International Journal of Ecology and Environmental Sciences 35 (1): 35-52, 2009

Land Use Intensification in Indian Himalaya: Meaning, Measurement and Implications

Joylata Laishram[1], R.K. Maikhuri[2], K.S. Rao[3*] and K.G. Saxena[1]
[1] *School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India*
[2] *G.B. Pant Institute of Himalayan Environment and Development, Garhwal Unit, P.O. Box 92, Srinagar (Garhwal) 246174, India*
[3] *Department of Botany, University of Delhi, Delhi 110007, India*
* Corresponding author: *E-mail: srkottapalli@yahoo.com; srkottapalli@botany.du.ac.in*

ABSTRACT

Land use intensification is a crucial process influencing biodiversity, ecosystem functions and livelihoods. There are multiple ways of defining and measuring intensification. This article presents a review of the meaning, methods of measurement and ecological implications of land use intensification, with special reference to central Himalayan region of India. It is concluded that (i) land use intensity should be evaluated at different levels: from crop level through agroecosystem/farm level to village landscape level, (ii) homegardens, which constitute a minor land use in terms of spatial extent, are the most intensive land use system in terms of agricultural input rates, output rates and output to input ratios as well as the most rich one in terms of soil organic carbon and nutrient stocks, (iii) a significant improvement in local farm economy and ecosystem functions can be achieved by increasing the rates of locally available inputs, increasing the efficiency of use of inputs for farm production and matching crop/cultivar combinations with the environmental opportunities and constraints and (iv) land use intensification-biodiversity-ecosystem function relationships would depend on the criteria and spatio-temporal scales chosen for measuring explanatory and response variables.

Key Words: Resource Inputs, Labour Inputs, Crop Productivity, Labour Productivity, Traditional Land Use Practices

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 as the crucial determinant of cultivation 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 agricultural intensification minimizing the demand for natural habitat (Green et al. 2005). However, intensification can accelerate rather than contain deforestation if effective forest conservation policies are not in place. For example, in the Ecuadorian Amazon higher yields obtained on richer soils led farmers to invest the profits in land uses that involved more extensive deforestation (Pichon 1996). In contrast, in the Indian central Himalayan region, where policy restrictions on forest conversion were enforced way back in the nineteenth century, agricultural expansion in forest land has been negligible (Maikhuri et al. 2000, Semwal et al. 2004). Many workers have concluded agricultural land use intensification as the major cause of loss 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). In contrary, a few researchers have argued in favour of intensification by demonstrating enhancement of carbon sequestration in agroecosytems receiving a proper mix of inorganic fertilizers and organic manure (Kundu et al. 2007). As biodiversity and ecosystem functions are likely to show non-linear responses to 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). The degree to which intensification is a priority concern relative to other social and environmental objectives will vary from region to region (Shriar 2000). This article provides a review of the meaning, measurement and implications of land use intensification in Indian Himalaya.

MEANING OF LAND USE INTENSIFICATION

There is a considerable variation in the expressed meaning of intensification (Box 1). The notion of increasing crop/livestock productivity cuts across all definitions of intensification. The differences in the meaning and measures of intensification derive from the variation in the spatio-temporal scale of measuring agricultural inputs and outputs [i.e., criteria adopted for demarcation of spatial (e.g., a crop field, a farm or a landscape) and temporal (e.g., in shifting agriculture, number of harvests per year during cropping phase or number of harvests during the entire cultivation cycle)] boundaries of agricultural production system, measures of productivity (human food yield or livestock feed/fodder yields valued in terms of energy or market value) and in selection of factors determining productivity (e.g., local inputs or external inputs; household scale or community scale factors) (Tables 1, 2 and 3). As intensification process is driven by humans, the magnitude of human impact on ecosystems is a reflection of intensification (Fedoroff et al. 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 use of mineral fertilizers is likely 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/cultivars in the mixture facilitate growth of each other and suppress negative crop-weed interactions. Increase in planned biodiversity

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 1972)
- 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 2000)
- Intensification is the process that allows the reduction in use of inputs (including land acreage) without negatively affecting output levels (Pascual 2005).
- Land use intensification can be defined subjectively by the increasing impact of man on the landscape (Fedoroff et al. 2005)

Table 1. Measures and indices of agricultural intensification

Author(s)	Measures or indicators of intensification
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 or (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)	Productive (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 (1976) 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. Land use stages/types in intensification gradients studied in a cross section of studies

Study	Intensification gradient from the least to the most intensive land use
Steffan-Dewenter et al. (2007)	Near-primary forest < Cacao agroforest (80% shade) < Cacao agroforest (40% shade) < Cacao agroforest (unshaded)
Collard and Zammit (2006)	Brigalow (*Acacia harpophylla*) < Grasslands following clearing of original vegetation < Grasslands that have been previously cultivated but left fallow for 3-15 years < Recently (< 2 years) cultivated land
Fedroff et al. (2005)	Old growth forests < Managed forests < Mixed landscape dominated by woodland < Mixed landscape not dominated by a single land use < Mixed landscape dominated by pasture < Mixed landscape dominated by arable crops
Urama (2005)	Rainfed farms < Irrigated farms
Pascual (2005)	Shifting agriculture with low technical efficiency, i.e., ability to transform inputs into outputs < Land uses with high technical efficiency
Thierfelder et al. (2005)	Crops receiving 4 t/ha/year of chicken manure < Crops receiving 8 t/ha/year of chicken manure
Roschewitz et al. (2005)	Areas with higher landscape complexity, higher farm specialization, higher fertilization input rates and higher yields < Areas with lower landscape complexity, lower farm specialization, lower fertilization rates and higher yields

Table 3. Selected features of land-use/cover types differentiated in Bacchelikhal village landscape, Garhwal, India (Singh et al. 2008)

Land-use	Relative area (% of total village area)	Distance from dwellings (km)	General appearance and land 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.

