being associated with determinants like disturbance regimes (soil tillage) and direct/deliberate selection or removal of weed species (chemical, manual or mechanical elimination).

As seed germination and growth are affected by quality and intensity of light reaching the soil surface, management of canopy cover offers an opportunity for weed control (Gallagher et al., 1999). Seavers & Wright (1999) reported that because of allelopathic exudates, oat had a higher ability to suppress weeds as compared to barley and wheat. As yield and competitive ability are not necessarily correlated, improved cultivars may be bred which can effectively control yield loss due to weed competition (Christensen, 1995). An understanding of reproductive behaviour of weeds and intrinsic growth rates of crop and weed species at particular densities may help in predicting a critical period which corresponds to a period when weeds actively compete with the crop (Garcia, 1995; Kumar & Singh, 1994; Vitta & Sattore, 1999).

Andersson & Milberg (1998) found site differences to be the most important factor influencing weed flora, followed by crop species type whereas crop rotation and nitrogen application rate had only a marginal effect on the composition of the weed community. Zanin et al. (1997) equated the nature and intensity of management (range of tillage treatments and chemical control) with events creating, modifying and eliminating specific niches and thereby directing the response of weed community in two different evolutionary directions: (a) one of repeated recruitment and colonization due to disruption of the natural successional process by soil ploughing (b) a successional community development that altered the ratio between biological (from hemi and therophytes to chaemo, nanophanerans and phanerophytes) and dispersal types (from wind to animal dispersal). Deliberate manipulation of weed species composition and structure through selective weeding may also give rise to specific patterns of weed occurrence (De Jong, 1996).
Colbach & Debaeke (1998) in an assessment of the status of current research on weed demography identified the theoretical and methodological constraints faced in attempts to explain the effects of cultural practices on patterns of weed occurrence and abundance and to design agroecosystems where potential of weeds in realised/negative role is eliminated. Field studies investigating weed demography/crop-weed interactions as influenced by land use have, by and large, failed to:

a) distinguish (in quantitative terms) between the direct effect of the cropped plant (competition for resources, suppression by shade casting, allelopathy) and the indirect effects through the associated management practices specific to that crop species type (sowing date, mechanical disturbance, fertility amendments)

b) comprehensively describe crop-weed interaction as affected by the finer parameters like crop cultivar, cropping density and crop growth patterns

c) identify the regulatory role that cultural practices like weeding frequency and intensity, and biomass harvesting might be having on weed seed production, dispersal and establishment

d) decompose or subparametrize the broad determinants (e.g., soil tillage is a variable that acts through the intervening subvariables like soil moisture, solar radiation, temperature and seed burial) which they have termed as the ‘black box patterns’ (combined effect of subvariables) into a more ‘mechanistic relationship’. This particular issue can be illustrated through a study carried out by Froud-Williams et al. (1983) who found that soil cultivation practices such as ploughing may influence soil temperature thus affecting seed germination time, may bring dormant seeds to the surface resulting in an increased population of such species and may even influence the potency of a herbicide treatment thus affecting the weed vegetation in a number of ways.

4.2.1.2. Other Organisms

Aboveground pests, beneficial arthropods, soil macro and micro fauna regulate soil biological processes influencing soil physical and biochemical properties (Giller et al., 1997). Agricultural activities influence species diversity, abundance and
functional composition of earthworms and often survival of endogeic groups that have the ability to assimilate low quality foods is favoured (Fragoso et al., 1997). Continuous cropping and increased soil disturbance associated with agricultural intensification has been shown to have a detrimental effect on soil macroarthropods like termites and microarthropods (Adejuyigbe et al., 1999; Black et al., 1997).

It has been contended that occurrence of wilderness areas in close proximity of agricultural fields may render cropped areas more vulnerable to herbivory. However evidences do not support any direct correlation between increased crop damage and landscape complexity (Holland & Fahrig., 2000). Heterogenous landscapes offer habitat and refuge to organisms some of which may be beneficial to crop production in addition to increasing the overall biodiversity. Menalled et al. (2000) suggested that complex landscapes composed of numerous small fields interspersed with woodlots and hedgegrows may favour higher post dispersal removal of weed seeds as compared to simpler landscapes. Beneficial arthropods like predators of agricultural pests may take refuge in semi-disturbed sites close to the cropped fields (Pfiffer & Luka., 2000).