(i.e., crop diversity) 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 (Fedoroff et al. 2005, Collard and Zammit 2006). In regions undergoing conversion of primary forests to plantations (e.g., Indonesia), primary forests represent the lowest, the un-shaded cacao plantations the highest and shaded cacao agroforests the medium levels of land use intensity, reflecting intensification as the degree of change in climax forest ecosystems (Steffan-Dewenter et al. 2007). Differing from this scenario, are the scenarios where intensification implies changes in the rates of inputs and/or outputs within agricultural or pasture or forestry land uses or in relative proportions of these land uses in the landscapes (Fedoroff et al. 2005, Ponge et al. 2000) (Table 2).

Traditional crop-livestock mixed farming, the backbone of livelihood of local people in the central Himalayan region of India (viz. Uttarakhand), 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 one ha of traditional settled agriculture (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 Himalaya and other regions, where agriculture and forests are interacting rather than independent and isolated land uses, intensification should be viewed as a landscape process, looking into changes in various ecosystem types differentiated in the landscape (Ives and Messerli 1989, Hurni 1999, Briggs and Twomlow 2002, Ghersa et al. 2002, Desbiez et al. 2004, Baijukya et al 2005)

Intensification, Land Use Histories and Land Use Differentiation in Landscapes

Generally, farmers intensify production in two situations: (i) when they perceive land scarcity because of population pressure or other demands on land and (ii) when they perceive market related or other benefits from intensification (Brookfield 1972, Boserup 1981, Turner and Ali 1996). Studies from Western Africa show that soil fertility management practices follow a path from fallow, via improved recycling of nutrients achieved through an efficient integration of crop and animal husbandry to using external inputs (deRidder et al. 2004). Instead of a complete replacement of one land use intensification stage by the other over time, different states of intensification often coexist. Differentiation of land use along intensification gradient in the landscapes is determined by interaction of a multitude of factors including environmental limits to productivity, farmers' needs and desires, resources availability, market potential and influence of policies on farmers' decision making process.

Land management objectives and practices have changed over time with changing socio-economic conditions, technological innovations and policy interventions in the Himalaya as also elsewhere (Baijukya et al 2005, Singh et al. 1997, Sherchan et al. 1999, Plieninger and Wilbrand 2001, Zhang et al. 2004). The present landscape structure thus is a cumulative reflection of past land use/cover 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 (Table 3). Irrigated crop systems differ based on the reasons behind their origin: government subsidy available for small run-off harvesting tanks to individual families, minor/major irrigation canal systems as services provided by the government to farmers and indigenous irrigation systems innovated and maintained by local communities (Rao and Saxena 1994, Chandrasekhar et al. 2007, Singh et al. 2008). While indigenous irrigation systems may be centuries old, the introduced ones came in existence after 1970. The instances of intensification through conversion of traditional rainfed to irrigated agriculture by local communities free from any external influence are rare in recent times possibly because of lack of any serious level of food insecurity (Singh et al. 2008). There are many instances of collapse of government irrigation systems soon after their establishment, but not of indigenous systems, possibly because of a mismatch between the introduced irrigation technologies and existing socio-cultural and ecological conditions. In many villages, 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 (Table 3) but the most intensive one in terms of output and input rates (Tables 4, 5), seems as old as the typical agricultural land use. Farmers use multiple criteria to value a given land use, including availability of inputs, returns to land and labour in terms of both local food security and income and resilience to environmental risks and uncertainties. For example, farmers attach 3 primary

Table 4. Annual mean inputs, land productivity and labour productivity per hectare of different agricultural land-use types in Bacchelikhal village landscape, Garhwal Himalaya, India (Singh et al. 2008). Values with different letters within a column are significantly (P <0.05) different.

	Inputs			Labour				Edible Yield				Fodder	
	Manure (Mg)	Bullock power (GJ)	Seed (GJ)	Person days Male	Person days Female	Energy (GJ) Male	Energy (GJ) Female	Land Productivity Food energy (GJ)	Land Productivity Monetary value (Rs)	Labour Productivity Food energy (GJ GJ^{-1})	Labour Productivity Monetary value (Rs GJ^{-1})	Land Productivity (GJ)	Labour Productivity (GJ GJ^{-1})
Homegarden system	50^{a}	1.55^{b}	0.73^{c}	22.7^{c}	139.1^{a}	0.13^{c}	0.47^{a}	102^{a}	63340^{a}	171^{a}	105567^{a}	36^{c}	60^{c}
Rainfed agroforestry system	30^{b}	2.36^{a}	2.62^{a}	33.2^{b}	100.6^{b}	0.19^{b}	0.34^{b}	55^{b}	20362^{b}	103^{b}	38419^{b}	99^{a}	187^{b}
Rainfed crop system	1^{c}	0.77^{c}	2.14^{a}	15.7^{d}	74^{c}	0.09^{d}	0.25^{c}	34^{c}	6674^{d}	99^{b}	19629^{d}	73^{b}	216^{a}
Irrigated crop system	33^{b}	1.95^{ab}	2.26^{a}	66.3^{a}	106.5^{b}	0.38^{a}	0.36^{b}	39^{c}	20747^{b}	53^{c}	28036^{c}	36^{c}	49^{d}
Shifting agriculture	nil	nil	1.08^{b}	26.2^{c}	47.3^{d}	0.15^{c}	0.16^{d}	19^{d}	12170^{c}	61^{c}	39258^{b}	nil	nil

purposes behind maintaining homegardens: (i) productive re-cycling of household wastes, (ii) achieving nutritional security/health care and conservation of agro-biodiversity and (iii) enhancement of indigenous know-ledge (Table 6).

The abundance and species composition of farm tree community in the Himalaya enormously vary in time and space and this variation stems from the variations 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 (Nautiyal et al. 1988, Gilmour and Nurse 1991, 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. 1997, 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. 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, Rao et al. 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- and protected area-centred forest management. 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 continues to persist 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). Establishment of shifting agriculture system in previously uncultivated lands requires lesser energy and time compared to the traditional settled farming. Further, shifting cultivation does not require any manure and draught power inputs essential for sustaining settled

Table 5. Crop-wise relative area (area of a crop as % of total cropped area in rainy season/winter season), inputs of manure (Mg ha^{-1}) and human labour (GJ ha^{-1}), land productivity (energy available from human food/fodder and labour productivity (food/fodder energy (GJ ha^{-1}) or monetary value (Rs ha^{-1}) of produce per GJ human labour input) related to individual crops grown in different agricultural land-uses (monetary value of fodder is not given as it is not sold) in Bacchelikhal village landscape, Garhwal Himalaya, India (Singh et al. 2008)

Land-use/crop	Relative area	Inputs		Edible yield				Fodder	
		Manure	Labour	Land productivity Food energy	Land productivity Monetary value	Labour productivity Food energy	Labour productivity Monetary value	Land productivity	Labour productivity
Rainfed agroforestry system									
Echinochloa frumentacea Link*	36	26 ^{b}	0.28 ^{d}	34 ^{b}	5219 ^{de}	121 ^{a}	18639 ^{bcd}	59 ^{a}	213 ^{f}
Eleusine coracana (L.) Gaertner									
+ *Glycine max* (L.) Merrill*	30	12 ^{cd}	0.32 ^{d}	33 ^{b}	11973 ^{bcd}	104 ^{ab}	37415 ^{b}	65 ^{a}	203 ^{f}
Zea mays L. + *Glycine max* *	34	42 ^{a}	0.45 ^{b}	49 ^{a}	33635 ^{a}	108 ^{ab}	74744 ^{a}	71 ^{a}	158 ^{cd}
Hordeum vulgare L.**	40	1 ^{e}	0.19 ^{e}	23 ^{b}	2858 ^{e}	120 ^{a}	15042 ^{cd}	36 ^{bc}	187 ^{bc}
Triticum aestivum L.**	60	8 ^{de}	0.21 ^{e}	15 ^{c}	7021 ^{c}	69 ^{bcd}	33433 ^{bc}	23 ^{cd}	111 ^{ef}
Rainfed crop system									
Echinochloa frumentacea Link*	50	1 ^{e}	0.21 ^{e}	27 ^{b}	4151 ^{e}	128 ^{a}	19766 ^{bcd}	62 ^{a}	296 ^{a}
Eleusine coracana **	50	1 ^{e}	0.22 ^{e}	27 ^{b}	5076 ^{de}	124 ^{a}	23072 ^{bcd}	40 ^{b}	184 ^{fc}
Hordeum vulgare L.**	14	1 ^{e}	0.17 ^{e}	21 ^{b}	2571 ^{e}	121 ^{a}	15124 ^{cd}	18 ^{de}	103 ^{ef}
Triticum aestivum L.									
+ *Hordeum vulgare* L.**	57	1 ^{e}	0.11 ^{f}	4 ^{d}	2032 ^{e}	40 ^{cd}	18472 ^{bcd}	13 ^{de}	117 ^{ef}
Triticum aestivum L.**	29	1 ^{e}	0.09 ^{f}	3 ^{d}	1159 ^{e}	38 ^{d}	12878 ^{d}	6 ^{e}	62 ^{g}
Irrigated crop system									
Sesamum indicum L.*	100	21 ^{bc}	0.30 ^{d}	12 ^{c}	8201 ^{cde}	41 ^{cd}	27337 ^{bcd}	nil	nil
Triticum aestivum L.**	100	12 ^{cd}	0.39 ^{c}	27 ^{b}	12546 ^{d}	69 ^{bcd}	32169 ^{bc}	36 ^{bc}	83 ^{fg}
Shifting agriculture									
Sesamum indicum L.-first year crop*	25	nil	0.83 ^{a}	28 ^{b}	17796 ^{b}	33 ^{d}	21440 ^{bcd}	nil	nil
Macrotyloma uniflorum (Lam.) Verdc.									
- fourth year crop*	75	nil	0.16 ^{e}	14 ^{c}	13032 ^{bc}	87 ^{abc}	81450 ^{a}	nil	nil

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

Table 6. 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*	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 out-migration for off-farm employment in urban/sub-urban centres) constraining realization of the potential of this highly productive system
Rainfed settled agroforestry (nearer to the 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 dwellings)	1. Assertion of land ownership	1. Wastage of huge time and labour in travel and transport 2. A low level of management results in abundance of weeds increasing risks of their spread to other land uses
Irrigated crop system (away from dwellings)	1. Benefiting 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	1. Forest fire

* in the order of priority given by numbers 1-3; the objectives given equal priorities are referred by digits followed by alphabets

cultivation. 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 1994, 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), providing a scope for agricultural intensification through conversion of shifting to settled agriculture (Gilmour and Nurse 1991, Saxena et al. 1993). There seem several reasons for absence of such a land-use change. First, as the villages are self-sufficient in terms of their food requirements, farmers have so far not realised the need of raising land productivity through intensification (i.e., 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 its further expansion. Third, labour shortage arising from migration of rural people to urban areas favours persistence of shifting agriculture for its high labour productivity. Fourth, the availability of high quality fuelwood from *Rhus parviflora* and *Murraya koeningii*, the dominant species of fallow vegetation, mitigates the problem of shortage of fuelwood arising from timber- and protected area-centred forest policies.