4.2.2. Planned biodiversity
Agroforestry, multiple and mixed cropping and crop rotations are all instances of manipulation of planned biodiversity over space and time to optimize production from an agroecosystem/production system. Niche divergence leading to complementarity in resource capture and ‘facilitation process’ where one species enhances the performance of other species in a mixture has formed the ecological basis of much of the current theoretical knowledge regarding the functional attributes of planned diversity in multispecies agroecosystems (Pimental et al., 1992; Swift et al., 1996; Vandermeer, 1989). Studies have demonstrated that intercropping cereal with a legume may enhance both quantity as well as quality of the yield (Allen & Obura, 1983; Herbert et al., 1984). Nitrogen fixing species like soyabean and blackgram have been shown to increase grain yield of intercropped maize by 15%-20 % and its protein content as well (Singh et al., 1986). Cropping systems incorporating legume-cereal rotations have been found to be much more productive than sole cereal system (Rao & Mathuva, 2000).
Maintaining crop/tree diversity at species/subspecies level may provide resistance against pests, diseases and climatic risks (Altieri et al., 1991; Settle et al., 1996). For the farmer, higher diversity translates into staggering demand for labour and multiplicity of products that could be utilized over a period of time on a sustained basis (Tsegaye, 1997).

5. Shifting cultivation

Shifting cultivation is practiced over 30% of the global arable land including 240 million hectares of closed forest and 170 million hectares of open forest (Brady, 1996). In India itself, swidden or shifting cultivation is practiced by 109 tribes in 16 states/provinces covering over 25.3 million ha (GOI, 1999). Agroecosystem function under this land use is subsidized by the nutrient pool in secondary vegetation (developed during intervening fallow period between two successivecroppings on a site) which enriches the soil pool as a result of burning of slashed vegetation. Shifting cultivation can, therefore, be described by a series of events where a phase of disruption of integrity of plant-soil system required for cropping alternates with a restoration phase (Palm et al., 1996). The land use, when practiced in its traditional form over large land area, maximizes returns to labour and forms a viable land use option.

Depending on the vegetation cover at the site, these systems could be tree fallow, bush fallow or grass fallow. Fujisaka et al. (1996) examined and classified the world’s slash and burn systems on the basis of four important variables viz., (a) initial forest cover (b) user group (c) final vegetation cover (d) fallow length. They concluded, considering the case studies at their disposal, that indigenous communities who utilize primarily the secondary forests, leaving long fallows with natural regeneration, form the dominant group practicing this land use. The activities of this group would largely conform to the ‘equilibrium model’ of shifting cultivation developed by Juo & Mano (1996), where there is minimum deviation from the natural ecological state. Shifting cultivation as carried out by the rest of the users, driven by inappropriate state policies and socioeconomic scenario causes large scale deforestation, biodiversity loss, soil erosion and net loss of C and N to the atmosphere (Arnason et al., 1981; Fujisaka et al., 1998;
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Mishra & Panda, 1999; Roder et al., 1993; Tinker et al., 1996). This has been referred to as ‘depletion model’ of shifting cultivation by Juo & Mano (1996).

Although there is no dearth of literature that deals with the ecological aspects of shifting cultivation, a wide range of variation in energy efficiencies, crop productivities, and vegetation and soil recovery rates makes the results highly site specific and limits the scope for extrapolation. This variation is partly because of variation in methodology adopted by different workers and partly because of variation in ecological (e.g., climate and soil type) and socio-economic factors of the system analysed (Andriesse & Schelhaas, 1987a). An understanding of ecosystem dynamics does provide a context of assessment of possible options for improved management.

5.1. Dynamics of soil characters in shifting cultivation

The clearing of vegetation results in a deterioration of soil physical attributes like bulk density, macroaggregate stability and infiltration rates (Alegre & Cassel, 1996). Fire intensity and the temperatures attained during burn affect the nature of immediate changes in soil fertility status through ash fertilization, lowering of C/N ratio of soil organic matter and incompletely burnt biomass, loss of microbial biomass and usually an increased cation exchange capacity (Andriesse and Schelhaas, 1987b; Andriesse & Koopman, 1984; Pietikainen & Fritze, 1995). However, equally important are the changes in distribution pattern of nutrient across the soil profile due to leaching and heat effects on nitrification rates in addition to mobilization and/diffusion of highly mobile ions like K⁺ and NO₃⁻ (Holscher et al., 1997; Stromgaard, 1984).

The cropping phase of shifting cultivation cycle is generally accompanied by a rapid decline in soil fertility, which leads to abandonment of land. Salcedo et al. (1997) examined the precise nature of nutrient limitation following cropping and feasibility of remedial fertilization as a strategy for increasing crop yields. Crop yield from the abandoned site was reported to be half of that from the recently burnt site as a result of depletion of organic pool (C, N, P) by 17% and still larger decreases of inorganic nutrient contents due to cropping. Fertilization as an option to extend the cropping period was found to be of limited use.
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The general trend during fallow regeneration phase is that of progressive accumulation of organic matter and inorganic nutrients, and improvement in physical properties of top soil (Aweto, 1981b; Swift et al., 1991). However, soil nutrient status in isolation can not be used as an indicator of nutrient accumulating or nutrient depleting status of a fallow. Total nutrient stocks particularly nitrogen and to some extent phosphorus may remain unchanged in fallows due to internal redistribution in different ecosystem compartments or due to conversion into less available forms, whereas almost 30% to 40% of the total ecosystem Ca stocks may be lost during the early years of fallow (Szott et al., 1999).

5.2. Dynamics of vegetation in shifting cultivation

Vegetation dynamics in shifting cultivation system have been of interest in relation to the weed potential during the cultivation phase and the recovery rate during the fallow phase. Changes in species composition and productivity during fallow development are affected by: (a) inherent site characteristics (b) resource procurement and allocation strategies of the successional plant species (c) regeneration and reproductive potential of the species and availability of suitable microhabitats and (d) nutrient availability. These factors have been validated in a number of studies involving monitoring of sites over entire cultivation cycle or indirect inferential approach where plots representing different stages are compared at the same point of time.

Different theories of succession have been evoked to characterize successional process under shifting agriculture. Amongst these, the theory of facilitation and relay floristics (Connell & Slatyer, 1977) and predetermined succession pattern as affected by initial species composition and life history of their propagules (Egler, 1954) have been particularly influential in explaining the observed vegetation dynamics following anthropogenic disturbance. Wilcox (1988) while studying early plant succession on abandoned farmland observed the dominance of competitive perennial right from the very beginning of fallow development. Experimental exclusion of perennials and seeding/inclusion of annuals did not influence species composition of regenerating vegetation and thus facilitation model was discounted for fallow development on abandoned farmland. Uhl (1987) found that succession following a less frequent slash-burn disturbance
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is best described by the initial floristic composition theory whereas fallow vegetation development in between frequent cycles of slash and burn would better conform to the relay floristic model of succession. It seems more appropriate to view the processes of facilitation, tolerance, competitive inhibition and allelopathy as mechanisms which operate simultaneously and successively on individuals during their life cycle while analyzing the nature of species interactions and floristic changes during secondary succession (Finegean, 1984; Myster and Pickett, 1992). Changes in abundance and distribution of species in successional plant community can influence the spatial pattern of resource heterogeneity in a given sere (Gross et al., 1995).

Depending on fire regimes, regeneration may occur from soil seed bank, sprouting of vegetative organs or from dispersal from surrounding sites. Among the sprouting shrubs, sprouting in some species may take place through axillary buds all along the main stem whereas in others, sprouting is restricted to stem bases and is rapidly lost with shoot growth (Hodgkinson, 1998). Intense, high temperature fire as reported from areas with long slash and burn cycles resulting in increased fuel load have been found to be detrimental to the viability of germinable seeds in the soil seed bank and survival of sprouts (Uhl et al., 1981). In contrast, as Saxena and Ramakrishnan (1984) reported, under short cycles of four to six years between cultivation, there was a much less deviation from the initial state following slash and burn. However, this preserved vegetation composition is that of an arrested early successional stage largely composed of weedy herbaceous vegetation. Additional disturbance in the form of cropping and non selective weeding further alters the vegetation composition as the successional woody species are weeded out before they can establish through seeds and species with life cycles adapted to such disturbance are the ones that dominate (Staver, 1991). Thus, increasingly intense use of land not only eliminates successional woody species but also impairs the weed suppression function of the fallow (Akobondu, 1991; De Rouw, 1995). It has been suggested that soil resource patchiness may generate vegetation heterogeneity due to uneven colonization and establishment (Collins and Wien, 1998). Indeed, differential biomass accumulation patterns and species preferences associated with specific microsites like under remnant trees or
near unburnt biomass have been recorded following slash and burn agriculture (Sirois et al., 1998; Uhl et al., 1981).