Agricultural intensification trajectories constructed based on our studies in the Himalayan region are summarized in Figure 1. Though climate permitted harvesting of two crops in a year, one grown during rainy season and the other during winter season, traditional rainfed agriculture involved harvesting of three crops every two years. The agricultural land of a village used to be divided into two almost equal halves called 'Sar', with all households having land parcels in both halves and each Sar fallowed in winter season 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 management practices differ depending on the environmental and socio-economic circumstances (Singh et al. 1997, Rao et al. 2003). In traditional irrigated land uses, land use intensity in terms of number of crops harvested in a year has remained unchanged but staple food crops (paddy and wheat) are being replaced by cash crops (particularly vegetables) together with an increase in manure input rates and use of chemicals if available at

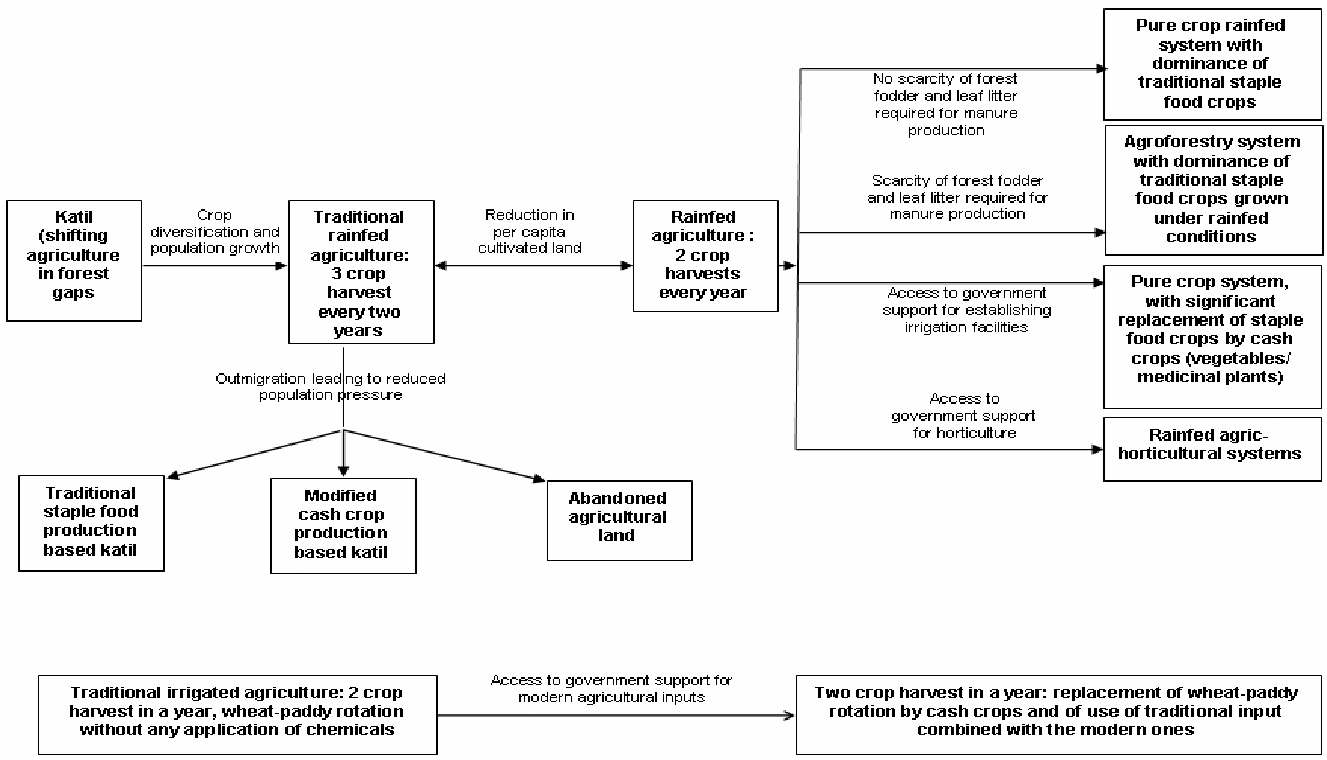


Figure 1. Stages in land use intensification in traditional agriculture in Garhwal Himalaya

subsidized price. The examples of decline in land use intensity, though few, do exist. Agricultural land use is casual and less intensive in distant fields and is completely abandoned if a family is able to secure livelihood from non-farm occupations or agricultural land is extremely degraded as a result of past unsound land uses (Maikhuri et al. 1996, Singh et al. 2008). While social mechanisms and institutions fostering sustainable agricultural land use have weakened due to cultural transformation, this dimension of sustainability in private farm land has not received adequate attention in the present land use policies (Nautiyal et al. 1988, Singh et al. 2008).

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: (a) the risk of climate arising from uncertainty of monsoon rainfall and (b) of cultivating distant fields arising from huge labour and time to be spent in travel/transport. Our village level case studies show that 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 (Table 6). The most risky rainfed crop system received the lowest and the least risky homegardens the highest level of agricultural inputs (Table 5). Crops common to rainfed agroforestry system and rainfed crop system were paid more attention in the former system because of lesser risks (Table 5). 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 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 crop-environment relationships. Cultivation of a range of local millet cultivars differing

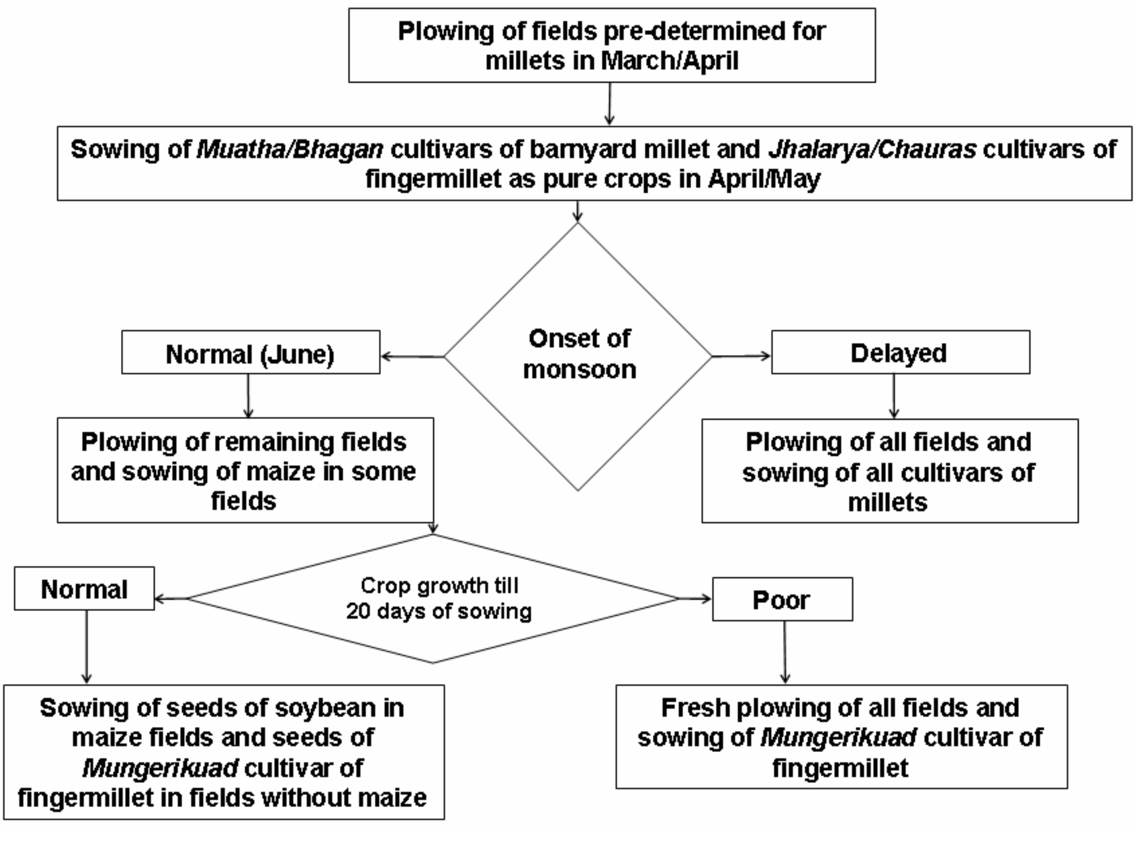


Figure 2. Farmers' decision making on cropping pattern during rainy season in rainfed agroforestry system in village Bacchelikhal, Garhwal, India (Singh et al. 2008)

in respect of their performance under varied monsoon conditions is a means of coping with climatic variability and uncertainty (Figure 2) as also reported by Bardsley (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 and a 17-fold variation in maize yield compared to 2- fold variation in millet yield over a range of manure/fertilizer input rates. A more stable yield of millets compared maize has been observed in long term trials too (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, differentiation of land use based on intensification level in the landscape is guided by interaction of environmental and socio-economic factors (Guyer and Lambin 1993).

MEASUREMENT OF LAND USE INTENSIFICATION

The measures used to quantify agricultural intensity fall in three groups: (i) farm output as a measure of agricultural intensity estimated 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 land and (iii) input rates, i.e., labour, materials, energy inputs 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.

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 monetary value of farm produce, which may not be correlated. The measures would also vary depending on 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). 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*, after its recognition as cash crop since 1980s in Garhwal Himalaya, enabled high labour productivity on low quality land (Singh et al. 2008). 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 intensi-fication levels based on monetary outputs (Shriar 2000).

Cropping Frequency Based Measurements

Frequency of cultivation or land use is the most common measure of comparing intensity of agricultural land uses 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 7). 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).

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 treatments 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. A broadly similar approach is also illustrated by Turner and Doolittle (1978). An element of subjective bias in ranking is a major drawback of such approaches. The so called 'low tech' systems may not necessarily be less productive than the 'high tech' systems, e.g., wheat yields in agricultural systems with extensive tractor uses in USA and Canada (2128-2655 kg ha^{-1}) are lower than that (4689-4735 kg ha^{-1}) in Mexico and Central America where tractor use is much less common (Shriar 2000). Shriar (2000) proposed that agrotechnoloies 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 yield per unit area per unit time.