Biomass accumulation by natural secondary vegetation proceeds almost in a linear manner during early succession and may range from 4 to 15 Mg/ha/yr in humid regions and 1 to 8 Mg/ha/yr in drier regions (Szott et al., 1999). Aweto (1981b) observed a distinct shift from early successional microphytes and non-phanerophytes through an intermediate stage dominated by mesophanerophytes that are finally replaced by phanerophytes. The early successional species have distinct functional traits in terms of biomass and nutrient allocation and life history strategy which enables them to establish and colonize the early seral stages (Fujisaka et al., 2000; Saxena & Ramakrishnan, 1982; Saxena & Ramakrishnan, 1983; Uhl, 1987). Early successional species may sustain a higher photosynthetic capacity per unit leaf area as compared to late successional species (Ellsworth and Reich, 1998). Uhl & Murphy (1981) found longer leaf retention time, larger leaf area index and higher leaf production to be important features resulting in higher productivity of the early seral communities which exceeded that of cropped site within a short span of two years following slash and burn.

The relationship between soil fertility and vegetation cover is recognized by the traditional shifting cultivator (De Jong, 1996; Ramakrishnan, 1992; Sirois et al., 1998). Paniagua et al. (1999) could associate distinct vegetation classes identified by the farmers to soil fertility indices representing complex chemical and physical data. Fallow management may involve promotion of selected species that can alter the light environment, attenuate soil temperature, encourage seed predation of harmful weeds and modify soil ecology reducing weed growth and recruitment (Gallagher et al., 1999). Leguminous species that accumulate large amounts of biomass may increase C & N stocks, reduce leaching of Ca and Mg through uptake, can mobilize, if deep rooted P & K from formerly non-extractable sources and can effectively suppress weedy species (Roder & Maniphone, 1998; Szott, 1999; Szott & Palm, 1996). Substitution of recovery through natural vegetation regeneration by velvet bean (Mucuna sp.) cultivation, a practise developed by farmers in Honduras, apart from improving the soil quality, doubled the maize (primary crop) yield and maximized returns to land and labour due to lower land preparation cost and weeding requirements (Buckles and Triomphe,
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1999). Unless a highly site specific and farmer oriented solution is proposed, the anticipated positive results may fail to appear. Variable biomass production, uncertain residual effect and possible role of the introduced fallow species as a host for crop pests may act as a disincentive to the farmer to adopt these techniques (Drechsel et al., 1996; Roder & Maniphone, 1998).

6. Ecosystem/land use diversity

Land use heterogeneity integrates structural and functional aspects associated with the diversification of planned and associated biodiversity, and differentiation of nutrient cycling patterns. Traditional land use practices are highly complex, in that one may find complex set of ecosystems varying in space and time in respect of biodiversity, productivity and management intensity, fine-tuned to micro-scale environmental heterogeneity and soil productivity.

Farmers often deliberately manipulate regeneration processes in their lands through selective weeding and clearing, and create suitable microhabitats for useful wild species (De Jong, 1996; High & Shackleton, 2000) or for crop species which are most productive under those conditions (Wilken, 1977). Complex interactions between indigenous soil and water conservation practices and different biophysical and socioeconomic farm characteristics were revealed by Tengberg et al. (1998). They observed maximum adoption of risk aversion strategies like diversification of crops and use of soil and water conservation measures by farmers belonging to the medium resource strata. Low-resource farmers were constrained by limited access to resources whereas high resource farmers were probably insulated against the effects of deteriorating environment. In resource-limited environments, allocation of management effort to alternate land uses is guided by farmer’s decision which tends to concentrate on and intensify use of those areas where production potential is highest and associated risk, minimum (Carter & Murwira, 1995).

Farmers have been shown to possess deep knowledge about soil fertility in relation to landscape position and crop requirements (Steiner, 1998). Land use practices, which may be perceived as unsuitable from an external viewpoint, may actually be refined adaptive strategies, which ensure best possible outcome within the constraints of the farmer’s environment. For instance, expansion of fields into marginal, sandy areas and reallocation of these fields to maize crop in Sahel was a
response to declining rainfall regimes under which sandy soils are better suited to a demanding crop like maize (Reenberg et al., 1998). Often farmer behaviour that is apparently at variance with accepted norms may at closer examination turn out to be rational management decision as farmers tend to perceive environmental quality in a more holistic manner than scientific workers (Kiome & Stocking, 1995; Murage et al., 2000).