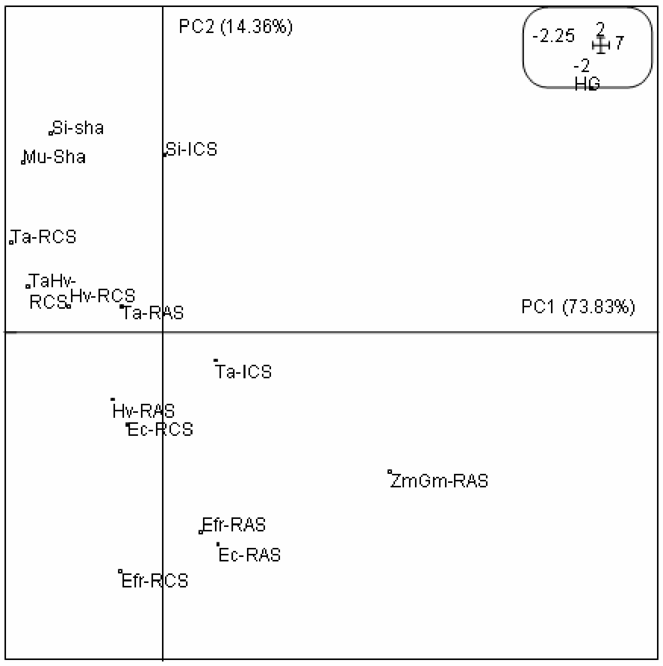
As different inputs or outputs may not follow the same spatio-temporal trends, a land use more intensive in terms of one input or output may appear less or equally intensive in terms of other input(s) or output(s) (Menalled et al. 1999, Thies and Tscharntke 1999, Roschewitz et al. 2005). To the extent possible, it will be worthwhile to identify some common denominator, such as energy or monetary value of the inputs/outputs as given in Tables 4 and 5, to obtain a clearer overall picture of land use intensity (Kates et al. 1993). 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 the land use is. 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 that of homegardens but the two land uses resemble in terms of proportion of productivity utilized by humans. Working with actual indicators, which have a physical unit (e.g. kg N ha^{-1}, cm irrigation water input ha^{-1}, GJ fossil fuel energy ha^{-1}), 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).

Ordination of Ecosystems along Intensification Gradient

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 (Wander and Bollero 1999, Andrews et al. 2002). PCA analysis based on a range of indicators of 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 3a, b) showed that 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 the factor explaining this variation was not included in the list of selected explanatory variables. It is also evident that radically different crops may resemble in terms of their intensification levels (e.g., *Echinochloa frumentacea* grown in rainfed agroforestry system and *Trticum aestivum* in irrigated crop system – Figure 3a). Also divergent land use types may resemble more than similar land uses in terms of intensification (e.g., rainfed agroforestry system seems closer to irrigated crop system than rainfed crop system in terms of land use intensification; Figure 3b).

Table 7. Some examples of calculation of cropping frequency (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) = 0.41



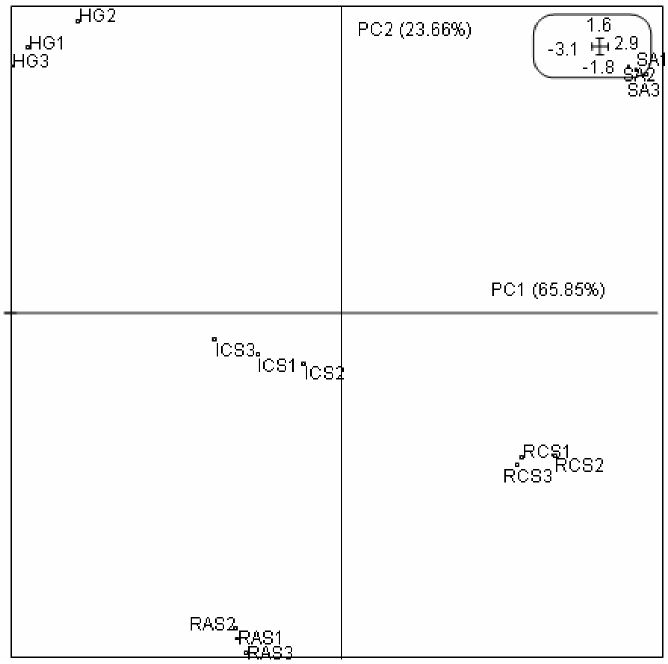


Figure 3a (left). Principal component analysis scatter plot (PC 1 and 2) of crops grown in different agroecosystems based on crop-wise input/output rates. Crops: Efr, *Echinochloa frumentacea*; Ec, *Eleusine coracana*; ZmGm, *Zea mays* + *Glycine max* mixed crop; Hv, *Hordeum vulgare*; Ta, *Triticum aestivum*; TaHv, *Triticum aestivum* + *Hordeum vulgare* mixed crop; Si, *Sesamum indicum*; Mu, *Macrotyloma uniflorum*. Agroecosystems: RAS, Rainfed agroforestry system; RCS, Rainfed crop system; ICS, Irrigated crop system; Sha, Shifting agriculture; HG, Home garden.

Figure 3b (right). Principal component analysis scatter plot (PC 1 and 2) of different agroecosystem types based on agroecosystem-wise input/output rates

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 (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, Lemenih et al. 2005, Komatsuzaki and Ohta 2007) 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. The magnitude of decline in soil organic 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). However, Sparling et al. (2004) did not find utility of microbial biomass because of ephemeral nature of its measurement and the difficulty in justifying its target range. 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 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) = TCLi / TCLr
where TCLi = Total C of a given land use, and
TCLr = Total C of the reference land use

Lability Index (LI) = (LCLi / NCLi) x (LCLr / NCLr)
where LCLi and LCLr = Labile C content of a given land use and the reference land use, respectively, and NCLi and NCLr = Non-labile C content of a given land use, and the reference land use, respectively.

Carbon Management Index (CMI) = CPI × LI × 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 their relative areas.