The interdependency of different ecosystem types signifies the importance of landscape level analysis for designing sustainable agriculture and forestry development programs (Naveh, 1998; Vandermeer et al., 1998).

7. Indicators of agroecosystem/land management sustainability

Assessment of agricultural sustainability requires the development of integrative indicators that take into account the complex interactions between different socioeconomic and biophysical determinants of agroecosystem structure and function. biomass is one such readily conceivable and tangible integrator of ecosystem attributes. Nisanka & Misra (1990) evaluated the ecological status of a village landscape based on an analysis of biomass flow between cropland, grassland and plantations. energy and monetary budgeting have been frequently used as a measure of agroecosystem performance. Such energy and monetary budget analysis have been applied for comparative analysis of cropping systems and for ascertaining the role of external energy flows in the form of natural or fossil fuel based subsidies (Sharma, 1991; Singh & Singh, 1984; Singh et al., 1997). However, these indicators do have their limitations. Energy measures of resources may not necessarily reflect the manner in which they are valued through social and economic capital/processes. Like wise, monetary indicators may underscore the value of reusable resource thus presenting a distorted illustration of production from a given system (Tellarini & Caporali, 2000). soil quality has also been used as an indicator of agroecosystem sustainability as soil status can influence farmer’s decision making and affects all spheres of agroecosystem productivity (Murage et al., 2000). land quality indicators which have added upon basic soil quality measures to include criteria such as climate and cropping system provide a much more holistic approach to evaluation of condition and capacity of land to provide services on a sustained basis. Bindraban et al. (2000)
proposed application of yield gap analysis and soil nutrient balance analysis as two land quality measures which reflect the ecological status as well as the potential of achieving optimum production from land. While soil nutrient balance can identify the detrimental processes and locate deteriorating nutrient stocks, yield gap analysis gives a measure of the gap between the realized and potential cereal yields. A major limitation with which these indicators suffer from is their inability to register and reflect the socioeconomic perception and response. They do not take into account the biotic stresses related to management practices and may not be appropriate in areas where cereals are not the dominant crop. Drawing upon detailed biophysical and socioeconomic information collected at village as well as household level from several villages, Lefroy et al. (2000) developed qualitative and quantitative indicators for sustainable land management that extended over five fundamental sustainability themes viz. productivity, security, protection, viability and acceptability.

8. Forestry/forest management and agroforestry

Forestry and agroforestry represent ecologically desirable and economically viable land use alternatives for environmentally restorative purposes as well as for augmentation of an agricultural economy.

8.1. Forestry

The specific design and management of the forest/plantation influences the extent to which it allows for the provision of ecological services like sequestration of carbon, conservation of biological diversity and stabilization and amelioration of soil fertility, and confers benefits to the local population (Fisher, 1995; Pathak & Dagar, 1998). Keller & Goldstien (1998) estimated that restoration of degraded land can sequester up to 0.8 billion tons of carbon per year. Mixed plantations may be more productive, reduce pests, suppress weeds and confer multiple economic benefits when species mixed have divergent niches compared to monospecific plantations which may result in rapid nutrient depletion and lower productivity due to self thinning at high tree density (Montagnini et al., 1995; Montagnini & Porras, 1998). Recent researches have suggested that in a mixed forest stand, individual trees can exert strong influences on the fertility status of soil beneath them.
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(Montagnini & Sancho, 1994; Finzii et al., 1998). Species which display spatial (overstorey vs. understorey) and temporal (evergreen vs. deciduous) differences in their light interception ability have fundamental differences in partitioning of resources to various plant organs, leaf life span, assimilation rate and cost/benefit ratios associated with production and maintenance of leaves (Eamus, 1999; Niinemets, 1998). Therefore competition for resources can be minimized/complementarity can be maximized by appropriate selection of species in mixed plantation.

While thinning and harvesting is an integral part of forest management, determination of the ideal harvesting regime for a forest/plantation is a critical management issue. Intensive harvest can result in removal of large amounts of nutrients from the site (Tritton et al., 1987). Limited lopping targeted at shaded or senescent leaf may actually stimulate growth by checking the energy drain and also enhance the overall system productivity by promoting understorey growth (Bhat et al., 1995). Sustainable silvicultural practices like the ‘strip clear-cut system’ where the harvesting regimes mimic gap phase dynamics in tropical forest have to be developed to minimize ecological damage (Buschbacher, 1990).

In developing countries, where social considerations form the core of forestry objectives, diverse institutional mechanisms have to be evoked and/or supported depending on the physical environment and the socio-economic status of the beneficiaries (Chatterjee, 1995; Samwal, 1988). In India, farm forestry programs, where trees are grown along farm boundaries or in distinct blocks, have chiefly addressed the relatively more commercialised areas where large land-owners augment their economic profit through cultivation of trees used in timber and paper industry. This implies that government initiated farm forestry programs remained confined to western and north-western India characterized by large land holdings (Saxena, 1992). Community forestry on commonly owned lands that give due consideration to local needs and rural social organization hold potential in socio-economically marginal and environmentally rich areas characterized by a relatively higher socio-economic homogeneity (Samwal, 1988). In many instances, village afforestation programs implemented by the government adopting a community approach have met with limited success. In such cases, individual initiatives and private tree planting may play a major role in village development (Carter &
Gilmour, 1989; Price & Campbell, 1998; Salam et al., 2000). Strengthening of existing traditional agroforestry practices may be an integral component of any forest conservation strategy (Levasseur & Olivier, 2000; Morrisson et al., 1996; Nair & Dagar, 1991; Pathak & Dagar, 1998).

8.2. Agroforestry

Agroforestry systems are defined by the structural and functional interactions between tree, crop and livestock components. Sanchez (1993) derived a set of hypothesis that addressed the various biophysical and socio-economic aspects of tree-crop interactions, which may be conferring net benefits to the system. For an agroforestry system incorporating trees, crops and livestock, niche complementarity has been proposed as a necessary condition in order to minimize competition and achieve optimum productivity (Sanchez, 1995). Complementary resource use has been demonstrated between shallow rooted crops and deep rooted trees as indicated through achievement of land equivalent ratio values of 1.37 and 1.47 at low and high tree density, respectively (Droppelmann et al., 2000). Cannell et al. (1996) highlighted the role of complementarity in resource capture in conferring a net yield benefit to the system and reduced most of the biophysical hypothesis given by Sanchez (1995) into a single agroforestry hypothesis stating that trees will enhance yield of associated crops only in environments where they are able to capture resources that are in excess of crop requirement. Kho (2000) further refined the tree-crop interaction model given by Cannell et al. (1996) by incorporating an environmental component. He postulated that tree effect on availability of a resource does not necessarily imply an increased capture of that resource by the associated crop and there would be a strong correlation between tree effect on capture and availability of resource only when the resource in question is limiting.

The three major aspects of tree-crop interactions that need to be addressed while designing viable agroforestry systems include:

a) **Species selection**: Selection of tree-crop association is a crucial factor that determines the extent to which net benefit is realised. The choice of species has to take into account phenology and adaptive traits (Cannell, 1991). Traditional home gardens exemplify how niche complementarity can be achieved by
organising tree-crop mixtures in four or more vertical strata (De Clerck & Negreros-Castillo, 2000). The ability of species to partition a higher portion of biomass to edible parts is an important criterion for selection of crop. The LER (land equivalent ratio) for grain may be higher compared to that for total biomass and therefore it has been proposed that combining cereal with a tree legume may elicit a favourable response as cereals partition more dry matter to grains (Ong, 1991).

b) **Plant architecture**: Each plant has a more or less constrained growth and branching pattern which exhibit limited plasticity in response to environmental factors (De Reffye et al., 1995). Loose, cladophyllous canopies like that of *Casuarina* sp. which intercept minimum light may have a relatively less suppressive effect on the growth and yield of understorey crop and forage species (Mathew et al., 1992; Okorio et al., 1994).