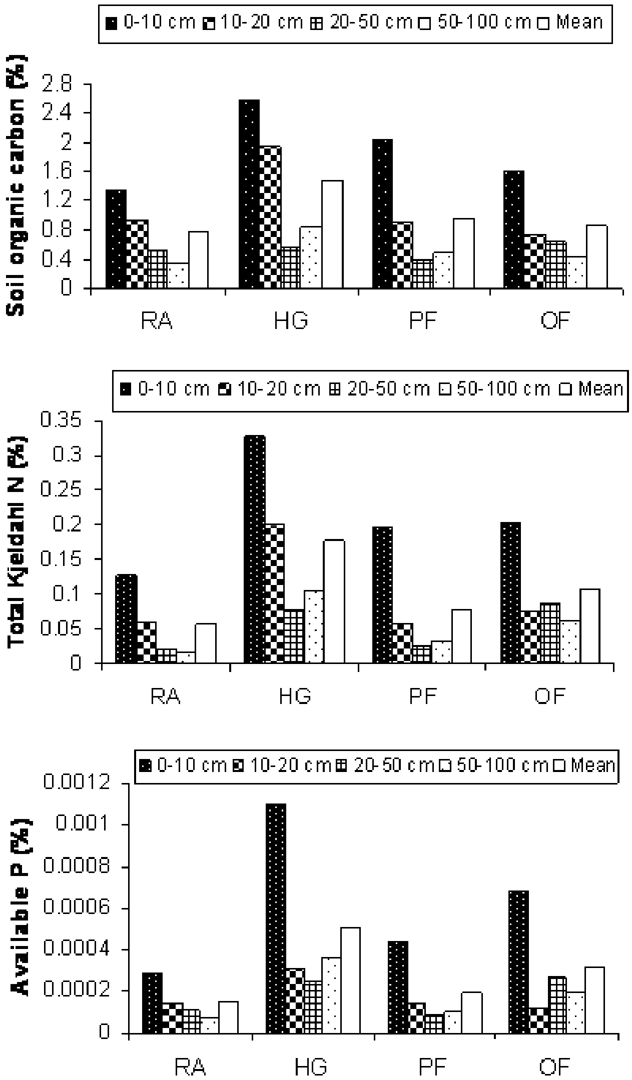


Figure 4. Organic C, total N and available P pools in soil under different land use/cover types in village Bacchelikhal, Garhwal, India. RA, Rainfed Agriculture; HG, Home Garden; PF, Pine Forest; OF, Oak Forest.

Unlike many other regions where the resource flows between ecosystem/land use types differentiated in the landscape are negligible, traditional resource management practices in the Himalaya are such that some forest outputs (e.g., litter and livestock feed) are inputs to agroecosystems (farm yard manure prepared by mixing forest leaf litter and livestock excreta). Crop-livestock-forests interactions are such that diverse land uses may resemble in terms of mean soil organic carbon and nutrient concentrations. 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 receiving larger quantities of manure have soil organic carbon and nutrient stocks larger than rainfed agriculture and forests (Figure 4). 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 condi-tions (Magdoff 1996, Billeter et al. 2008).

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.

Achieving higher yields and profits is an important but not the sole objective of upland 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 (iii) 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 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.

ACKNOWLEDGEMENTS

We are grateful to the Director, G.B. Pant Institute of Himalayan Environment and Development for the facilities. TSBF-CIAT, GEF and UNEP provided the financial support for the work.

REFERENCES

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

Andrews, S.S., Karlen, D.L. and Mitchell, J.P. 2002. A comparison of soil quality indexing methods for vegetable production systems in Northern California. Agriculture, Ecosystems and Environment 90: 25-45.

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

Baijukya, F.P., de Ridder, N., 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. Agriculture, Ecosystems and Environment 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.

Billeter, R., Liira, J., Bailey, D., Bugter, R., Arens, P., Augenstein, I., Aviron, S., Baudry, J., Bukacek, R., Burel, F., Cerny, M., DeBlust, G., DeCock, R., Diekotter, T., Dietz, H., Dirksen, J., Dormann, C., Durka, W., Frenzel, M., Hamersky, R., Hendrickx, F., Herzog, F., Klotz, S., Koolstra, B., Lausch, A., LeCoeur, D., Maelfair, J.P., Opdam, P., Roubalova, M., Schermann, A., Schermann, N., Schmidt, T., Schweiger, O., Smulders, M.J.M., Speelmans, M., Simova, P., Verboom, J., van Wingerden, W.K.R.E., Zobel, M. and Edwards, P.J. 2008. Indicators for biodiversity in agricultural landscapes: A pan-European study. Journal of Applied Ecology 45: 141-150.

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 Research 46: 1459-1466.

Bohle, H. and Adhikari, J. 1998. Rural livelihoods at risk. How Nepalese farmers cope with food insecurity. Mountain Research and Development 18: 321-332.

Boserup, E. 1981. Population and Technology. Blackwells, Oxford, UK. Xxx pages.

Boserup, E.1965. The Conditions of Agricultural Growth. Aldine, Chicago. Xxx pages.

Breland, T.A. and Eltun, R. 1999. Soil microbial biomass and mineralization of carbon and nitrogen in ecological, integrated and conventional forage and arable cropping systems. Biology and Fertility of Soils 30: 193-201.

Briggs, L. and Twomlow, S.J. 2002. Organic material flows within a smallholder highland farming system of South West Uganda. Agriculture, Ecosystems and Environment 89: 191-212.

Brookfield, H.C. and Hart, D. 1971. Melanesia: A geographical Interpretation of an Island World. Methuen, London. 464 pages.

Brookfield, H.C. 1972. Intensification and disintensification in Pacific agriculture: A theoretical approach. Pacific Viewpoint 25: 15-44.

Cairns, M. and Garrity, D.P. 1999. Improving shifting cultivation in Southeast Asia by building on indigenous fallow management strategies. Agroforestry Systems 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. Journal of Arid Environment 69: 299-314.

Chapin III, F.S., Zavaleta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M., Reynolds II, H.L., Hooper, D.U., Lavorel, S., Sala, O.E., Hobbie, S.E., Mack, M.C. and Diaz, S. 2000. Consequences of changing biodiversity. Nature 405: 234-242.

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.