c) **Species management**: In most cases trees have a depressive effect on understorey crop yield due to root competition and light interception (Khybri et al., 1992; Okorio et al., 1994). Therefore appropriate management of tree-crop component becomes essential. Mixed canopies in agroforestry system can be managed for optimum light interception and maximum production by pruning the tree at a time when the crop needs more light (Ong, 1991). Pruning trees which is expected to remove new shoots, buds and stem carbohydrates, may decrease tree productivity only upto a certain limit because the increased photosynthetic rate of the remaining foliage compensates for the loss (Cannell, 1991; High & Shackleton, 2000; Larbi et al., 2000). Apart from yield depression of understorey crop due to interception of light, at high densities, trees may also intercept rainfall thus adversely affecting the soil moisture status of the ground below (Braziotis & Papanostasis, 1995). If trees are being managed for soil fertility amelioration, selection of appropriate mulch combination, timing and position of placement of mulch may be important factors to be considered for achieving desired level and rate of nutrient release (Palm, 1995). Mulch quality, which affects its decomposition rate and therefore persistence in soil may also influence the weed suppression ability of the respective trees (Kamara et al., 2000)
However, Tornquist et al. (1999) found no indication of improvement in soil biological or chemical parameters due to agroforestry system established on unmanaged pastures even 3 years after canopy closure. Benefits of agroforestry over the sole crop or tree production system in many circumstances are not supported by experimental evidence (Ong, 1991; Sanchez, 1995). Ong (1991) and Kho (2000) have argued that experimental evidences demonstrating advantages of agroforestry system over sole tree/crop systems are highly location specific.

9. Himalayan environment
The Himalayas is a vast mountain system covering partly or fully eight south Asian countries viz., Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. India’s recognition as one of the four ‘megadiversity’ countries of Asia and as one of the ten largest forested areas in the world derives partly from the Himalaya. The Indian Himalaya, although covering only 18% of the total geographical area of India, accounts for more than 50% of India’s forest cover and for 40% of the species endemic to the Indian subcontinent.

A huge biodiversity wealth, environmental heterogeneity and diversity in traditional agroecosystem and forest management practices characterize the Himalayan Mountain system. Agricultural crops, livestock and forests are the interlinked subsystems all across the Himalayas, though the attributes of each sub-system and the nature of sub-system linkages may vary. Ecological and economic attributes of traditional agricultural/agroforestry have been examined in a number of studies. Energy and economic efficiency of Central Himalayan hill agroecosystems have been analysed by Sharma (1991), Singh et al. (1984), Singh & Singh (1991) and Semwal & Maikhuri (1997). Sharma et al. (1997a,b) compared the nutrient cycling patterns in four agroforestry systems representing different stages in land use transformation in the Sikkim Himalayas. Toky et al. (1989) assessed the biomass, productivity and nutrient budget patterns under three agroforestry systems. Fuelwood and fodder quality and utilization patterns have also been dealt in a few studies (Bhatt & Todaria, 1990; Khosla et al., 1992; Samant et al., 2000). Ecological status of the agricultural landscape has been determined through studies focussing on nutrient and biomass flows and ability of various components of the landscape to provide the required outputs. Biomass
and energy flow between the various landscape components viz. forest, livestock and crops have been quantified by Pandey & Singh (1984) and Singh et al. (1997). Pilbeam et al. (2000) estimated the nitrogen balances for an agricultural landscape in Nepal and described the major pathways of nitrogen flow across forest, livestock and cropped areas. The carrying capacity of land resources in Nepal to support livestock population was ascertained by Thapa & Paudel (2000).

However, very few studies have taken into account the agroecosystem diversity at the landscape level. Landscape level diversity and associated processes involved with shifting cultivation systems in North Eastern Himalayas have been comprehensively researched and documented (Ramakrishnan, 1992). Singh & Singh (1992) provide a synthesis of knowledge on settled agriculture and forest interactions in the Central Himalaya. However, comprehensive analysis of ecosystem differentiation, interactions between different ecosystem types in the village landscape and human dimensions of ecosystem management in the Central and Western Himalayas is lacking.

The present effort:
This study aims to analyze the agricultural and forest ecosystem structure, diversity and functional interlinkages in a village landscape and to understand the impact of agricultural land use intensification on ecosystem attributes.

The wider objective of this study was to analyze ecosystem differentiation, interactions between different ecosystem types in the village landscape and human dimensions of ecosystem management in a typical Garhwal Village viz., Pali village. Specific elements looked at in the study include:
1. Characterization of ecosystem differentiation and diversity in the landscape
2. Comparison of planned and associated biodiversity, land use intensity, management practices, productivity and soil fertility in different ecosystem types in the landscape
3. Examining the human dimensions of biodiversity/ecosystem management
4. Analysis of interlinkages between different ecosystem types and their ecological and socio-economic implications
5. Investigation of the effects of selected multipurpose tree species/establishment of mixed plantation on soil fertility parameters