Davidson, E.A. and Ackerman, I.L. 1993. Changes in soil carbon inventories following cultivation of previously untilled soils. Biogeochemistry 20: 161-193.

de Ridder, N., Breman, H., van Keulen, H. and Stomph, T.J. 2004. Revisiting a 'curse against land hunger': Soil fertility management and farming systems dynamics in the West African Sahel. Agricultural Systems 80: 109-131.

DeFries, R.S., Foley, J.A. and Asner, G.P. 2004. Land use choices: Balancing human needs and ecosystem function. Frontiers in Ecology and the Environment 2: 249-257.

Desbiez, A., Mathews, R., Tripathi, B. and Ellis-Jones, J. 2004. Perceptions and assessment of soil fertility by farmers in the mid-hills of Nepal. Agriculture, Ecosystems and Environment 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. Agriculture, Ecosystems and Environment 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.

Green, R.E., Cornell, S.J., Scharlemann, J.P.W. and Balmford, A. 2005. Farming and the fate of wild nature. Science 307: 550-555.

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.

Herzog, F., Steiner, B., Bailey, D., Baudry, J., Billeter, R., Bukacek, R., DeBlust, G., DeCock, R., Dirksen, J., Dormann, C.F., DeFilippi, R., Frossard, E., Liira, J., Schmidt, T., Stockli, R., Thenail,C., van Wingerden, W. and Bugter, R. 2006. Assessing the intensity of temperate European agriculture at the landscape scale. European Journal of Agronomy 24: 165-181.

Hoekstra, J.M., Boucher, T.M., Ricketts, T.H. and Roberts, C. 2005. Confronting a biome crisis: Global disparities of habitat loss and protection. Ecology Letters 8: 23-29.

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. 295 pages.

Jodha, N.S. 2000. Globalisation and fragile mountain environments: Policy challenges and choices. Mountian Research and Development 20: 296-299.

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

Komatsuzaki, M. and Ohta, H. 2007. Soil management practices for sustainable agro-ecosystems. Sustainability Science 2: 103-120.

Kundu, S., Bhattacharyya, R., Prakash, V., Ghosh, B.N. and 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.

Magdoff, F. 1996. Soil organic matter fractions and implications for interpreting organic matter tests. Pages 11-19, In: Magdoff, F.R., Hanlon, E.A., and Tabatabai, M.A. (Editors) Soil Organic Matter: Analysis and Interpretation. Soil Science Publication No. 46. American Society of Agronomy, Madison, USA.

Maikhuri, R.K., Rao, K.S. and Saxena, K.G. 1996. Traditional crop diversity for sustainable development of Central Himalayan agroecosystems. International Journal of Sustainable Development and World Ecology 3: 8-31.

Maikhuri, R.K., Semwal, R.L., Rao, K.S., Singh, K. and 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. 499 pages.

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. Smallholders, Householders: Farm Familes and the Ecology of Intensive, Sustainable Agriculture. Stanford University Press, Stanford, CA, USA. 416 pages.

Nortcliff, S. 2002. Standardisation of soil quality attributes. Agriculture, Ecosystems and Environment 88: 161-168.

Oldeman, L., van Engelen, V. and Pulles, J. (Editors). 1990. The Extent of Human-Induced Soil Degradation. International Soil Reference and Information Center, Wageningen. 21 pages.

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. Agriculture, Ecosystems and Environment 79: 61-72.

Plieninger, T. and Wilbrand, C. 2001. Land-use, biodiversity conservation, and rural development in the dehesas of Cuatro Lugares, Spain. Agroforestry Systems 51: 23-34.

Ponge, J.F., Gillet, S., Dubs, F., Fedoroff, E., Haese, L., Sousa, J.P. and Lavelle, P. 2000. Collembolan communities as bioindicators of land use intensification. Soil Biology and Biochemistry 35: 813-826.

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.

Pryor, F.L. 1985. The invention of the plow. Comparative Studies in Society and History 27: 727-743.

Ramakrishnan, P.S. 1992. Shifting Agriculture and Sustainable Development – An Inter-disciplinary Approach from North-Eastern Himalayas. UNESCO, Paris, and Parthenon Publishing, Carnforth, UK. 424 pages.

Rao, K.S. and Saxena, K.G. 1996 Minor forest product's management - problems and prospects in remote high altitude villages of Central Himalaya. International Journal of Sustainable Development and World Ecology 3: 60-70.

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. 287 pages.

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

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 Research and Development 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.

Ruthenberg, H. 1976. Farming Systems in the Tropics. 2nd Edition. Clarendon Press, Oxford. 366 pages.

Sangha, K.K., Midmore, D.J., Rolfe, J. and Jalota, R.K. 2005. Tradeoffs between pasture production and plant diversity and soil health attributes of pasture systems of central Queensland, Australia. Agriculture, Ecosystems and Environment 111: 93-103.

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. Agroforestry Systems 56: 57-63.

Semwal, R.L., Nautiyal, S., Sen, K.K., Rana, U., Maikhuri, R.K., Rao, K.S. and Saxena, K.G. 2004. Patterns and ecological implications of agricultural land-use changes: a case study from central Himalaya, India. Agriculture, Ecosystems and Environment 102: 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. Experimental Agriculture 35: 1-13.

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

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

Singh, 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. The Environmentalist 28: 429-445.

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. Proceedings of the National Academy of Sciences USA 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. and 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. 1996. Isolated State: As English Version of Der Isolierte Statt. Pergamon Press, Oxford, U.K..

Wander, M.M. and Bollero, G.A. 1999. Soil quality assessment of tillage impacts in Illinois. Soil Science Society of America Journal 63: 961-971.

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. Agriculture, Ecosystems and Environment 103: 535-543.